Soybean cultivars subjected to narrow row spacing and plant populations in early sowing in subtropical region in southern Brazil

Cultivares de soja submetidas ao espaçamento reduzido e populações de plantas em semeadura antecipada em região subtropical no sul do Brasil

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ABSTRACT
Spatial arrangement between plants and sowing time used are decisive practices for obtaining adequate agronomic performance in soybean crop. The aim of this work was to evaluate morphological attributes, yield components and grain yield of soybean cultivars installed with different row spacing and seeding densities, in early (10/04/2017) and conventional (11/08/2017) sowing dates in subtropical climate region in southern Brazil. The experimental design was in a 2×2×4 factorial arrangement: soybean cultivars BRS 433 RR (MG 5.8) and BRS 1003 IPRO (MG 6.3) installed with row spacing of 25 and 50 cm and seeding densities of 160,000; 240,000; 320,000; and 400,000 viable seeds ha^{-1}. Morphological attributes and yield components are altered by spatial arrangement between plants and cultivar, with variable responses according to the sowing date. In the early sowing date, soybean has yield raise due to the increase in seeding density with different responses between cultivars. In the conventional sowing date, soybean installed with 25-cm row spacing has an increase in 1000-grains weight. In the conventional sowing date, there is an increase in soybean yield installed with 25-cm row spacing associated with a seeding density of 320,000 to 400,000 viable seeds ha^{-1}.

Keywords: *Glycine max* L. Merrill, early sowing date, seeding density, 25-cm row spacing.

RESUMO
O arranjo espacial entre plantas e a época de semeadura utilizada são práticas determinantes para obtenção de adequado desempenho agronômico na cultura da soja. O objetivo do trabalho foi avaliar atributos morfológicos, componentes de produção e produtividade de grãos de cultivares de soja instaladas com diferentes espaçamentos entrelinhas e densidades de semeadura, em datas de semeadura antecipada (04/10/2017) e convencional (08/11/2017) em região de clima subtropical no sul do Brasil. O delineamento experimental foi no esquema fatorial de 2×2×4: cultivares de soja BRS 433 RR (GM 5.8) e BRS 1003 IPRO (GM 6.3) instaladas com espaçamento entrelinhas de 25 e 50 cm e densidades de semeadura de 160000, 240000, 320000 e 400000 sementes viáveis ha^{-1}. Os atributos morfológicos e componentes de produção são alterados pelo arranjo espacial entre plantas e cultivar, com respostas variáveis de acordo com a data de semeadura. Na semeadura antecipada a soja tem incremento de produtividade em função do aumento da densidade de semeadura com respostas distintas entre cultivares. Na semeadura convencional a soja instalada com espaçamento entrelinhas de 25 cm tem incremento da massa de 1000 grãos. Na semeadura convencional há aumento da produtividade da soja instalada com espaçamento entrelinhas de 25 cm associado à densidade de semeadura de 320 a 400 mil sementes viáveis ha^{-1}.

Palavras-chave: *Glycine max* L. Merrill, data de semeadura antecipada, densidade de semeadura, espaçamento entrelinhas de 25 cm.

1 INTRODUCTION

Soybean (*Glycine max* L. Merrill) occupied 38.93 million hectares in Brazil in the 2020/21 crop season, of which 12.38 million in southern region, where the climate is humid subtropical with no defined dry season (ALVARES et al., 2013; CONAB, 2022). It is possible to carry out early sowing of soybean in mid-September to early October in subtropical regions with rainy winters in southern Brazil (KASTER; FARIAS, 2012; ALVARES et al., 2013).

The early sowing of soybean has agronomic advantages such as lower incidence of Asian soybean rust and the possibility of installing a second crop in the autumn-winter period (DE BRUIN; PEDERSEN, 2008; MEOTTI et al., 2012; TECNOLOGIAS..., 2013; PELIN; WORDELL FILHO; NESI, 2020). However, there are significant variations in photoperiod, temperature and water availability as a function of soybean sowing date, and these climatic variations significantly impact the crop growth rate, phenological phases, plant morphology, yield components, yield and grain quality (HU; WIATRAK, 2012; MEOTTI et al., 2012; HANKINSON; LINDSEY; CULMAN, 2015; BATEMAN et al., 2020).

