Journal of Agricultural Science; Vol. 10, No. 1; 2018
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

# Plot Size and Number of Replications for Evaluation of the Yield of Grains in Cultivars and Dates of Sowing of Rye

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Received: October 8, 2017 Accepted: November 7, 2017 Online Published: December 15, 2017

doi:10.5539/jas.v10n1p122 URL: https://doi.org/10.5539/jas.v10n1p122

**Abstract**

The objectives of this study were to determine the optimum plot size ($X_o$) and the number of replications to evaluate the grains yield of rye (*Secale cereale* L.) and investigate the variability of $X_o$ between two cultivars and three sowing dates. Eighteen uniformity trials were conducted with rye. The $X_o$ was determined by the method of maximum curvature of the coefficient of variation model. The number of repetitions was determined in scenarios formed by combinations of i treatments (i = 3, 4, ... 50) and d minimum differences between means of treatments to be detected as significant at 0.05 of probability, by Tukey test, expressed in percentage of the average of the experiment (d = 10, 12, ... 30%). There is variability in optimum plot size to evaluate the grains yield among the cultivars BRS Progresso and Temprano and among sowing dates in the rye crop. The optimum plot size to evaluate the grains yield of rye is 6.08 $m^2$. Seven replicates are sufficient to evaluate the grains yield of rye in experiments with up to 50 treatments, and identify, as significant at 5% probability by Tukey test, differences among averages of treatments of 29.65% of the mean of the experiment in designs completely randomized and randomized block.

**Keywords:** *Secale cereale* L., uniformity trials, experiment planning

## 1. Introduction

Rye (*Secale cereale* L.) is a winter crop belonging to family Poaceae (Hoffmann, Mudra, & Plarre, 1970) which has a wide geographic distribution due to the several events of domestication (Zohary & Hopf, 2000). The crop is an alternative of farming exploration with great potential for expansion. According to Mori, Nascimento Junior, and Miranda (2013), the advance in productivity of rye cultivars can be the result of an effort begun in the 1970s, restoring and preserving cultivated populations. However, according to Nascimento Junior (2014), the crop expresses greater unevenness regarding heading stage, maturity and type of plant, in comparison with other species of winter cereals. In order to improve and adapt the characteristics of rye plants to the Brazilian conditions, new combinations, selections and tests of genotypes were performed in experiments (Mori, Nascimento Junior, & Miranda, 2013).

The starting point to perform an experiment is the experimental planning. The same depends on the crop, the evaluated characteristics, the treatments and the conditions of the experimental area (Storck, Garcia, Lopes, & Estefanel, 2016). Through such planning the steps are defined to control the environmental effects in such a way as to find significant differences among the factors in test, if they exist (Banzatto & Kronka, 2013). In the planning and implementation of agronomic research, field experiments have as basic problem to determine the plot size (Henriques Neto, Sediyama, Souza, Leite, & Blanco, 2009).

Among the methods used to estimate the optimum plot size, the maximum curvature of the coefficient of variation model stands out, proposed by Paranaíba, Ferreira, and Morais (2009). The method has as main advantage the fact that it is not necessary to plan plots of various sizes through the data gathering of the experimental adjacent basic units (Paranaíba, Ferreira, & Morais, 2009). The optimum plot size and/or the number of replications have been investigated for crops such as wheat (Muhammad et al., 2001), corn (Masood & Javed, 2003; Singh, 2015), rice (Masood & Raza, 2012) and black oat (Cargnelutti Filho et al., 2014a).

From the optimum plot size, it is possible to determine the experimental precision in scenarios formed by combinations of numbers of treatments, replications and designs (Cargnelutti Filho, Storck, Lúcio, Toebe, & Alves, 2016). The uniformity trials, also called blank experiments, characterize trials where there is no influence of treatments which have been used to obtain data for the estimation of optimum plot size (Storck et al., 2016).

When working with rye, each researcher has adopted plot size and distinct number of replications in his or her experiments, and thus there is the need for the development of experimental techniques for trials carried out with the crop, since there is a lack regarding the correct experimental design. In these studies, plots were used ranging from 5 m² (Lehmen, Fontaneli, Fontaneli & Santos, 2014) to 35 $m^2$ (Hovary et al., 2016), and with two (Auinger et al., 2016) to eight replications (Souza et al., 2013).

The dimensioning of the optimum plot size and the number of replications in the rye crop is important to ensure the reliability of the results of agricultural experiments that seek to evaluate the grain yield of the crop. Therefore, the objectives of this study were to determine the optimum plot size and number of replications to evaluate the grains yield of rye (*Secale cereale* L.) and investigate the variability of optimum plot size between two cultivars and three sowing dates.

## 2. Material and Methods

Eighteen uniformity trials were performed (blank experiments) with the crop of rye, in the experimental area of the Department of Crop Science, Federal University of Santa Maria, Santa Maria, Rio Grande do Sul (29°42′ S, 53°49′ W, altitude 95 m asl.) in the agricultural year of 2016. According to the classification of Köppen, the climate of the region is Cfa humid subtropical with hot summers (Heldwein, Buriol, & Streck, 2009) and without a dry season and the soil of the place is classified as paleaudalf soil (Santos et al., 2013).

