



## Optimal plot size for experiments with black oats and the common vetch

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**ABSTRACT:** *The aim of this study was to determine the optimal plot size for evaluating the fresh weight of black oats (*Avena strigosa* Schreb) and the common vetch (*Vicia sativa* L.) in scenarios comprising combinations of the number of treatments, number of replications and levels of precision. Fifteen uniformity trials were conducted with single-crop and intercropped black oats and vetch. Fresh weight was evaluated in 540 basic experimental units (BEU), each of 1 m × 1 m (36 BEU per trial). The Smith index of soil heterogeneity (1938) was estimated. Plot size was determined using the HATHEWAY method (1961), in scenarios comprising combinations of *i* treatments (*i* = 5, 10, 15 and 20), *r* replications (*r* = 3, 4, 5, 6, 7 and 8) and *d* levels of precision (*d* = 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% and 20%). To evaluate the fresh weight of monocropped or intercropped black oats and vetch in a completely randomized or randomized complete block design, with from 5 to 20 treatments and five replications, plots of 10 m<sup>2</sup> are sufficient to identify, at a probability of 0.05, significant differences between treatments of 10% of the overall mean value of the experiment.*

**Key words:** *Avena strigosa, cover crop, experimental design, uniformity trial, Vicia sativa.*

## Tamanho ótimo de parcela para experimentos com aveia preta e ervilhaca

**RESUMO:** *O objetivo deste trabalho foi determinar o tamanho ótimo de parcela para avaliar a massa de matéria fresca de aveia preta (*Avena strigosa* Schreb) e de ervilhaca (*Vicia sativa* L.), em cenários formados por combinações de números de tratamentos, números de repetições e níveis de precisão. Foram conduzidos 15 ensaios de uniformidade com aveia preta e ervilhaca, em cultivo solteiro e em consórcio. Foi avaliada a massa de matéria fresca em 540 unidades experimentais básicas (UEB) de 1 m × 1 m (36 UEB por ensaio). Foi estimado o índice de heterogeneidade do solo de SMITH (1938). Foi determinado o tamanho de parcela por meio do método de HATHEWAY (1961) em cenários formados pelas combinações de *i* tratamentos (*i* = 5, 10, 15 e 20), *r* repetições (*r* = 3, 4, 5, 6, 7 e 8) e *d* níveis de precisão (*d* = 2%, 4%, 6%, 8%, 10%, 12%, 14%, 16%, 18% e 20%). Para avaliar a massa de matéria fresca de aveia preta e de ervilhaca, em cultivo solteiro ou em consórcio, nos delineamentos inteiramente casualizado e de blocos completos ao acaso, com 5 a 20 tratamentos e com cinco repetições, parcelas de 10 m<sup>2</sup> são suficientes para identificar diferenças significativas entre tratamentos, a 0,05 de probabilidade, de 10% da média geral do experimento.*

**Palavras-chave:** *Avena strigosa, cultura de cobertura de solo, dimensionamento experimental, ensaio de uniformidade, Vicia sativa.*

## INTRODUCTION

In field experiments with species of winter cover crops, such as black oats (*Avena strigosa* Schreb) and the common vetch (*Vicia sativa* L.), it is important to evaluate the fresh weight of the plants, whether grown as single crops or intercropped. Research has shown the importance of monocropping or intercropping in these species. Intercropping resulted in a more-balanced C/N ratio than did monocropping, as well as providing

enough crop residue to protect the soil against erosive agents and to supply N to maize (HEINRICHS et al., 2001). Greater growth was obtained in maize when grown in succession to vetch as a single crop or intercropped with black oats or turnip (FORTE et al., 2018a). Intercropping these two species gave maximum weed control in a crop of soya (FORTE et al., 2018b). Both single-crop and intercropped black oats and vetch resulted in a lower density of weed species, especially *Lolium multiflorum* (FORTE et al., 2018c).

In planning such experiments, aspects related to plot size, number of treatments and the number of replications are important; these should be adequately sized, so that the results are reliable and inferences concerning the treatments under evaluation are valid. Proper sizing optimizes resources involved in the research, such as labour, time, financial resources and the experimental area. Sizing is a common question of researchers involved in this area of knowledge.

In uniformity trials or blank experiments, it is possible to divide the experimental area into basic experimental units (BEU) of the smallest possible size that is compatible with the evaluations (STORCK et al., 2016). From the data collected in these BEU, the coefficient of variation (CV) between the BEU, and the Smith index of soil heterogeneity (b) (1938) can be estimated. Estimates of CV and b can be used with the HATHEWAY methodology (1961) to calculate the optimal plot size ( $X_o$ ) according to the experimental design, number of treatments, number of replications and experimental precision. After establishing the experimental design and number of treatments, the researcher can then choose the best combination of plot size, number of replications and level of experimental precision. This approach has been used with the common bean (MAYOR-DURÁN et al., 2012), and for evaluating fresh weight in potential ground cover species, such as the velvet bean (CARGNELUTTI FILHO et al., 2014b) and the forage turnip (CARNELUTTI FILHO et al., 2014c). Important results were generated in those studies, which can be applied when planning experiments with these species grown as single crops.

Although, plot size was investigated using the maximum curvature of the model of the coefficient of variation (PARANAÍBA et al., 2009) in the single cultivation of black oats (CARGNELUTTI FILHO et al., 2014a) and vetch (CARGNELUTTI FILHO et al., 2017), it is assumed that intercropping, commonly used with ground cover plants, can generate distinct patterns of experimental design, and that the use of this approach can combine information for planning experiments with these two ground cover species.

Thus, the aim of this study was to determine the optimal plot size for evaluating the fresh weight of black oats (*Avena strigosa* Schreb) and the common vetch (*Vicia sativa* L.) in scenarios comprising combinations of the number of treatments, number of replications and levels of precision.

## MATERIALS AND METHODS

Fifteen uniformity trials were conducted with black oats (*Avena strigosa* Schreb) 'Embrapa

139', and the common vetch (*Vicia sativa* L.) 'SS Ametista', in an experimental area located at 29°42' S and 53°49' W, at an altitude of 95 m. According to the Köppen classification, the climate in the area is type Cfa, humid subtropical with hot summers and no dry season (ALVARES et al., 2013); the soil is a Dystrophic Red Arenic Argisol (SANTOS et al., 2013). A physical and chemical analysis of the soil at a depth of 0-20 cm revealed:  $pH_{H_2O}$  1:1:5.8, Ca: 5.7  $cmol_c dm^{-3}$ , Mg: 2.4  $cmol_c dm^{-3}$ , Al: 0.0  $cmol_c dm^{-3}$ , H+Al: 3.5  $cmol_c dm^{-3}$ , SMP index: 6.2, organic matter: 2.4%, clay content: 29.0%, S: 13.3  $mg dm^{-3}$ , P (Mehlich): 25.7  $mg dm^{-3}$ , K: 0.696  $cmol_c dm^{-3}$ ,  $CEC_{pH7}$ : 12.4  $cmol_c dm^{-3}$ , Cu: 1.28  $mg dm^{-3}$ , Zn: 0.753  $mg dm^{-3}$ , and B: 0.1  $mg dm^{-3}$ . These results were used to define the fertilization (CQFS, 2016).