There is an agronomic recommendation to adjust the soybean plant population according to the sowing date to increase the grain yield potential (SPADER; DESCHAMPS, 2015; UMBURANAS et al., 2019; NLEYA et al., 2020). In conditions of low plant populations, soybean has increased branching and a greater number of pods per plant (COX; CHERNEY, 2011; CRUZ et al., 2016; WERNER et al., 2016; RIBEIRO et al., 2017; FERREIRA et al., 2018). On the other hand, in high plant populations there are fewer branching and soybean grain yield is more dependent on stem pods (WERNER et al., 2016; 2021; XU et al., 2021).

In soybean crops, the row spacing varies between of 40 to 60 cm in all regions of Brazil. However, there are reports of increased in soybean grain yield with narrow row spacing of 20 and 25 cm (RAHMAN; RAHMAN; HOSSAIN, 2013; CARMO et al., 2018). It is possible to raise soybean grain yield by reducing the row spacing, but this increase depends on the cultivar and agronomic procedures, such as adjusting the plant population and sowing date (MODOLO et al., 2016; CARMO et al., 2018; ANDRADE et al., 2019).

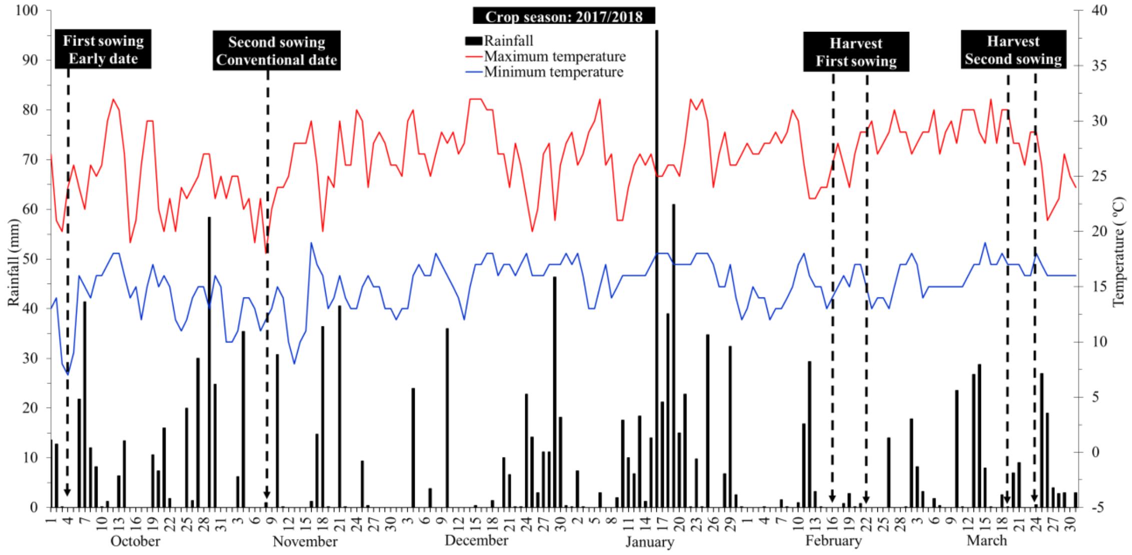
Thus, the aim of this work was to evaluate morphological attributes, yield components and grain yield of soybean cultivars installed with row spacing of 25 cm and 50 cm and different seeding densities, in early and conventional sowing dates in a subtropical climate region in southern Brazil.

2 MATERIAL AND METHODS

The work was carried out on an experimental farm of the Brazilian Agricultural Research Corporation (Embrapa) in Ponta Grossa, Paraná state, Brazil, with a geographic location at 25º 09' 07" south, 50º 05' 11" west and altitude of 982 m, in the 2017/18 crop season.