The experimental area was prepared evenly and in a soil conventional system. As a basic fertilizer 500 kg $ha^{-1}$ of NPK with commercial formulation of 05-20-20 was applied. As top-dressing fertilizers 25 kg of N $ha^{-1}$ were applied when the plants reached the stage V3, as well as the same quantity at the stage V4. The cultural practices were performed evenly across the experimental area, as recommended for the uniformity trials (Storck et al., 2016). Distributed in three sowing dates, three uniformity trials were performed with the cultivar BRS Progresso and three with the cultivar Temprano totaling 18 trials. The sowings were performed on May 3, 2016 (date 1), May 25, 2016 (date 2) and June 7, 2016 (date 3). The sowing of the seeds of the cultivars BRS Progresso and Temprano, with distinct purposes, was performed by broadcasting, with a density of 455 seeds $m^{-2}$.

Each uniformity trial was performed in area of 24 $m^2$ (6 m × 4 m). Each trial was divided into 24 basic experimental units (BEU) of 1 $m^2$ (1 m × 1 m), forming an array of six rows and four columns. At the physiological maturation stage, in each trial, the ears of the plants of each BEU (1 $m^2$) were collected. Soon after manual threshing of the ears was performed and immediately obtained the moisture content of the grains. The grains yield in g $m^{-2}$, was obtained by the moisture correction to 13%.

For each uniformity trial, from the grains yield data in 24 BEU, the following statistics was determined: means (m), variance ($s^2$), coefficient of variation of the trial (CVtrial, in %) and first order spatial autocorrelation coefficient (ρ). The estimate of ρ was obtained with the pathway in the direction of the lines, according to methodology of Paranaíba, Ferreira and Morais (2009). It was initiated at BEU located at line 1, column 1, until the line 1, column 4, returning from the row 2, column 4, until the line 2, column 1, and so on, successively, until completing the pathway at BEU from line 6, column 1.

Later on the optimum plot size was determined ($X_o$, in $m^2$) for the character grains yield, in each one of the 18 uniformity trials, by means of the Equation (1) of the method of maximum curvature of the coefficient of variation model (Paranaíba, Ferreira, & Morais, 2009), where ρ is the first order spatial autocorrelation coefficient, $s^2$ is the variance and m is the mean.

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

Then the coefficient of variation in the optimum plot size ($CV_{X_o}$), in percentage, was determined through the Equation (2) (Paranaíba, Ferreira, & Morais, 2009). $CV_{X_o}$ corresponds to the CV expected for the experiment with the optimum plot size determined (Cargnelutti Filho et al., 2014a).

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

Thus, for each cultivar in each sowing date, 3 estimates were obtained of m, $s^2$, CVtrial, ρ, $X_o$ and $CV_{X_o}$. The comparisons of means of statistics m, $s^2$, CVtrial, ρ, $X_o$ and $CV_{X_o}$, among cultivars and among sowing date, were performed at 5% of probability through the Scott-Knott test, via *bootstrap* with 20,000 resamplings.

For the calculation of number of replications, it was started from the least significant difference (d) of Tukey test, expressed in percentage of general mean of the experiment, estimated by the Equation (3). The degrees of freedom of the error was used (DFE) equal to [i·(r – 1)] for the completely randomized experimental design and [(i – 1)·(r – 1)] for the randomized block experimental design, where i is the number of treatments and r is the number of replications. The next Equation (3), $q_{\alpha(i;DFE)}$ is the critical value of the Tukey test at level α of probability of error and MSE is the mean squared of the error.

$$d = \frac{q_{\alpha(i;DFE)}\sqrt{\frac{MSE}{r}}}{m} \times 100 \quad (3)$$

Replacing the Equation (4) of the coefficient of experimental variation (CV), in percentage, in the Equation (3), we have the Equation (5) to determine the number of replications.

$$CV = \frac{\sqrt{MSE}}{m} \times 100 \quad (4)$$

$$r = \left(\frac{q_{\alpha(i;DFE)}CV}{d}\right)^2 \quad (5)$$

The number of replications (r) to evaluate the grains yield was determined from the mean $CV_{X_o}$ between the two cultivars and three sowing dates for the iterative process until the convergence, for experiments in completely randomized design (CRD) and randomized block (RBD) , in scenarios formed by combinations of i treatments (i = 3, 4, ... 50) and d minimum differences among means of treatments to be detected as significant at 5% probability by Tukey test, expressed as a percentage of mean of the experiment (d = 10, 12, ... 30%). The statistics d was used by Lúcio, Storck, and Banzatto (1999) to evaluate the experimental precision, with limits very low, medium and very high, according to experiments of competition of cultivars in different managements. Statistical analyzes were performed with the aid of the application Microsoft Office Excel® and the software Sisvar® (2014).

## 3. Results and Discussion

In the period of the uniformity trials, the absolute minimum temperatures of the air oscillated between 0 (June 13, 2016) and 23 °C (August 27, 2016), and the maximum absolute temperatures between 12.2 (July 17, 2016) and 35.2 °C (October 31, 2016), providing thus distinct meteorological conditions (Figure 1). Between the sowing dates, the record of maximum rainfall was equivalent to 94.2 mm and occurred on October 18, 2016.