The uniformity trials comprised combinations of sowing densities of black oats (*Avena strigosa* Schreb) 'Embrapa 139' (BO) and vetch (*Vicia sativa* L.) 'SS Ametista' (VE). Three trials were conducted for each of the following combinations, with the respective sowing densities shown in parentheses: 100% BO (80  $kg ha^{-1}$ ), 75% BO (60  $kg ha^{-1}$ ) + 25% VE (15  $kg ha^{-1}$ ), 50% BO (40  $kg ha^{-1}$ ) + 50% VE (30  $kg ha^{-1}$ ), 25% BO (20  $kg ha^{-1}$ ) + 75% VE (45  $kg ha^{-1}$ ), and 100% VE (60  $kg ha^{-1}$ ). On 16 June 2017, base fertilizer was applied using 20  $kg ha^{-1}$  N, 80  $kg ha^{-1}$   $P_2O_5$  and 80  $kg ha^{-1}$   $K_2O$  (as 05-20-20 formulation NPK) with broadcast seeding.

For each uniformity trial, the central area of 6 m × 6 m (36  $m^2$ ) was divided into 36 basic experimental units (BEU) of 1 m × 1 m (1  $m^2$ ), to form a matrix of six rows and six columns. At flowering, the plants in each BEU were cut close to the ground and the fresh weight (FW) was determined, in  $g m^{-2}$ . Weighing was carried out immediately after cutting to minimise possible variations in plant moisture.

In the period between sowing (16/06/2017) and evaluating the FW (20/09/2017), daily data were recorded for the minimum (Tmin) and maximum (Tmax) air temperature, in °C, and rainfall, in mm, at the Automatic Weather Station of the Federal University of Santa Maria, located 40 m from the experimental area. The daily mean air temperature (Tm) was calculated in °C, using the expression:  $Tm = (Tmin + Tmax)/2$ .

With the FW data of the 36 BEU in each uniformity trial, plots were marked out consisting of  $X_r$  adjacent BEU in a row and  $X_c$  adjacent BEU in a column. Plots of different sizes and/or shapes were marked out as ( $X = X_r \times X_c$ ), i.e. (1 × 1), (1 × 2), (1 × 3), (1 × 6), (2 × 1), (2 × 2), (2 × 3), (2 × 6), (3 × 1), (3 × 2), (3 × 3), (3 × 6), (6 × 1), (6 × 2) and (6 × 3). The

abbreviations  $X_R$ ,  $X_C$  and  $X$  indicate the number of adjacent BEU in a row, the number of adjacent BEU in a column, and the size of the plot in number of BEU respectively.

For each plot size ( $X$ ), the following were determined:  $n$  - the number of plots with a size of  $X$  BEU ( $n = 36/X$ ),  $M_{(X)}$  - mean value of the plots with a size of  $X$  BEU,  $V_{(X)}$  - variance between plots with a size of  $X$  BEU,  $CV_{(X)}$  - coefficient of variation (in %) between plots with a size of  $X$  BEU, and  $VU_{(X)}$  - variance per BEU between plots with a size of  $X$  BEU [ $VU_{(X)} = V_{(X)}/X^2$ ].

The parameters,  $V1$  (estimate of the variance per BEU between plots with a size of one BEU) and  $b$  (estimate for the index of soil heterogeneity), and the coefficient of determination ( $r^2$ ) of the function  $VU_{(X)} = V1/X^b$  (SMITH, 1938), were estimated by logarithmic transformation and linearisation of the function  $VU_{(X)} = V1/X^b$  (SMITH, 1938), i.e.  $\log VU_{(X)} = \log V1 - b \log X$ , the estimate being weighted by the degrees of freedom ( $DF = n-1$ ) associated with each plot size (STEEL et al., 1997). The observed values of the dependent [ $VU_{(X)}$ ] and independent ( $X$ ) variables and the function  $VU_{(X)} = V1/X^b$  (SMITH, 1938) were plotted.

Experimental plans were simulated in completely randomized and randomized complete block designs for scenarios comprising combinations of  $i$  treatments ( $i = 5, 10, 15$  and  $20$ ),  $r$  replications ( $r = 3, 4, 5, 6, 7$  and  $8$ ) and  $d$  differences between the mean values of those treatments detected as significant at a probability of  $0.05$ , expressed as a percentage of the overall mean value for the experiment, i.e. at levels of precision [ $d = 2\%$  (greatest precision),  $4\%$ ,  $6\%$ ,  $8\%$ ,  $10\%$ ,  $12\%$ ,  $14\%$ ,  $16\%$ ,  $18\%$  and  $20\%$  (lowest precision)].

For each experimental plan, the optimal plot size ( $X_o$ ) was calculated in number of BEU (rounded up to the next integer), using the expression  $X_o = \sqrt[3]{2(t_1 + t_2)^2 CV^2 / r d^2}$  (HATHEWAY, 1961). In this expression,  $b$  is the estimated index of soil heterogeneity (for each combination in this study, the mean value of  $b$  in the three uniformity trials was considered);  $t_1$  is the critical value of Student's  $t$ -distribution for the significance level of the test (type I error) of  $\alpha = 5\%$  ( $5\%$  bilateral test), with  $DF$  degrees of freedom;  $t_2$  is the critical value of Student's  $t$ -distribution, corresponding to  $2(1-P)$  (bilateral test), where  $P$  is the probability of obtaining a significant result, i.e. the power of the test ( $P = 0.80$ , in this study), with  $DF$  degrees of freedom;  $CV$  is the estimate of the coefficient of variation between plots with a size of one BEU as a percentage (in this study, the

mean value of  $CV$  for the three uniformity trials was considered for each combination);  $r$  is the number of replications and  $d$  is the difference between the mean values of those treatments detected as significant at a probability of  $0.05$ , expressed as a percentage of the overall mean value for the experiment (precision). The degrees of freedom ( $DF$ ) for obtaining the critical (tabulated) values of Student's  $t$ -distribution were given by the expressions,  $DF = (i)(r-1)$  for the completely randomized design and  $DF = (i-1)(r-1)$  for the randomized complete block design, where  $i$  is the number of treatments and  $r$  is the number of replications. In this study, the values for  $t_1$  and  $t_2$  were obtained with the Microsoft Office Excel® software, using the functions,  $t_1 = \text{INVT}(0.05; DF)$  and  $t_2 = \text{INVT}(0.40; DF)$  respectively. The statistical analyses were carried out using the Microsoft Office Excel® software.