This location is in the edaphoclimatic adaptation region (REC) 103 for the registration of soybean cultivars, according to the official methodology of the Ministry of Agriculture, Livestock and Food Supply (MAPA) of the Brazilian government (KASTER; FARIAS, 2012). The region climate is classified as humid subtropical (Cfb according to Köppen), with summers of mild temperatures and no defined dry season, with average temperatures in the coldest month below 18 °C and in the warmest month below 22 °C (ALVARES et al., 2013). Figure 1 shows the daily data of rainfall, maximum and minimum air temperature that occurred during the conduction of the experiments.

Figure 1. Daily data of rainfall, maximum and minimum temperature that occurred during conduction of the experiments in Ponta Grossa, Paraná state, southern region of Brazil. Early date: October 4th; Conventional date: November 8th.



Soybean sowing dates were established as follows: (1) Early sowing date from September 20th to October 10th, as indicated by farmers and agronomists in the region; and (2) Conventional sowing date from October 21st to November 30th, according to the MAPA methodology for carrying out experiments to register soybean cultivars in REC 103 (KASTER; FARIAS, 2012). In this work, two experiments were carried out for the early and conventional sowing dates, as follows: (1) Early date: sowing on 10/04/2017; and (2) Conventional date: sowing on 11/08/2017. The experiments were carried out in contiguous areas separated by 2-m border.

The experiments were carried out on wheat straw in an area conducted under no-tillage system (NTS) for more than 10 years, which had been managed with soybean and corn rotation in the summer, and wheat and black oat in the winter. The soil was classified as a medium texture dystrophic Red Latosol (EMBRAPA, 2018). Before installing the experiments, soil sampling was carried out at the 0-20 cm depth layer to characterize chemical (EMBRAPA, 2009) and granulometric (EMBRAPA, 1997) attributes, namely: pH ($CaCl_2$): 5.78; organic matter: 39.21 g dm^{-3}; P (Mehlich-1): 14.01 mg dm^{-3}; K: 0.27 $cmol_c$ dm^{-3}; Ca: 5.71 $cmol_c$ dm^{-3}; Mg: 1.93 $cmol_c$ dm^{-3}; H+Al: 3.16 $cmol_c$ dm^{-3}; CEC (pH 7.0): 11.07 $cmol_c$ dm^{-3}; base saturation: 71.45% ; sand: 548 g kg^{-1}; silt: 120 g kg^{-1}; clay: 332 g kg^{-1}.

Phytosanitary management (diseases, pests, and weeds), seed treatment with inoculant for biological N fixation, fertilization with macro and micronutrients and all other agronomic procedures for soybean cultivation were carried out in accordance with Tecnologias... (2013) and Agrofit (2017).

Soybean cultivars were BRS 433 RR (MG 5.8) with a cycle of 118 to 126 days, and BRS 1003 IPRO (MG 6.3) with a cycle of 128 to 136 days, both registered for REC 103 in Paraná state (MAPA, 2017). The seeds of the two cultivars were previously analyzed for germination (BRASIL, 2009) and vigor by the tetrazolium test (FRANÇA-NETO; KRZYZANOWSKI, 2018) which presented values of these variables above 90%, thus, they presented high physiological quality.

A seeder-fertilizer developed for agricultural experimentation in the NTS was used, equipped with cutting discs for straw and precision dosers for seed and fertilizer distribution. The rows spacing were 25 and 50 cm, adjusted in the same equipment. The fertilizer with P and K used in sowing was adjusted to have an equivalent dose in both spacing. Seeding densities were calculated according to the seeds germination power of the two cultivars, and the amounts of viable seeds ha^{-1} were established.

The experimental design for the two sowing dates was in randomized complete blocks with four replicates, in a 2×2×4 factorial arrangement, as follows: soybean cultivars BRS 433 RR (MG 5.8) and BRS 1003 IPRO (MG 6.3) installed with row spacing of 25 and 50 cm and seeding densities of 160,000; 240,000; 320,000; and 400,000 viable seeds ha^{-1}.