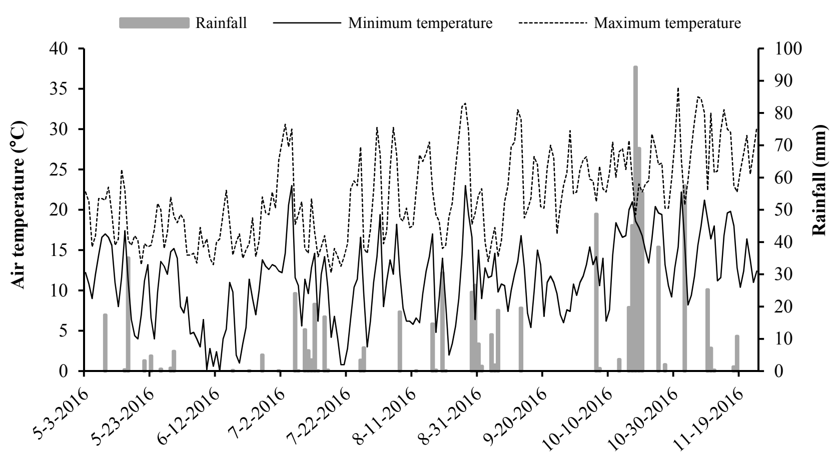


Figure 1. Minimum and maximum daily temperatures of the air and daily precipitation in the months of May to November 2016, in Santa Maria, RS

There were variations among the dates in full cycle of cultivation of the cultivars (Table 1). The number of days that includes the period of flowering until the harvest of the grain was 77, 76 and 65 days for the cultivar BRS

Progresso, and 46, 46 and 45 days for the cultivar Temprano, respectively for the dates 1, 2 and 3. When analyzing the cultivars, the interval of time observed from the flowering until physiological maturity was more stable among the dates for the cultivar Temprano comparing to cultivar BRS Progresso. In the last one, there was a reduction of the later sowing period. When evaluating the productive characteristics of annual winter forages, among them the rye, Ferrazza, Soares, Martin, Assmann, and Nicola (2013) concluded that sowing dates interfere with the productive traits, since earlier sowing promote higher yields of forage and duration of the vegetative cycle and later sowings, higher densities of plants and tillers.

Table 1. Date and sowing dates, emergency, flowering, harvest and cycle (in days), in uniformity trials composed of two cultivars of rye (*Secale cereale* L.), BRS Progresso and Temprano, in the agricultural year of 2016, Santa Maria, RS

| Date | Sowing | Emergency | | Flowering | | Harvest | | Cycle (in days) | |
|---|---|---|---|---|---|---|---|---|---|
| | | BRS Progresso | Temprano | BRS Progresso | Temprano | BRS Progresso | Temprano | BRS Progresso | Temprano |
| 1 | 05/03/16 | 05/09/16 | 05/10/16 | 08/08/16 | 09/22/16 | 10/24/16 | 11/07/16 | 174 | 188 |
| 2 | 05/25/16 | 06/01/16 | 06/02/16 | 08/26/16 | 10/03/16 | 11/10/16 | 11/18/16 | 169 | 177 |
| 3 | 06/07/16 | 06/17/16 | 06/20/16 | 09/15/16 | 10/10/16 | 11/19/16 | 11/24/16 | 165 | 170 |

There was statistical variability in the uniformity trials of the estimates: means, variance, coefficient of variation of the trial, first order spatial autocorrelation coefficient (Table 2). According to methodology proposed by Paranaíba, Ferreira, and Morais (2009), when there is variability in estimates of ρ, $s^2$ and m, it will also be observed variability in estimates of optimal plot size and coefficient of variation in the optimum plot size. Scenarios of variability of statistics among uniformity trials are considered important for the study of the scalability of optimal plot size and number of replications, because they reflect real conditions of field areas (Cargnelutti Filho, Toebe, Burin, Fick, & Casarotto, 2011; Cargnelutti Filho et al., 2015a). Thus, the plot size estimated can become a reference for future work with the crop of rye.

Table 2. Means (m), variance ($s^2$), coefficient of variation of the trial (CVtrial in %), first order spatial autocorrelation coefficient (ρ), optimum plot size ($X_o$, em $m^2$) and coefficient of variation of the optimum plot size ($CV_{X_o}$, em %), for grains yield, in grams, per basic experimental units of 1 $m^2$ (1 m × 1 m) in uniformity trials composed of cultivars of rye (*Secale cereale* L.), BRS Progresso and Temprano, and three sowing dates in the agricultural year of 2016, Santa Maria, RS

| Grains yield | | | | | | |
|---|---|---|---|---|---|---|
| Date | m (g) | | $s^2$ | | CVtrial (%) | |
| | BRS Progresso | Temprano | BRS Progresso | Temprano | BRS Progresso | Temprano |
| 1 | 159.15 Aa | 109.21 Ab | 1032.62 Aa | 844.05 Aa | 19.03 Ba | 26.75 Aa |
| 2 | 153.62 Aa | 80.05 Bb | 1276.78 Aa | 128.85 Bb | 23.17 Ba | 13.99 Bb |
| 3 | 153.19 Aa | 28.53 Cb | 3070.48 Aa | 43.16 Ca | 34.50 Aa | 22.99 Aa |
| Mean | 155.32 | 72.60 | 1793.29 | 338.69 | 25.57 | 21.24 |
| Date | ρ | | $X_o$ ($m^2$) | | $CV_{X_o}$ (%) | |
| | BRS Progresso | Temprano | BRS Progresso | Temprano | BRS Progresso | Temprano |
| 1 | 0.07 Ab | 0.37 Aa | 4.13 Ba | 4.93 Aa | 9.24 Ba | 11.07 Aa |
| 2 | 0.09 Aa | -0.03 Ba | 4.68 Ba | 3.38 Bb | 10.47 Ba | 7.57 Bb |
| 3 | 0.12 Aa | 0.09 Ba | 6.08 Aa | 4.69 Aa | 13.58Aa | 10.48 Aa |
| Mean | | | 4.69 | 4.34 | 11.10 | 9.70 |

*Note*. For each statistic (m, $s^2$, CVtrial, ρ, $X_o$ and $CV_{X_o}$), means that are not followed by the same letter, lowercase on the line (comparison of means between cultivars in each data) and capital in the column (comparison of means between dates in each cultivar), differ at 5% probability by the Scott-Knott test via bootstrap analysis with 20,000 resamplings.