## RESULTS AND DISCUSSION

In the 15 uniformity trials comprising combinations of the sowing densities of black oats (*Avena strigosa* Schreb) 'Embrapa 139' (BO) and vetch (*Vicia sativa* L.) 'SS Ametista' (VE), there was an increase in the mean value of the plots [ $M_{(X)}$ ] and the variance between plots [ $V_{(X)}$ ], with a decrease in the coefficient of variation [ $CV_{(X)}$ ] and the variance per BEU between plots [ $VU_{(X)}$ ], for increases in the planned size of the plot ( $X$ ) (Table 1 and Figure 1). These results indicate an improvement in experimental precision (a decrease in  $CV_{(X)}$  and  $VU_{(X)}$ ), with the increase in plot size. Therefore; although, it is possible to evaluate fresh weight (FW) in plots of  $1 \text{ m}^2$ , it is important to evaluate the precision in larger plots, i.e. it is essential to design the experiment with the optimal plot size to ensure a proper discrimination of the treatments under evaluation and the reliability of the inferences. In addition, smaller sizes may not represent plant development for either single crops or intercrops; whereas larger sizes would make it possible to evaluate the plants in the central area of the plot (working area) and disregard the borders, thereby reducing interference from plants in adjacent plots, i.e. inter-plot competition.

The mean value of FW in the three trials of each combination was  $24055$ ,  $24005$ ,  $23189$ ,  $23579$  and  $21252 \text{ kg ha}^{-1}$  for the combinations of  $100\%$  BO,  $75\%$  BO +  $25\%$  VE,  $50\%$  BO +  $50\%$  VE,  $25\%$  BO +  $75\%$  VE and  $100\%$  VE respectively (Table 1). There was, therefore, adequate growth and development of the black oats and vetch, with similar values for FW between the single crops and the intercrops under the environmental conditions of the site (Figure 2). The

Table 1 - Planned plot size ( $X = X_R \times X_C$ ) in basic experimental units (BEU), with  $X_R$  adjacent BEU in a row and  $X_C$  adjacent BEU in a column; number of plots with a size of X BEU ( $n = 36/X$ ); mean value of plots with a size of X BEU [ $M_{(x)}$ ], in g; coefficient of variation (%) between plots with a size of X BEU [ $CV_{(x)}$ ]; and variance per BEU between plots with a size of X BEU [ $VU_{(x)}$ ]. Fresh weight for sowing density in black oats (BO) and vetch (VE).

T <sup>(1)</sup>	X <sub>R</sub>	X <sub>C</sub>	X	n	-----100% BO-----			-75% BO + 25% VE-			-50% BO + 50% VE-			-25% BO + 75% VE-			-----100% VE-----		
					M <sub>(x)</sub>	CV <sub>(x)</sub>	VU <sub>(x)</sub>	M <sub>(x)</sub>	CV <sub>(x)</sub>	VU <sub>(x)</sub>	M <sub>(x)</sub>	CV <sub>(x)</sub>	VU <sub>(x)</sub>	M <sub>(x)</sub>	CV <sub>(x)</sub>	VU <sub>(x)</sub>	M <sub>(x)</sub>	CV <sub>(x)</sub>	VU <sub>(x)</sub>
1	1	1	1	36	2285	13.54	95739	2323	12.64	86233	2317	11.54	71514	2322	13.23	94428	2134	19.25	168693
1	1	2	2	18	4569	10.93	62376	4645	11.41	70265	4633	8.53	39071	4644	11.14	66890	4268	16.13	118459
1	1	3	3	12	6854	10.48	57313	6968	10.70	61792	6950	8.09	35138	6967	9.92	53013	6402	11.33	58431
1	1	6	6	6	13707	9.68	48901	13936	11.04	65750	13900	7.61	31065	13933	8.01	34561	12805	8.08	29699
1	2	1	2	18	4569	9.43	46379	4645	7.75	32433	4633	8.55	39216	4644	10.01	54061	4268	14.49	95676
1	2	2	4	9	9138	6.75	23775	9291	6.74	24517	9267	6.10	19969	9289	9.11	44767	8536	12.21	67913
1	2	3	6	6	13707	6.98	25450	13936	6.52	22934	13900	5.82	18187	13933	7.74	32325	12805	8.22	30741
1	2	6	12	3	27414	5.56	16108	27873	7.08	27020	27801	6.14	20216	27866	4.92	13055	25609	5.14	12017
1	3	1	3	12	6854	10.47	57253	6968	6.74	24500	6950	7.36	29042	6967	8.53	39211	6402	11.75	62887
1	3	2	6	6	13707	8.38	36678	13936	6.47	22603	13900	5.50	16223	13933	7.43	29805	12805	9.35	39790
1	3	3	9	4	20561	9.12	43445	20905	6.36	21800	20851	5.75	17725	20900	6.44	22345	19207	6.16	17296
1	3	6	18	2	41122	9.47	46767	41809	7.62	31333	41701	6.43	22214	41799	3.63	7120	38414	0.84	319
1	6	1	6	6	13707	5.82	17679	13936	3.10	5201	13900	4.68	11739	13933	6.46	22528	12805	10.93	54365
1	6	2	12	3	27414	3.26	5534	27873	2.71	3967	27801	2.35	2971	27866	5.66	17304	25609	10.30	48348
1	6	3	18	2	41122	4.98	12952	41809	1.52	1239	41701	0.18	18	41799	4.79	12359	38414	7.27	24090
2	1	1	1	36	2463	10.93	72509	2457	10.96	72457	2334	11.12	67332	2333	10.94	65108	2272	19.23	190881
2	1	2	2	18	4925	8.67	45585	4914	8.29	41505	4667	6.03	19783	4667	8.06	35357	4543	13.76	97754
2	1	3	3	12	7388	8.03	39133	7370	5.86	20706	7001	6.62	23882	7000	6.91	25961	6815	8.80	39986
2	1	6	6	6	14776	6.20	23346	14741	4.60	12758	14002	5.50	16485	14000	5.50	16483	13630	7.89	32160
2	2	1	2	18	4925	8.60	44881	4914	7.67	35518	4667	8.76	41791	4667	9.31	47193	4543	14.61	110175
2	2	2	4	9	9850	6.63	26654	9827	5.06	15467	9334	4.62	11639	9333	6.85	25520	9087	10.03	51908
2	2	3	6	6	14776	5.91	21209	14741	3.32	6666	14002	5.34	15504	14000	6.24	21183	13630	6.67	22988
2	2	6	12	3	29551	3.52	7495	29481	2.70	4392	28003	4.56	11300	28000	5.41	15939	27260	6.30	20466
2	3	1	3	12	7388	7.73	36229	7370	7.80	36713	7001	6.36	22015	7000	7.95	34435	6815	12.40	79316
2	3	2	6	6	14776	5.39	17639	14741	5.12	15810	14002	2.44	3238	14000	5.74	17947	13630	8.79	39884
2	3	3	9	4	22164	4.80	13997	22111	2.46	3661	21002	2.25	2749	21000	5.34	15520	20445	3.16	5149
2	3	6	18	2	44327	0.67	272	44222	0.10	7	42005	1.34	980	42001	4.49	10977	40890	3.19	5259
2	6	1	6	6	14776	6.31	24110	14741	6.89	28632	14002	5.68	17596	14000	6.98	26491	13630	10.72	59327
2	6	2	12	3	29551	4.55	12573	29481	4.30	11174	28003	1.93	2028	28000	4.44	10745	27260	9.01	41864
2	6	3	18	2	44327	4.08	10098	44222	0.04	1	42005	2.09	2384	42001	4.74	12229	40890	1.78	1637
3	1	1	1	36	2469	10.81	71294	2422	11.15	72928	2306	17.34	159883	2418	10.42	63494	1970	16.22	102041
3	1	2	2	18	4939	7.84	37451	4844	9.84	56838	4613	13.15	91912	4837	6.65	25851	3940	13.32	68816
3	1	3	3	12	7408	7.74	36575	7266	9.02	47765	6919	12.62	84719	7255	6.47	24488	5910	11.43	50699
3	1	6	6	6	14817	7.79	37025	14532	9.22	49886	13838	10.82	62323	14510	3.64	7734	11819	7.16	19875
3	2	1	2	18	4939	8.50	44041	4844	7.07	29349	4613	12.31	80655	4837	7.37	31776	3940	9.80	37278
3	2	2	4	9	9878	6.25	23822	9688	5.12	15400	9225	7.93	33417	9673	5.32	16552	7879	7.54	22042
3	2	3	6	6	14817	6.12	22873	14532	4.05	9625	13838	7.74	31843	14510	5.65	18668	11819	3.69	5297
3	2	6	12	3	29633	6.81	28239	29065	3.99	9361	27676	5.11	13865	29019	1.20	839	23638	3.68	5266
3	3	1	3	12	7408	8.55	44598	7266	7.15	29980	6919	7.80	32364	7255	7.03	28932	5910	8.24	26361
3	3	2	6	6	14817	5.55	18813	14532	5.69	19022	13838	5.42	15618	14510	5.23	16024	11819	6.91	18524
3	3	3	9	4	22225	5.34	17401	21799	5.30	16468	20757	3.96	8354	21765	5.63	18547	17729	1.95	1479
3	3	6	18	2	44450	6.54	26081	43597	6.36	23738	41514	0.34	60	43529	1.33	1033	35458	1.19	550
3	6	1	6	6	14817	5.76	20249	14532	4.30	10844	13838	6.32	21245	14510	6.63	25697	11819	7.19	20053
3	6	2	12	3	29633	2.21	2972	29065	2.32	3155	27676	4.53	10938	29019	5.56	18051	23638	6.22	15035
3	6	3	18	2	44450	0.17	18	43597	1.15	774	41514	4.72	11832	43529	6.77	26783	35458	1.55	936