The experimental plots consisted by 8 crop rows with 6 m long, with row spacing of 25 and 50 cm. The useful area was formed by the 6 central rows with 5 m long. 4 rows of the useful area were separated to determine grain yield and two rows for plant sampling.

Lodging and final plant population evaluations were carried out at the R8 soybean stage (FEHR; CAVINESS, 1977), as follows: (1) Lodging: visual evaluations were carried out in the useful area of the plots with scores 1, 2, 3, 4, and 5 for 0 to 10%, 11 to 25%, 26 to 50%, 51 to 75%, and 76 to 100% of plants show stem lodging, respectively; and (2) Final plant population: plant counts were carried out in 2 contiguous m of crop row at three random points in the useful plots area.

Sampling of 10 plants was carried out at random points in the useful area of two rows of the plots at the R8 soybean stage (FEHR; CAVINESS, 1977), for the following determinations: (1) plant height; (2) number of nodes stem^{-1}; (3) internode length of stem; (4) number of branches plant^{-1}; (5) number of pods plant^{-1}; (6) number of grains pod^{-1}; (7) number of grains plant^{-1}; and (8) number of pods m^{-2}.

Grain yield was quantified from mechanized harvesting of four rows of the useful plots area with a self-propelled harvester developed for agronomic experimentation. The grains were threshed, cleaned, weighed and the water content determined for correction at 130 g kg^{-1}. Then, three aliquots of the grains from each plot were sampled to determine the 1000-grains weight, with water content determined for correction at 130 g kg^{-1} (BRASIL, 2009).

The two experiments installed to evaluate sowing dates were analyzed separately. The results by sowing date were submitted to tests for normality and homogeneity of variances, model additivity and independence of errors. Then, analysis of variance was performed using the F test ($p \leq 0.05$) and the treatment means were compared using the Tukey test ($p \leq 0.05$). Regression analysis was performed using the F test ($p \leq 0.05$) for the quantitative variable seeding density, and statistically significant linear and quadratic equations with the highest coefficients of determination (R^2) were chosen. When there was a significant interaction between treatments, the standard errors of the means (n=4) were calculated.

3 RESULTS AND DISCUSSION

Tables 1, 2, 3, and 4 show the summary of the analysis of variance and the results of the experimental treatments of row spacing, seeding density and cultivar, for early (October 4th) and conventional (November 8th) sowing dates.

The final plant population was increased as a function of the increment in seeding density in the two sowing dates (Table 1). Cultivar and row spacing had no effect on the final plant population at both sowing dates. These results show that the seed quality and the experiment installation procedures were adequate.

Table 1. Final plant population, plant height, and nodes in stem affected by row spacing, cultivar, and seeding density at sowing on October 4th (early date at sowing time) and at sowing on November 8th (conventional date at sowing time) in subtropical region, Ponta Grossa, Paraná state, southern region of Brazil.

Treatment	**Final plant population**		**Plant height**		**Nodes in stem**	
	Oct. 4th	**Nov. 8th**	**Oct. 4th**	**Nov. 8th**	**Oct. 4th**	**Nov. 8th**
Row spacing (cm)	Nº plants m^{-2}		cm			
25	24.7 a	25.9 a	77.8 a	93.0 a	19.1 a	16.8 a
50	24.1 a	24.8 a	80.1 a	89.1 b	18.6 a	16.2 a
Cultivar						
MG 5.8	24.8 a	25.7 a	80.2 a	93.6 a	18.4 a	16.2 b
MG 6.3	24.1 a	25.2 a	78.3 a	90.2 b	18.9 a	17.1 a
Viable seeds ha^{-1}						
Regression equation(1)	L(2) **	L(3) **	L(4) **	ns(5)	L(6) *	L(7) **
160000	13.1 a	13.8 a	75.5 c	90.1 a	19.1 a	17.6 a