The cultivar Temprano showed a reduction of the grains yield with the advance of sowing dates, which can be attributed to the greater forage capacity presented by the cultivar. However, the cultivar BRS Progresso presented stable behavior in grains yield, which did not differ among the dates, at the level of 5% probability of error by the Scott-Knott test, corroborating the characterization of productive stability of the cultivar performed by Nascimento Junior, Caierão, and Mori (2014).

In general, the cultivar BRS Progresso exceled the cultivar Temprano, presenting higher grains yield in three sowing dates. Regarding the purpose of cultivation, the cultivar BRS Progresso has as purpose the production of grains and the cultivar Temprano is characterized by high production of dry matter of forage, and thus it is intended for animal feed. This characterization of the purpose of cultivation may explain the fact that the medium productivity achieved by the cultivar Temprano (726.0 kg $ha^{-1}$) fall next to the half of the medium productivity obtained by the cultivar BRS Progresso (1553.2 kg $ha^{-1}$) in this work.

The increase in the medium values of variance has a direct reflex on the increase of $X_o$. Therefore, it is possible to observe the direct relationship between the optimum plot size, variance and the mean, since that the methodology of Paranaíba, Ferreira, and Morais (2009) considers these variables to obtain the $X_o$. Regarding the means of $X_o$, it is possible to observe the same statistical difference among the sowing dates and among cultivars, for the statistics CVtrial and $CV_{X_o}$. Thus, likewise, the behavior of CVTrial and $CV_{X_o}$ are related to the increase or reduction of ρ, $s^2$, m, $X_o$.

The CVtrial varied from 13.99% (Temprano - date 2) to 34.50% (BRS Progresso - date 3), and $CV_{X_o}$ from 7.57% (Temprano - date 2) to 13.58% (BRS Progresso - date 3). This reduction in values for the CVtrial for the $CV_{X_o}$ demonstrates the gains in experimental precision in the use of optimum plot size. The lower the coefficient of variation, the greater the precision and quality of the experiment will be, and consequently, lower differences among estimates of means will be considered significant (Cargnelutti Filho & Storck, 2007).

In agricultural trials, the coefficient of variation was classified as low (less than a 10%), medium (between 10 and 20%), high (between 20 and 30%) and very high (higher then 30%) (Pimentel-Gomes, 1990). Specifically for the variable grains yield, in trials of competition of cultivars of winter cereals (wheat, barley, rye, oats and triticale), Estefanel, Pignataro, and Storck (1987) classified the coefficients of variation as medium when between 11.0 and 19.0%. Values of CV classified as high can be attributed to the fact that the evaluations were performed in BEU of only 1m², which can result in high variability in the observations. Another possible explanation for the high variability in the observations may be the fact that the crop expresses higher unevenness regarding the silking and final maturation (Nascimento Junior, 2014).

The medium values of $X_o$ observed for the estimates of grains yield varied from 3.38 $m^2$ (Temprano - date 2) to 6.08 $m^2$ (BRS Progresso - date 3). Therefore, in the crop of rye there is variability in optimum plot size to evaluate the grains yield among cultivars and among sowing dates. So, to evaluate the grains yield it is recommended to use the highest value of $X_o$ (6.08 $m^2$), in order to reduce the experimental error and contemplate more efficiently the scenarios of variability. It can be observed that in the trials where the data have higher variability, there were also higher plot size, once that the methodology proposed by Paranaíba, Ferreira, and Morais (2009) the variance appears at the formula numerator.

Regardless of crop, the estimate and posterior use of the optimum plot size provides the increase of precision and maximizes the information obtained in the experiment. This is attributed to the fact that works that use an appropriate plot size allow the best use of resources and more rigid control of the experiment management, when performed in the area of smaller size (Silva, Campos, Morais, Cogo, & Zambon, 2012).

No studies were found in literature that report the optimal plot size to assess the grains yield of rye in order to perform the comparison with the results obtained in this study. However, studied were found with other crops belonging to the family Poaceae. At the cultivation of grain sorghum, when verifying the influence of plant arrangement in the estimate of optimum plot size, Lopes et al. (2005) found estimated size of parcels of 3.2 m² for variable grains yield. When estimating the optimum plot size using different methods and checking the possible precision in experiments with the wheat crop, Lorentz et al. (2007) found a plot size from 0.89 $m^2$ to 6.48 $m^2$ for grains yield. In order to evaluate the grains yield of oat, Lavezo et al. (2017) verified that there is variability in $X_o$ among the cultivars, with value determined in 1.57 m².

To evaluate the yield of rye grains, the number of replications was determined for scenarios formed by combinations of i treatments (i = 3, 4, ..., 50) and d minimum differences among means of treatments to be detected as significant at 5% probability by Tukey test, expressed as a percentage of mean of the experiment (d = 10, 12, ..., 30%), from optimum plot size ($X_o$ = 6.08 $m^2$) and coefficient of variation in the optimum plot size ($CV_{X_o}$ = 13,58%). The statistic d is considered the most appropriate to evaluate the experimental precision, followed by the variation index and, subsequently, the coefficient of variation, since it considers the mean, the number of treatments and replications (Cargnelutti Filho et al., 2014b). It is worthwhile highlighting that lower values of d indicate higher experimental precision, *i.e.*, lower differences among means of treatments will be considered significant and vice versa (Cargnelutti Filho et al., 2014a). According to different managements, in competition experiments of crops belonging to the family of rye, Lúcio, Storck, and Banzatto (1999) observed variation in statistic d classified as medium in the crops: wheat (ranging from 19.4 to 63.0), barley (ranging from 16.0 to 33.0) oats (ranging from 34.5 to 87.5) and triticale (ranging from 24.0 to 45.0).