<sup>1)</sup>Each uniformity trial with a size of 6 m × 6 m (36 m<sup>2</sup>) was divided into 36 BEU of 1 m × 1 m (1 m<sup>2</sup>) forming a matrix of six rows and six columns.

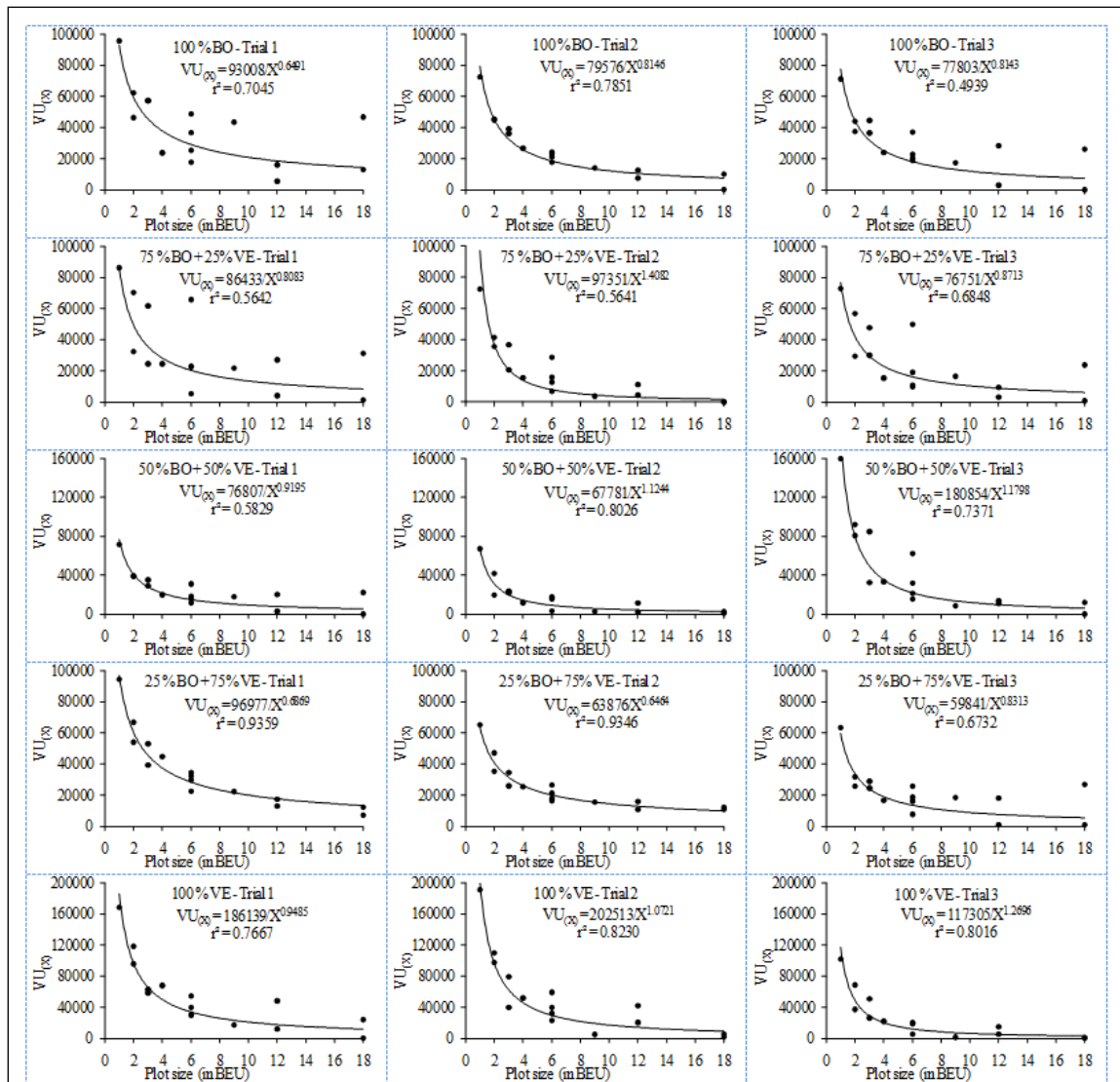
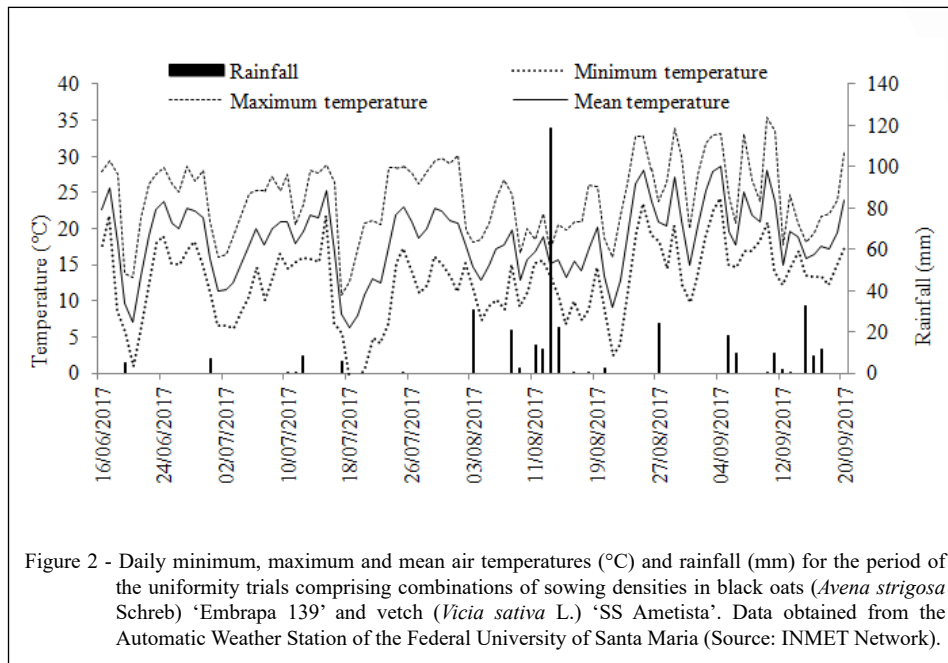