240000	20.4	b	21.5	b	78.4	b	90.7	a	18.7	a	17.0	b
320000	28.2	c	28.9	c	80.5	a	92.0	a	18.6	a	16.5	b
400000	36.0	d	37.5	d	81.4	a	92.4	a	17.9	b	15.2	c
Variation source	ANOVA (F probability)											
Row spacing (R)	0.49	ns	0.34	ns	0.11	ns	<0.001	**	0.94	ns	0.31	ns
Seed density (S)	<0.001	**	<0.001	**	<0.001	**	0.29	ns	0.03	*	<0.001	**
Cultivar (C)	0.63	ns	0.62	ns	0.19	ns	0.04	*	0.07	ns	0.03	*
R x S	0.82	ns	0.65	ns	0.28	ns	0.24	ns	0.29	ns	0.34	ns
R x C	0.69	ns	0.85	ns	0.15	ns	0.67	ns	0.66	ns	0.49	ns
S x C	0.95	ns	0.93	ns	0.27	ns	0.96	ns	0.62	ns	0.80	ns
R x S x C	0.91	ns	0.97	ns	0.24	ns	0.74	ns	0.47	ns	0.29	ns
CV (%)	14.24		15.51		7.10		4.18		5.58		5.83	

Means followed by the same letter in a column are not significantly different by Tukey's test at $p < 0.05$. * and ** significant at $p \leq 0.05$ and $p \leq 0.01$ by F-test, respectively. ns = not significant. CV = coefficient of variation. (1) Regression equation: L = linear and Q = quadratic; (2) $\hat{y} = 0.96x - 23897$ ($R^2 = 0.99$); (3) $\hat{y} = 0.98x - 20661$ ($R^2 = 0.99$); (4) $\hat{y} = 3E\text{-}05x + 71.95$ ($R^2 = 0.94$); (5) $\hat{y} = \bar{y} = 91.0$; (6) $\hat{y} = -5E\text{-}06x + 19.9$ ($R^2 = 0.92$); (7) $\hat{y} = -1E\text{-}05x + 19.2$ ($R^2 = 0.95$).

Soybean height was not affected by the row spacing in the early sowing date (Table 1). On the other hand, in the conventional sowing date, greater soybean height was observed at 25-cm spacing than at 50-cm spacing. In a similar study, an increase in soybean height was observed due to the reduction of the row spacing from 60 to 20 cm, in a crop with 400,000 plants ha^{-1} (SOLANO; YAMASHITA, 2011). There was no difference in plant height between cultivars in the early sowing date (Table 1). However, in the conventional sowing date, the shorter cycle cultivar (MG 5.8) had greater height than the longer cycle cultivar (MG 6.3).

In the early sowing date, there was a raise in soybean height as a function of the increase in seeding density (Table 1). However, in the conventional sowing date, soybean height did not change in response to seeding density. The photoperiod in the early sowing date (between mid-September to early October) is relatively shorter in southern Brazil, and in this environmental condition, greater competition between plants promotes stem elongation (PRICINOTTO; ZUCARELI, 2014).

The number of nodes stem^{-1} was not influenced by the row spacing in the two sowing dates (Table 1). In the early sowing date, there was no difference between cultivars for the number of nodes stem^{-1}. However, in the conventional sowing date, the MG 6.3 cultivar had a higher number of nodes stem^{-1} than the MG 5.8 cultivar. In addition, for the number of nodes stem^{-1}, a linear reduction was observed in this parameter as the seeding density increased, in the two sowing dates.

The internodes length of soybean stem was not altered by the row spacing in the two sowing dates (Table 2). The MG 5.8 cultivar had greater internodes length than the MG 6.3 cultivar in both sowing dates. In addition, a raise in the internodes length of soybean stem was observed due to the increase in seeding density in the two sowing dates. In another study about seeding density in soybean, a greater internodes length of stem was observed as a function of the increase in seeding density. The justification for this result was that the greater internodes length occurs due to the reduction of luminosity in the soybean canopy resulting from the greater number of plants ha^{-1}, that is, there is stem etiolation (PROCÓPIO et al., 2014).

The number of branches plant^{-1} was lower at 25-cm row spacing than at 50-cm row spacing in the two sowing dates (Table 2). In another study on soybean, row spacing of 30 cm and 60 cm were compared, and it was verified that the 60-cm row spacing had a greater number of branches plant^{-1} for all evaluated seeding densities (BALBINOT JUNIOR et al., 2015).