The number of replications found in the present study ranged between 3.45 (3 treatments and d = 30%) and 59.00 (50 treatments and d = 10%) for experiments in a completely randomized design (CRD) (Table 3), and between 3.79 (3 treatments and d = 10%) and 59.01 (50 treatments and d = 10%), for experiments in a randomized block design (RBD) (Table 4). The compliance to basic principles of experimentation, such as the use of the appropriate number of replications is related to the increase in the precision of experiments (Resende & Souza Júnior, 1997; Banzatto & Kronka, 2013), since that the standard error of the mean of a treatment is estimated by the standard deviation, calculated from the mean square of the residue and the number of replications (Steel, Torrie, & Dickey, 1997). Thus, the use of a greater number of replications allows to obtain works with reduced experimental error and consequently more precise means. Nonetheless, obtaining the highest precision (d = 10%) becomes not feasible due to the high number of replications required. This attributes importance in studies of experimental design and mainly in the use of number of pre-defined replications in these studies.

Table 3. Number of replications for experiments in completely randomized design in scenarios formed by combinations of i treatments (i = 3, 4, ... 50) and d least differences between treatment means to be detected as significant at 5% probability of type I error by Tukey test, expressed in percentage of the overall experimental mean (d = 10, 12, ... 30%), for evaluation of the yield of grains in rye (*Secale cereale* L.), from the optimum plot size ($X_o$ = 6.08 $m^2$) and coefficient of variation in the optimum plot size ($CV_{X_o}$ = 13.58%)