Figure 1 - Graphical representation of the relationship between the variance per basic experimental unit (BEU) for plots with a size of X BEU [ $VU_{(x)} = V_{(x)}/X^2$ ] and the planned plot size (X), in BEU, and estimates of the parameters of the function  $VU_{(x)} = V1/X^b$  (SMITH,1938). Fresh weight data obtained from uniformity trials with 36 BEU of 1 m<sup>2</sup>, comprising combinations of sowing density in black oats (*Avena strigosa* Schreb) 'Embrapa 139' (BO) and vetch (*Vicia sativa* L.) 'SS Ametista' (VE).

beneficial aspects of the residue from these species, when intercropped, in relation to soil protection and nitrogen supply, control and a reduction in plant density, have been highlighted (HEINRICHS et al., 2001; FORTE et al., 2018a, 2018b, 2018c), and justify the importance of evaluating the FW of these plants.

The mean value of the coefficient of variation (CV) for FW in the three trials of each combination was 11.76%, 11.58%, 13.33%, 11.53%

and 18.23% for the combinations of 100% BO, 75% BO + 25% VE, 50% BO + 50% VE, 25% BO + 75% VE and 100% VE respectively. Although, in the single-crop vetch the CV was greater (CV = 18.23%) in relation to the single-crop black oats (11.76%) and to the intercropped BO and VE (11.53% ≤ CV ≤ 13.33%), at these values, all the coefficients are considered average according to the PIMENTEL-GOMES classification (2009) for agricultural crops



in general, i.e. they are within the range of 10% and 20%. This suggested that experiments with black oats and vetch, whether as single crops or intercropped, have similar experimental precision. The variations in CV between the combinations might be associated with environmental and genotypic variability, and genotype interaction with the environment.

In the 15 uniformity trials, there were visible marked decreases in variance per BEU [ $VU_{(x)}$ ] for plots of up to four BEU in size (4 m<sup>2</sup>), midway between four and ten BEU, tending to stabilise for plots greater than ten BEU (Figure 1). This variance is phenotypic, and is therefore the sum of environmental and genotypic variances, and of genotype interaction with the environment. The behaviour was similar for other ground cover plants such as the velvet bean (CARGNELUTTI FILHO et al., 2014b) and the forage turnip (CARGNELUTTI FILHO et al., 2014c). As such, a plot size of up to ten BEU (10 m<sup>2</sup>) is suggested for evaluating the fresh weight of single-crop or intercropped black oats and vetch, as the gain in experimental precision (a decrease in  $VU_{(x)}$ ) with the increase in plot size starting from ten BEU was negligible. This value of 10 m<sup>2</sup> is relatively greater than the plot size of 4.14 m<sup>2</sup> determined to evaluate the fresh weight of black oats (CARGNELUTTI FILHO et al., 2014a) and of 4.52 m<sup>2</sup> to assess the fresh weight of vetch (CARGNELUTTI FILHO et al., 2017). It should be considered that these

authors used another methodology, i.e. the maximum curvature of the model of the coefficient of variation (PARANAÍBA et al., 2009).

To evaluate the fresh weight of single-crop or intercropped black oats and vetch in experiments conducted in completely randomized (CRD) and randomized complete block (RCB) designs, the optimal plot size ( $X_o$ ), estimated by the HATHEWAY method (1961) from a fixed number of treatments ( $i$ ) and replications ( $r$ ), increases with the rise in precision ( $d$ ) (Tables 2 and 3). For example, to evaluate the FW of black oats (100% BO) in an RCB design with five treatments ( $i = 5$ ) and three replications ( $r = 3$ ), so that in 80% of the experiments (power = 0.80) differences between treatments of  $d = 20\%$  of the overall mean of the experiment (lower precision) are detected as significant at a probability of 0.05, the plot size should be four BEU (4 m<sup>2</sup>) (Table 3). A plot size equal to or greater than this is feasible in field experiments, which makes it possible to improve the experimental precision. For example, plots of 20 m<sup>2</sup> would make it possible to achieve  $d = 10\%$ . However, under these same conditions, for  $d = 2\%$  (greater precision), a plot of 1330 BEU (1330 m<sup>2</sup>) would be necessary. In this situation, the experimental precision is greater, however, conducting a field experiment with a plot of 1330 m<sup>2</sup> is impractical. As such, high experimental accuracies (low percentages of  $d$ ) are difficult to achieve in practice due to the need for large plot