The increase in seeding density reduced the number of branches plant^{-1} in the two sowing dates (Table 2). This result is explained by the lower intraspecific competition at relatively lower seeding densities (PETTER et al., 2016), favoring branch development in soybean.

In the early sowing date, the shorter cycle cultivar (MG 5.8) had a greater number of branches plant^{-1} than the longer cycle cultivar (MG 6.3) (Table 2). In the conventional sowing date, the number of branches plant^{-1} was influenced by the interaction between row spacing and cultivar. At 25-cm row spacing, no difference was observed between cultivars, but at 50-cm row spacing, the MG 5.8 cultivar had a greater number of branches plant^{-1} than the MG 6.3 cultivar (Figure 2 a).

Table 2. Internode length of stem, branches plant^{-1}, and lodging affected by row spacing, cultivar, and seeding density at sowing on October 4th (early date at sowing time) and at sowing on November 8th (conventional date at sowing time) in subtropical region, Ponta Grossa, Paraná state, southern region of Brazil.

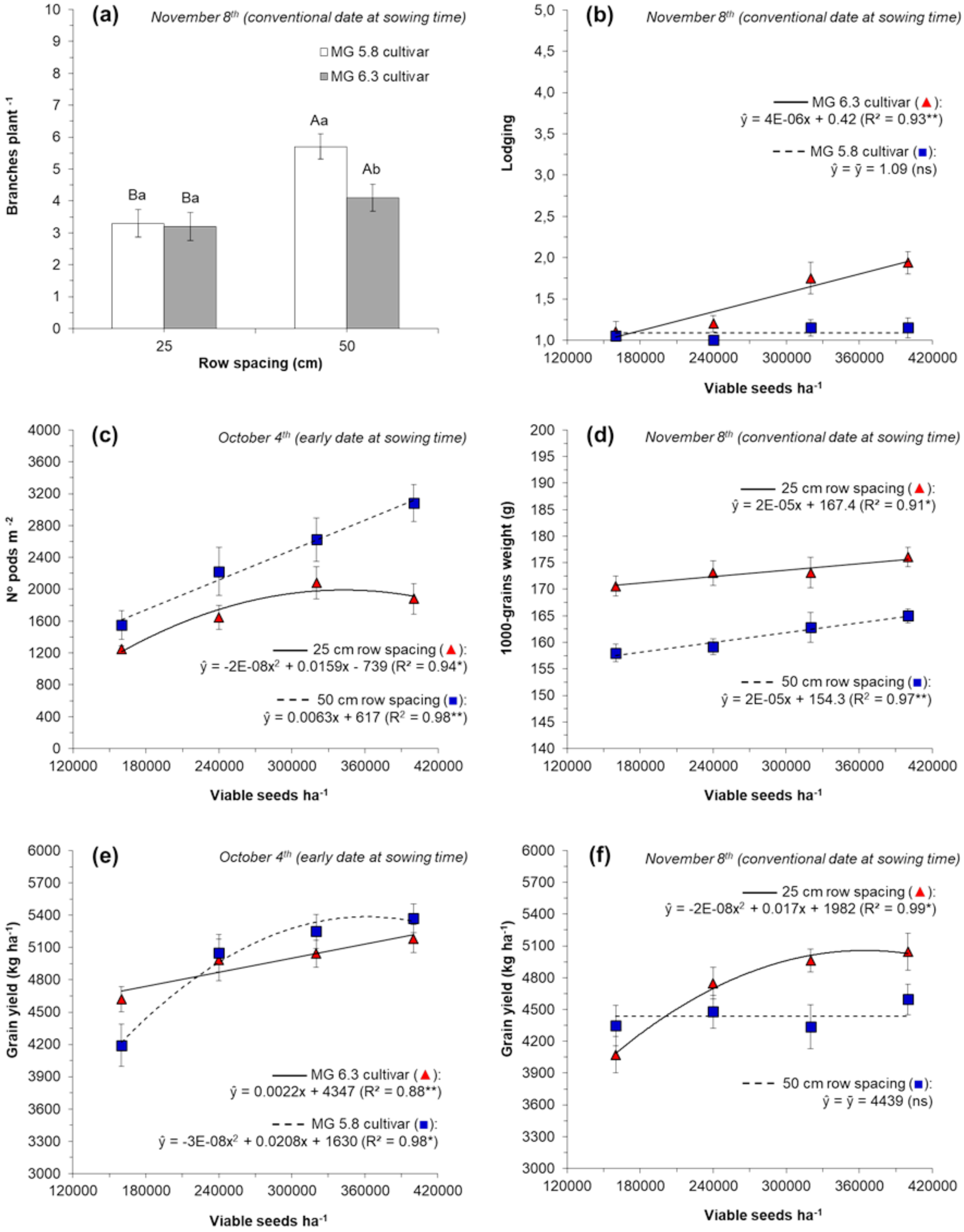
Treatment	**Internode length**		**Branches plant^{-1}**		**Lodging**	
	Oct. 4th	**Nov. 8th**	**Oct. 4th**	**Nov. 8th**	**Oct. 4th**	**Nov. 8th**
Row spacing (cm)	cm					
25	4.1 a	5.7 a	4.3 b	3.3 b	1.0 a	1.1 a
50	4.3 a	5.4 a	5.9 a	4.9 a	1.1 a	1.3 a
Cultivar						
MG 5.8	4.7 a	5.9 a	5.8 a	4.7 a	1.0 a	1.0 b
MG 6.3	4.1 b	5.1 b	4.6 b	3.4 b	1.1 a	1.5 a
Viable seeds ha^{-1}						
Regression equation$^{(1)}$	L$^{(2)}$ **	L$^{(3)}$ **	L$^{(4)}$ **	L$^{(5)}$ **	ns$^{(6)}$	L$^{(7)}$ **
160000	3.9 c	5.1 c	6.1 a	5.4 a	1.0 a	1.2 b
240000	4.2 b	5.4 b	5.3 b	4.3 b	1.1 a	1.2 b
320000	4.3 b	5.5 b	5.0 b	3.9 b	1.2 a	1.5 a
400000	4.6 a	6.1 a	3.9 c	2.6 c	1.1 a	1.6 a
Variation source	ANOVA (F probability)					
Row spacing (R)	0.14 ns	0.19 ns	<0.001 **	<0.001 **	0.70 ns	0.24 ns