| i | d (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 |
| 3 | 21.31 | 15.13 | 11.40 | 9.00 | 7.35 | 6.18 | 5.32 | 4.67 | 4.16 | 3.77 | 3.45 |
| 4 | 25.24 | 17.80 | 13.32 | 10.42 | 8.43 | 7.02 | 5.98 | 5.19 | 4.58 | 4.10 | 3.72 |
| 5 | 28.23 | 19.84 | 14.79 | 11.51 | 9.27 | 7.67 | 6.49 | 5.60 | 4.91 | 4.37 | 3.93 |
| 6 | 30.66 | 21.50 | 15.98 | 12.40 | 9.95 | 8.21 | 6.92 | 5.94 | 5.18 | 4.59 | 4.11 |
| 7 | 32.70 | 22.90 | 16.99 | 13.16 | 10.53 | 8.66 | 7.28 | 6.23 | 5.42 | 4.78 | 4.27 |
| 8 | 34.47 | 24.11 | 17.87 | 13.81 | 11.04 | 9.06 | 7.60 | 6.49 | 5.63 | 4.95 | 4.41 |
| 9 | 36.03 | 25.18 | 18.64 | 14.40 | 11.49 | 9.41 | 7.88 | 6.72 | 5.82 | 5.10 | 4.53 |
| 10 | 37.43 | 26.14 | 19.33 | 14.92 | 11.89 | 9.73 | 8.14 | 6.93 | 5.99 | 5.25 | 4.65 |
| 11 | 38.70 | 27.01 | 19.96 | 15.39 | 12.26 | 10.03 | 8.37 | 7.12 | 6.14 | 5.37 | 4.76 |
| 12 | 39.85 | 27.80 | 20.54 | 15.83 | 12.60 | 10.29 | 8.59 | 7.29 | 6.29 | 5.49 | 4.86 |
| 13 | 40.92 | 28.53 | 21.07 | 16.23 | 12.91 | 10.54 | 8.79 | 7.46 | 6.42 | 5.61 | 4.95 |
| 14 | 41.90 | 29.21 | 21.56 | 16.60 | 13.20 | 10.77 | 8.97 | 7.61 | 6.55 | 5.71 | 5.04 |
| 15 | 42.82 | 29.84 | 22.02 | 16.95 | 13.47 | 10.98 | 9.15 | 7.75 | 6.67 | 5.81 | 5.12 |
| 16 | 43.68 | 30.44 | 22.45 | 17.27 | 13.72 | 11.19 | 9.31 | 7.89 | 6.78 | 5.90 | 5.20 |
| 17 | 44.49 | 30.99 | 22.86 | 17.58 | 13.96 | 11.38 | 9.46 | 8.01 | 6.88 | 5.99 | 5.27 |
| 18 | 45.25 | 31.52 | 23.24 | 17.87 | 14.19 | 11.56 | 9.61 | 8.13 | 6.98 | 6.07 | 5.34 |
| 19 | 45.98 | 32.02 | 23.60 | 18.14 | 14.40 | 11.73 | 9.75 | 8.25 | 7.08 | 6.15 | 5.41 |
| 20 | 46.66 | 32.49 | 23.95 | 18.40 | 14.60 | 11.89 | 9.88 | 8.35 | 7.17 | 6.23 | 5.47 |
| 21 | 47.31 | 32.94 | 24.28 | 18.65 | 14.80 | 12.04 | 10.01 | 8.46 | 7.26 | 6.30 | 5.54 |
| 22 | 47.94 | 33.37 | 24.59 | 18.89 | 14.98 | 12.19 | 10.13 | 8.56 | 7.34 | 6.37 | 5.60 |
| 23 | 48.53 | 33.78 | 24.89 | 19.12 | 15.16 | 12.33 | 10.24 | 8.65 | 7.42 | 6.44 | 5.65 |
| 24 | 49.10 | 34.18 | 25.18 | 19.33 | 15.33 | 12.47 | 10.35 | 8.75 | 7.49 | 6.50 | 5.71 |
| 25 | 49.65 | 34.55 | 25.45 | 19.54 | 15.50 | 12.60 | 10.46 | 8.83 | 7.57 | 6.57 | 5.76 |
| 26 | 50.18 | 34.92 | 25.72 | 19.75 | 15.65 | 12.73 | 10.56 | 8.92 | 7.64 | 6.63 | 5.81 |
| 27 | 50.69 | 35.27 | 25.97 | 19.94 | 15.80 | 12.85 | 10.66 | 9.00 | 7.71 | 6.68 | 5.86 |
| 28 | 51.17 | 35.60 | 26.22 | 20.13 | 15.95 | 12.97 | 10.76 | 9.08 | 7.77 | 6.74 | 5.91 |
| 29 | 51.65 | 35.93 | 26.46 | 20.31 | 16.09 | 13.08 | 10.85 | 9.16 | 7.84 | 6.79 | 5.95 |
| 30 | 52.10 | 36.25 | 26.69 | 20.48 | 16.23 | 13.19 | 10.94 | 9.23 | 7.90 | 6.85 | 6.00 |
| 31 | 52.54 | 36.55 | 26.91 | 20.65 | 16.36 | 13.29 | 11.03 | 9.30 | 7.96 | 6.90 | 6.04 |
| 32 | 52.97 | 36.85 | 27.12 | 20.81 | 16.49 | 13.40 | 11.11 | 9.37 | 8.02 | 6.95 | 6.09 |
| 33 | 53.39 | 37.13 | 27.33 | 20.97 | 16.61 | 13.50 | 11.19 | 9.44 | 8.08 | 7.00 | 6.13 |
| 34 | 53.79 | 37.41 | 27.54 | 21.13 | 16.74 | 13.59 | 11.27 | 9.51 | 8.13 | 7.04 | 6.17 |
| 35 | 54.18 | 37.68 | 27.73 | 21.28 | 16.85 | 13.69 | 11.35 | 9.57 | 8.19 | 7.09 | 6.21 |
| 36 | 54.56 | 37.94 | 27.93 | 21.42 | 16.97 | 13.78 | 11.42 | 9.63 | 8.24 | 7.13 | 6.24 |
| 37 | 54.93 | 38.20 | 28.11 | 21.57 | 17.08 | 13.87 | 11.50 | 9.69 | 8.29 | 7.18 | 6.28 |
| 38 | 55.29 | 38.45 | 28.29 | 21.70 | 17.19 | 13.96 | 11.57 | 9.75 | 8.34 | 7.22 | 6.32 |
| 39 | 55.64 | 38.69 | 28.47 | 21.84 | 17.29 | 14.04 | 11.64 | 9.81 | 8.39 | 7.26 | 6.35 |
| 40 | 55.98 | 38.93 | 28.64 | 21.97 | 17.40 | 14.12 | 11.71 | 9.87 | 8.44 | 7.30 | 6.39 |
| 41 | 56.32 | 39.16 | 28.81 | 22.10 | 17.50 | 14.21 | 11.77 | 9.92 | 8.48 | 7.34 | 6.42 |
| 42 | 56.64 | 39.38 | 28.98 | 22.22 | 17.60 | 14.28 | 11.84 | 9.97 | 8.53 | 7.38 | 6.45 |
| 43 | 56.96 | 39.60 | 29.14 | 22.35 | 17.69 | 14.36 | 11.90 | 10.03 | 8.57 | 7.42 | 6.49 |
| 44 | 57.27 | 39.82 | 29.30 | 22.47 | 17.79 | 14.44 | 11.96 | 10.08 | 8.61 | 7.45 | 6.52 |
| 45 | 57.58 | 40.03 | 29.45 | 22.58 | 17.88 | 14.51 | 12.02 | 10.13 | 8.66 | 7.49 | 6.55 |
| 46 | 57.87 | 40.24 | 29.60 | 22.70 | 17.97 | 14.58 | 12.08 | 10.18 | 8.70 | 7.52 | 6.58 |
| 47 | 58.17 | 40.44 | 29.75 | 22.81 | 18.06 | 14.65 | 12.14 | 10.23 | 8.74 | 7.56 | 6.61 |
| 48 | 58.45 | 40.63 | 29.89 | 22.92 | 18.14 | 14.72 | 12.20 | 10.27 | 8.78 | 7.59 | 6.64 |
| 49 | 58.73 | 40.83 | 30.03 | 23.03 | 18.23 | 14.79 | 12.25 | 10.32 | 8.82 | 7.63 | 6.67 |
| 50 | 59.00 | 41.02 | 30.17 | 23.13 | 18.31 | 14.86 | 12.31 | 10.37 | 8.86 | 7.66 | 6.69 |