Table 2 - Optimal plot size in m<sup>2</sup>, for a completely randomized design, in combinations of i treatments, r replications and d levels of precision, for fresh weight at sowing densities in black oats and vetch.

d (%)	-----i = 5 treatments-----							-----i = 10 treatments-----							-----i = 15 treatments-----							-----i = 20 treatments-----							
	r=3	r=4	r=5	r=6	r=7	r=8	r=3	r=4	r=5	r=6	r=7	r=8	r=3	r=4	r=5	r=6	r=7	r=8	r=3	r=4	r=5	r=6	r=7	r=8	r=3	r=4	r=5	r=6	r=7
-----100% black oats (index of soil heterogeneity b = 0.7593, CV = 11.76%)-----																													
2	1236	770	548	420	337	279	1074	703	513	398	322	269	1027	683	502	391	318	265	1004	673	496	388	315	264					
4	200	124	89	68	55	45	173	114	83	65	52	44	166	110	81	63	52	43	162	109	80	63	51	43					
6	69	43	31	24	19	16	60	39	29	23	18	15	57	38	28	22	18	15	56	38	28	22	18	15					
8	33	20	15	11	9	8	28	19	14	11	9	7	27	18	14	11	9	7	27	18	13	11	9	7					
10	18	12	8	7	5	5	16	11	8	6	5	4	15	10	8	6	5	4	15	10	8	6	5	4					
12	12	7	5	4	3	3	10	7	5	4	3	3	10	7	5	4	3	3	9	6	5	4	3	3					
14	8	5	4	3	2	2	7	5	4	3	2	2	7	5	3	3	2	2	6	4	3	3	2	2					
16	6	4	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2					
18	4	3	2	2	2	1	4	3	2	2	1	1	4	3	2	2	1	1	4	3	2	2	1	1					
20	3	2	2	1	1	1	3	2	2	1	1	1	3	2	2	1	1	1	3	2	2	1	1	1					
-----75% black oats + 25% vetch (index of soil heterogeneity b = 1.0292, CV = 11.58%)-----																													
2	186	131	102	84	71	62	168	123	97	81	69	61	162	120	96	80	68	60	160	119	95	79	68	60					
4	49	34	27	22	19	17	44	32	26	21	18	16	43	32	25	21	18	16	42	31	25	21	18	16					
6	22	16	13	10	9	8	20	15	12	10	9	8	20	15	12	10	9	8	19	14	12	10	8	8					
8	13	9	7	6	5	5	12	9	7	6	5	5	11	9	7	6	5	5	11	9	7	6	5	5					
10	9	6	5	4	4	3	8	6	5	4	4	3	8	6	5	4	3	3	7	6	5	4	3	3					
12	6	5	4	3	3	2	6	4	3	3	3	2	5	4	3	3	3	2	5	4	3	3	3	2					
14	5	3	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2					
16	4	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2					
18	3	2	2	2	1	1	3	2	2	2	1	1	3	2	2	2	1	1	3	2	2	2	1	1					
20	3	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	1					
-----50% black oats + 50% vetch (index of soil heterogeneity b = 1.0746, CV = 13.33%)-----																													
2	194	139	109	91	78	68	175	130	104	87	75	66	170	127	103	86	74	66	167	126	102	86	74	65					
4	54	39	30	25	22	19	49	36	29	24	21	19	47	35	29	24	21	18	46	35	28	24	21	18					
6	25	18	15	12	10	9	23	17	14	12	10	9	22	17	14	12	10	9	22	17	14	12	10	9					
8	15	11	9	7	6	6	14	10	8	7	6	5	13	10	8	7	6	5	13	10	8	7	6	5					
10	10	7	6	5	4	4	9	7	6	5	4	4	9	7	6	5	4	4	9	7	6	5	4	4					
12	7	5	4	4	3	3	7	5	4	4	3	3	7	5	4	4	3	3	6	5	4	4	3	3					
14	6	4	3	3	3	2	5	4	3	3	2	2	5	4	3	3	2	2	5	4	3	3	2	2					
16	5	3	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2					
18	4	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2					
20	3	2	2	2	1	1	3	2	2	2	2	1	3	2	2	2	2	1	3	2	2	2	2	1					
-----25% black oats + 75% vetch (index of soil heterogeneity b = 0.7215, CV = 11.53%)-----																													
2	1697	1032	722	545	432	354	1464	938	672	515	412	341	1397	909	657	506	406	336	1364	895	650	501	403	334					
4	249	151	106	80	64	52	215	138	99	76	61	50	205	133	97	74	60	50	200	131	96	74	59	49					
6	81	50	35	26	21	17	70	45	32	25	20	17	67	44	32	25	20	16	65	43	31	24	20	16					
8	37	23	16	12	10	8	32	21	15	12	9	8	30	20	15	11	9	8	30	20	14	11	9	8					
10	20	12	9	7	5	5	17	11	8	6	5	4	17	11	8	6	5	4	16	11	8	6	5	4					
12	12	8	6	4	4	3	11	7	5	4	3	3	10	7	5	4	3	3	10	7	5	4	3	3					
14	8	5	4	3	2	2	7	5	4	3	2	2	7	5	3	3	2	2	7	5	3	3	2	2					
16	6	4	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2					
18	4	3	2	2	1	1	4	3	2	2	1	1	4	3	2	2	1	1	4	3	2	2	1	1					
20	3	2	2	1	1	1	3	2	2	1	1	1	3	2	2	1	1	1	3	2	2	1	1	1					
-----100% vetch (index of soil heterogeneity b = 1.0968, CV = 18.23%)-----																													
2	308	222	175	146	125	110	279	208	168	141	122	107	271	204	165	139	120	106	267	202	164	138	120	106					
4	87	63	50	42	36	31	79	59	48	40	35	31	77	58	47	40	34	30	76	57	47	39	34	30					
6	42	30	24	20	17	15	38	29	23	19	17	15	37	28	23	19	17	15	36	28	23	19	17	15					
8	25	18	14	12	10	9	23	17	14	12	10	9	22	17	14	12	10	9	22	17	14	11	10	9					
10	17	12	10	8	7	6	15	12	9	8	7	6	15	11	9	8	7	6	15	11	9	8	7	6					
12	12	9	7	6	5	5	11	8	7	6	5	5	11	8	7	6	5	5	11	8	7	6	5	5					
14	9	7	6	5	4	4	9	6	5	5	4	4	8	6	5	4	4	4	8	6	5	4	4	4					
16	7	5	4	4	3	3	7	5	4	4	3	3	7	5	4	4	3	3	7	5	4	4	3	3					
18	6	5	4	3	3	2	6	4	4	3	3	2	5	4	3	3	3	2	5	4	3	3	3	2					
20	5	4	3	3	2	2	5	4	3	3	2	2	5	4	3	3	2	2	4	4	3	3	2	2					

sizes, as noted by CARGNELUTTI FILHO et al. (2014b, 2014c). Similar behaviour was observed for the combinations of 75% BO + 25% VE, 50% BO + 50% VE, 25% BO + 75% VE and 100% VE (Table 3).