Table 4. Number of replications for experiments in randomized block design in scenarios formed by combinations of i treatments (i = 3, 4, ... 50) and d least differences between treatment means to be detected as significant at 5% probability of type I error by Tukey test, expressed in percentage of the overall experimental mean (d = 10, 12, ... 30%), for evaluation of the yield of grains in rye (*Secale cereale* L.), from the optimum plot size ($X_o$ = 6.08 $m^2$) and coefficient of variation in the optimum plot size ($CV_{X_o}$ = 13.58%)

| i | d (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 |
| 3 | 21.81 | 15.63 | 11.90 | 9.49 | 7.85 | 6.67 | 5.79 | 5.13 | 4.62 | 4.18 | 3.79 |
| 4 | 25.52 | 18.08 | 13.60 | 10.70 | 8.72 | 7.30 | 6.26 | 5.47 | 4.87 | 4.38 | 4,00 |
| 5 | 28.41 | 20.03 | 14.97 | 11.70 | 9.46 | 7.86 | 6.68 | 5.79 | 5.10 | 4.55 | 4.12 |
| 6 | 30.79 | 21.63 | 16.11 | 12.54 | 10.09 | 8.34 | 7.05 | 6.07 | 5.32 | 4.72 | 4.24 |
| 7 | 32.80 | 23,00 | 17.09 | 13.26 | 10.63 | 8.76 | 7.38 | 6.33 | 5.52 | 4.88 | 4.37 |
| 8 | 34.55 | 24.19 | 17.94 | 13.89 | 11.12 | 9.14 | 7.68 | 6.57 | 5.71 | 5.03 | 4.49 |
| 9 | 36.10 | 25.24 | 18.70 | 14.46 | 11.55 | 9.48 | 7.95 | 6.78 | 5.88 | 5.17 | 4.60 |
| 10 | 37.48 | 26.19 | 19.39 | 14.97 | 11.95 | 9.79 | 8.19 | 6.98 | 6.04 | 5.30 | 4.70 |
| 11 | 38.74 | 27.05 | 20.01 | 15.44 | 12.31 | 10.07 | 8.42 | 7.16 | 6.19 | 5.42 | 4.80 |
| 12 | 39.89 | 27.84 | 20.58 | 15.86 | 12.64 | 10.33 | 8.63 | 7.33 | 6.33 | 5.53 | 4.90 |
| 13 | 40.95 | 28.57 | 21.10 | 16.26 | 12.94 | 10.57 | 8.82 | 7.49 | 6.46 | 5.64 | 4.98 |
| 14 | 41.93 | 29.24 | 21.59 | 16.63 | 13.23 | 10.80 | 9,00 | 7.64 | 6.58 | 5.74 | 5.07 |
| 15 | 42.85 | 29.87 | 22.05 | 16.97 | 13.49 | 11.01 | 9.17 | 7.78 | 6.69 | 5.84 | 5.15 |
| 16 | 43.70 | 30.46 | 22.47 | 17.29 | 13.75 | 11.21 | 9.33 | 7.91 | 6.80 | 5.93 | 5.22 |
| 17 | 44.51 | 31.01 | 22.88 | 17.60 | 13.98 | 11.40 | 9.48 | 8.03 | 6.90 | 6.01 | 5.29 |
| 18 | 45.27 | 31.54 | 23.26 | 17.89 | 14.21 | 11.57 | 9.63 | 8.15 | 7,00 | 6.09 | 5.36 |
| 19 | 45.99 | 32.03 | 23.62 | 18.16 | 14.42 | 11.74 | 9.77 | 8.26 | 7.10 | 6.17 | 5.43 |
| 20 | 46.68 | 32.51 | 23.96 | 18.42 | 14.62 | 11.90 | 9.90 | 8.37 | 7.18 | 6.25 | 5.49 |
| 21 | 47.33 | 32.95 | 24.29 | 18.67 | 14.81 | 12.06 | 10.02 | 8.47 | 7.27 | 6.32 | 5.55 |
| 22 | 47.95 | 33.38 | 24.60 | 18.90 | 15,00 | 12.20 | 10.14 | 8.57 | 7.35 | 6.39 | 5.61 |
| 23 | 48.54 | 33.79 | 24.90 | 19.13 | 15.17 | 12.35 | 10.25 | 8.67 | 7.43 | 6.45 | 5.66 |
| 24 | 49.11 | 34.19 | 25.19 | 19.35 | 15.34 | 12.48 | 10.36 | 8.76 | 7.51 | 6.52 | 5.72 |
| 25 | 49.66 | 34.56 | 25.46 | 19.55 | 15.51 | 12.61 | 10.47 | 8.84 | 7.58 | 6.58 | 5.77 |
| 26 | 50.19 | 34.93 | 25.72 | 19.75 | 15.66 | 12.74 | 10.57 | 8.93 | 7.65 | 6.64 | 5.82 |
| 27 | 50.69 | 35.28 | 25.98 | 19.95 | 15.81 | 12.86 | 10.67 | 9.01 | 7.72 | 6.69 | 5.87 |
| 28 | 51.18 | 35.61 | 26.23 | 20.13 | 15.96 | 12.97 | 10.77 | 9.09 | 7.78 | 6.75 | 5.92 |
| 29 | 51.65 | 35.94 | 26.46 | 20.31 | 16.10 | 13.09 | 10.86 | 9.16 | 7.85 | 6.80 | 5.96 |
| 30 | 52.11 | 36.25 | 26.69 | 20.49 | 16.24 | 13.20 | 10.95 | 9.24 | 7.91 | 6.86 | 6.01 |
| 31 | 52.55 | 36.56 | 26.91 | 20.66 | 16.37 | 13.30 | 11.03 | 9.31 | 7.97 | 6.91 | 6.05 |
| 32 | 52.98 | 36.85 | 27.13 | 20.82 | 16.50 | 13.40 | 11.12 | 9.38 | 8.03 | 6.96 | 6.09 |
| 33 | 53.39 | 37.14 | 27.34 | 20.98 | 16.62 | 13.50 | 11.20 | 9.45 | 8.08 | 7,00 | 6.13 |
| 34 | 53.79 | 37.42 | 27.54 | 21.13 | 16.74 | 13.60 | 11.28 | 9.51 | 8.14 | 7.05 | 6.17 |
| 35 | 54.18 | 37.69 | 27.74 | 21.28 | 16.86 | 13.69 | 11.35 | 9.57 | 8.19 | 7.09 | 6.21 |
| 36 | 54.56 | 37.95 | 27.93 | 21.43 | 16.97 | 13.79 | 11.43 | 9.64 | 8.24 | 7.14 | 6.25 |
| 37 | 54.93 | 38.20 | 28.12 | 21.57 | 17.08 | 13.87 | 11.50 | 9.70 | 8.29 | 7.18 | 6.29 |
| 38 | 55.29 | 38.45 | 28.30 | 21.71 | 17.19 | 13.96 | 11.57 | 9.76 | 8.34 | 7.22 | 6.32 |
| 39 | 55.65 | 38.70 | 28.48 | 21.84 | 17.30 | 14.05 | 11.64 | 9.81 | 8.39 | 7.27 | 6.36 |
| 40 | 55.99 | 38.93 | 28.65 | 21.98 | 17.40 | 14.13 | 11.71 | 9.87 | 8.44 | 7.31 | 6.39 |
| 41 | 56.32 | 39.16 | 28.82 | 22.10 | 17.50 | 14.21 | 11.78 | 9.93 | 8.49 | 7.34 | 6.42 |
| 42 | 56.65 | 39.39 | 28.98 | 22.23 | 17.60 | 14.29 | 11.84 | 9.98 | 8.53 | 7.38 | 6.46 |
| 43 | 56.96 | 39.61 | 29.14 | 22.35 | 17.70 | 14.37 | 11.90 | 10.03 | 8.57 | 7.42 | 6.49 |
| 44 | 57.28 | 39.82 | 29.30 | 22.47 | 17.79 | 14.44 | 11.97 | 10.08 | 8.62 | 7.46 | 6.52 |
| 45 | 57.58 | 40.03 | 29.45 | 22.59 | 17.88 | 14.52 | 12.03 | 10.13 | 8.66 | 7.49 | 6.55 |
| 46 | 57.88 | 40.24 | 29.60 | 22.70 | 17.97 | 14.59 | 12.08 | 10.18 | 8.70 | 7.53 | 6.58 |
| 47 | 58.17 | 40.44 | 29.75 | 22.81 | 18.06 | 14.66 | 12.14 | 10.23 | 8.74 | 7.56 | 6.61 |
| 48 | 58.45 | 40.64 | 29.90 | 22.92 | 18.14 | 14.73 | 12.20 | 10.28 | 8.78 | 7.60 | 6.64 |
| 49 | 58.73 | 40.83 | 30.04 | 23.03 | 18.23 | 14.80 | 12.25 | 10.32 | 8.82 | 7.63 | 6.67 |
| 50 | 59.01 | 41.02 | 30.18 | 23.14 | 18.31 | 14.86 | 12.31 | 10.37 | 8.86 | 7.66 | 6.70 |

In experiments carried out in CRD or RBD designs, with fixed d, there is an increase in the number of replications necessary with the increase of the number of treatments. As the number of treatments is increased, the difference observed in the number of replications necessary for experiments in CRD and RBD is little expressive, until the moment in which the number of replications for experiments using the completely randomized and randomized block designs are virtually equal. These results agree with studies on crops of black oats (Cargnelutti Filho et al., 2014a), forage pea (Cargnelutti Filho et al., 2015a), canola (Cargnelutti Filho et al., 2015b), millet (Burin et al., 2015) and pigeonpea (Santos et al., 2016).

Finally, taking into consideration an experiment with up to 50 treatments, seven replications are necessary to evaluate the yield of rye grains, and identify as significant at 5% of probability, by the Tukey test, obtaining d equal to 29.65%, classified as medium by Lúcio, Storck, and Banzatto (1999) in the winter cereals: Rye, wheat and triticale, and with $CV_{X_o}$ equal to 13.58%, classified as medium by Pimentel-Gomes (1990). The researcher is liable to choose the number of replications based on the precision desired and the availability of resources, such as: area, work force and time. The same might use the data from Tables 3 and 4 in order to define the number of replications to be used according to his or her limitations.

## 4. Conclusion

There is variability in optimum plot size to evaluate the grains yield among the cultivars BRS Progresso and Temprano and among sowing dates in the rye crop.

The optimum plot size to evaluate the grains yield of rye is 6.08 $m^2$.

Seven replicates are sufficient to evaluate the grains yield of rye in experiments with up to 50 treatments, and identify, as significant at 5% probability by Tukey test, differences among averages of treatments of 29.65% of the mean of the experiment in designs completely randomized and randomized block.

## Acknowledgements

To the National Council of Scientific and Technological Development (CNPq), the Coordination of Improvement of Personnel of Superior Level (CAPES) and the Foundation of Amparo the Research of the state of Rio Grande do Sul (FAPERGS), by the granting of scholarship to the authors. Student fellows and volunteers assisted in data collection.

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