In the CRD and RCB designs, with fixed values for  $i$  and  $d$ , the value of  $X_o$  decreases for an increase in  $r$ . Furthermore, with fixed values for  $r$  and  $d$ , there is a decrease in  $X_o$  for an increase in  $i$  (Tables 2 and 3). The greater the number of treatments and number of replications, the greater the number of error degrees of freedom and, consequently, the lower the estimate of residual variance (mean square error), i.e. the greater the experimental precision.

In the HATHEWAY methodology (1961), based on a fixed value for the Smith index of soil heterogeneity (1938) ( $b$ ),  $X_o$  is dependent on  $i$ ,  $r$  and  $d$ . Therefore, taking the number of treatments and the desired precision as a basis, it is possible to use the information from this study to plan the plot size and number of replications to be used. For example, if the researcher wants to evaluate the FW of ten treatments of single-crop black oats (100% BO) in an RCB design and requires a precision ( $d$ ) of 10%, among the various options, he could use plots of 16 BEU (16 m<sup>2</sup>) and three replications, 11 BEU (11 m<sup>2</sup>) and four replications, eight BEU (8 m<sup>2</sup>) and five replications, six BEU (6 m<sup>2</sup>) and six replications, five BEU (5 m<sup>2</sup>) and seven replications or four BEU (4 m<sup>2</sup>) and eight replications (Table 3). For these six options, the area of the experiment would be 480, 440, 400, 360, 350 and 320 m<sup>2</sup> respectively. Therefore, for the same precision ( $d = 10\%$  in this case), smaller plots and a greater number of replications are more efficient in their use of the experimental area, as discussed in CARGNELUTTI FILHO et al. (2014b, 2014c) and STORCK et al. (2016). It is important to consider that with the increase in the number of replications, a greater number of evaluations become necessary, and as the characteristic is difficult to measure and/or costly to evaluate, the use of a larger plot size and smaller number of replications might be advantageous, as long as there is sufficient area for the experiment. Therefore, depending on the available area, the number of treatments to be evaluated and the desired precision, the researcher should investigate which combination of plot size and number of replications is the most appropriate.

The information from this study makes it possible to investigate 240 scenarios comprising combinations of  $i$  treatments ( $i = 5, 10, 15$  and  $20$ ),  $r$  replications ( $r = 3, 4, 5, 6, 7$  and  $8$ ) and  $d$  differences between the mean values of those treatments detected as significant at 5% probability ( $d = 2\%, 4\%, 6\%, 8\%, 10\%, 12\%, 14\%, 16\%, 18\%$  and  $20\%$ ) for each combination

and each design (Tables 2 and 3). Other scenarios can be simulated from the expression  $X_o = \sqrt[3]{2(t_1 + t_2)^2 CV^2 / rd^2}$  (HATHEWAY, 1961), based on the mean value of the index of soil heterogeneity ( $b$ ) of the SMITH function (1938) and the mean value of the coefficient of variation (CV) for FW in the three trials of each combination. The following estimates would therefore be used for the combinations: 100% BO ( $b = 0.7593$ ,  $CV = 11.76\%$ ), 75% BO + 25% VE ( $b = 1.0292$ ,  $CV = 11.58\%$ ), 50% BO + 50% VE ( $b = 1.0746$ ,  $CV = 13.33\%$ ), 25% BO + 75% VE ( $b = 0.7215$ ,  $CV = 11.53\%$ ) and 100% VE ( $b = 1.0968$ ,  $CV = 18.23\%$ ) (Tables 2 and 3).

In this context, as an example, to evaluate the FW of eight treatments of black oats (100% BO), with four replications and  $d = 10\%$  in a randomized complete block design (RCB), we have:  $b = 0.7593$ ,  $DF = (8-1)(4-1) = 21$ ,  $t_1 = \text{INVT}(0.05; 21) = 2.07961383$ ,  $t_2 = \text{INVT}(0.40; 21) = 0.85907403$ ,  $CV = 11.76\%$ ,  $r = 4$ ,  $d = 10\%$ . Therefore, the optimal plot size ( $X_o$ ) is  $X_o = \sqrt[3]{2(2.07961383 + 0.85907403)^2 11.76^2 / 4 \times 10^2} = 23.49 \approx 24 \text{ BEU}$ . In simulating scenarios for a completely randomized design (CRD), only the expression for calculating the number of degrees of freedom will change, i.e. for this design,  $DF = i(r-1)$ , where  $i$  is the number of treatments and  $r$  is the number of replications. In this example, therefore,  $b = 0.7593$ ,  $DF = (8)(4-1) = 24$ ,  $t_1 = \text{INVT}(0.05; 24) = 2.06389854$ ,  $t_2 = \text{INVT}(0.40; 24) = 0.85685545$ ,  $CV = 11.76\%$ ,  $r = 4$  and  $d = 10\%$ . Hence,  $X_o = \sqrt[3]{2(2.06389854 + 0.85685545)^2 11.76^2 / 4 \times 10^2} = 22.82 \approx 23 \text{ BEU}$ . For the same experimental values, the smaller plot size in CRD (23 BEU) compared to the RCB design (24 BEU) confirmed the greater efficiency of CRD when the experimental area is homogeneous (STORCK et al., 2016).

The results of this study make it possible to define the plot size and the number of replications in experiments to evaluate the fresh weight of black oats and the common vetch, grown as single crops or intercropped. However, it can generally be inferred that in experiments in a completely randomized or randomized complete block design, with from 5 to 20 treatments and five replications, plots of 10 m<sup>2</sup> are sufficient to identify, at a probability of 0.05, significant differences between treatments of 10% of the overall mean value of the experiment. The suggestion for a plot size of 10 m<sup>2</sup> is supported by viability in the field and the stabilized precision starting with this plot size.

## CONCLUSION

In experiments to evaluate the fresh weight of single-crop or intercropped black oats and



Table 3 - Optimal plot size in m<sup>2</sup>, for a randomized complete block design, in combinations of i treatments, r replications and d levels of precision, for fresh weight at sowing densities in black oats and vetch.

d(%)	i = 5 treatments							i = 10 treatments							i = 15 treatments							i = 20 treatments						
	r=3	r=4	r=5	r=6	r=7	r=8	r=3	r=4	r=5	r=6	r=7	r=8	r=3	r=4	r=5	r=6	r=7	r=8	r=3	r=4	r=5	r=6	r=7	r=8				
-----100% black oats (index of soil heterogeneity b = 0.7593, CV = 11.76%)-----																												
2	1330	807	567	431	344	284	1090	710	517	400	324	270	1033	686	503	392	318	266	1008	674	497	388	316	264				
4	215	130	92	70	56	46	176	115	84	65	53	44	167	111	81	64	52	43	163	109	80	63	51	43				
6	74	45	32	24	20	16	61	40	29	23	18	15	58	38	28	22	18	15	56	38	28	22	18	15				
8	35	21	15	12	9	8	29	19	14	11	9	7	27	18	14	11	9	7	27	18	13	11	9	7				
10	20	12	9	7	5	5	16	11	8	6	5	4	15	10	8	6	5	4	15	10	8	6	5	4				
12	12	8	6	4	4	3	10	7	5	4	3	3	10	7	5	4	3	3	9	7	5	4	3	3				
14	8	5	4	3	3	2	7	5	4	3	2	2	7	5	3	3	2	2	6	5	3	3	2	2				
16	6	4	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2				
18	5	3	2	2	2	1	4	3	2	2	1	1	4	3	2	2	1	1	4	3	2	2	1	1				
20	4	2	2	2	1	1	3	2	2	1	1	1	3	2	2	1	1	1	3	2	2	1	1	1				
-----75% black oats + 25% vetch (index of soil heterogeneity b = 1.0292, CV = 11.58%)-----																												
2	196	136	105	86	73	63	170	124	98	81	69	61	163	120	96	80	69	60	160	119	95	79	68	60				
4	51	36	28	23	19	17	44	33	26	21	18	16	43	32	25	21	18	16	42	31	25	21	18	16				
6	24	17	13	11	9	8	20	15	12	10	9	8	20	15	12	10	9	8	19	15	12	10	9	8				
8	14	10	8	6	5	5	12	9	7	6	5	5	11	9	7	6	5	5	11	9	7	6	5	5				
10	9	6	5	4	4	3	8	6	5	4	4	3	8	6	5	4	3	3	7	6	5	4	3	3				
12	7	5	4	3	3	2	6	4	3	3	3	2	5	4	3	3	3	2	5	4	3	3	3	2				
14	5	4	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2				
16	4	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2				
18	3	2	2	2	2	1	3	2	2	2	1	1	3	2	2	2	1	1	3	2	2	2	1	1				
20	3	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	1	2	2	2	1	1	1				
-----50% black oats + 50% vetch (index of soil heterogeneity b = 1.0746, CV = 13.33%)-----																												
2	204	143	112	92	79	69	177	131	105	88	75	66	171	128	103	86	75	66	168	126	102	86	74	65				
4	56	40	31	26	22	19	49	36	29	24	21	19	47	36	29	24	21	18	47	35	28	24	21	18				
6	27	19	15	12	11	9	23	17	14	12	10	9	23	17	14	12	10	9	22	17	14	12	10	9				
8	16	11	9	7	6	6	14	10	8	7	6	5	13	10	8	7	6	5	13	10	8	7	6	5				
10	11	8	6	5	4	4	9	7	6	5	4	4	9	7	6	5	4	4	9	7	6	5	4	4				
12	8	6	4	4	3	3	7	5	4	4	3	3	7	5	4	4	3	3	6	5	4	4	3	3				
14	6	4	3	3	3	2	5	4	3	3	3	2	5	4	3	3	2	2	5	4	3	3	2	2				
16	5	3	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2	4	3	3	2	2	2				
18	4	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2	3	3	2	2	2	2				
20	3	2	2	2	2	1	3	2	2	2	2	1	3	2	2	2	1	1	3	2	2	2	2	1				
-----25% black oats + 75% vetch (index of soil heterogeneity b = 0.7215, CV = 11.53%)-----																												
2	1834	1084	748	561	442	361	1488	947	678	518	414	342	1406	913	659	507	407	337	1369	897	651	502	404	334				
4	269	159	110	82	65	53	218	139	100	76	61	51	206	134	97	75	60	50	201	132	96	74	60	49				
6	88	52	36	27	22	18	71	46	33	25	20	17	67	44	32	25	20	16	66	43	31	24	20	16				
8	40	24	17	13	10	8	32	21	15	12	9	8	31	20	15	11	9	8	30	20	14	11	9	8				
10	22	13	9	7	6	5	18	11	8	6	5	4	17	11	8	6	5	4	16	11	8	6	5	4				
12	13	8	6	4	4	3	11	7	5	4	3	3	10	7	5	4	3	3	10	7	5	4	3	3				
14	9	5	4	3	3	2	7	5	4	3	2	2	7	5	3	3	2	2	7	5	3	3	2	2				
16	6	4	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2	5	3	3	2	2	2				
18	5	3	2	2	1	1	4	3	2	2	1	1	4	3	2	2	1	1	4	3	2	2	1	1				
20	4	2	2	1	1	1	3	2	2	1	1	1	3	2	2	1	1	1	3	2	2	1	1	1				
-----100% vetch (index of soil heterogeneity b = 1.0968, CV = 18.23%)-----																												
2	324	229	180	149	127	111	282	210	168	141	122	108	272	205	165	139	121	106	267	202	164	138	120	106				
4	92	65	51	42	36	32	80	60	48	40	35	31	77	58	47	40	34	30	76	58	47	39	34	30				
6	44	31	25	20	18	15	39	29	23	19	17	15	37	28	23	19	17	15	36	28	23	19	17	15				
8	26	19	15	12	11	9	23	17	14	12	10	9	22	17	14	12	10	9	22	17	14	11	10	9				
10	18	13	10	8	7	6	15	12	9	8	7	6	15	11	9	8	7	6	15	11	9	8	7	6				
12	13	9	7	6	5	5	11	8	7	6	5	5	11	8	7	6	5	5	11	8	7	6	5	5				
14	10	7	6	5	4	4	9	7	5	5	4	4	8	6	5	4	4	4	8	6	5	4	4	4				
16	8	6	5	4	3	3	7	5	4	4	3	3	7	5	4	4	3	3	7	5	4	4	3	3				
18	6	5	4	3	3	3	6	4	4	3	3	2	5	4	3	3	3	2	5	4	3	3	3	2				
20	5	4	3	3	2	2	5	4	3	3	2	2	5	4	3	3	2	2	5	4	3	3	2	2				

vetch in a completely randomized or randomized complete block design, with from 5 to 20 treatments and 5 replications, plots of 10 m<sup>2</sup> are sufficient to identify, at a probability of 0.05, significant differences between treatments of 10% of the overall mean value of the experiment.

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## DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

## AUTHOR CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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