Seed density (S)	<0.001	**	<0.001	**	<0.001	**	<0.001	**	0.65	ns	<0.001	**
Cultivar (C)	0.02	*	0.02	*	0.003	**	<0.001	**	0.72	ns	<0.001	**
R x S	0.21	ns	0.51	ns	0.57	ns	0.85	ns	0.65	ns	0.34	ns
R x C	0.13	ns	0.49	ns	0.64	ns	<0.001	**	0.68	ns	0.24	ns
S x C	0.79	ns	0.92	ns	0.18	ns	0.48	ns	0.27	ns	<0.001	**
R x S x C	0.42	ns	0.57	ns	0.19	ns	0.58	ns	0.65	ns	0.38	ns
CV (%)	8.40		7.43		19.40		21.35		16.33		18.89	

Means followed by the same letter in a column are not significantly different by Tukey's test at $p < 0.05$. * and ** significant at $p \leq 0.05$ and $p \leq 0.01$ by F-test, respectively. ns = not significant. CV = coefficient of variation. (1) Regression equation: L = linear and Q = quadratic; (2) $\hat{y} = 3E\text{-}06x + 3.51$ ($R^2 = 0.98$); (3) $\hat{y} = 4E\text{-}06x + 4.38$ ($R^2 = 0.93$); (4) $\hat{y} = -9E\text{-}06x + 7.5$ ($R^2 = 0.95$); (5) $\hat{y} = -1E\text{-}05x + 7.1$ ($R^2 = 0.97$); (6) $\hat{y} = \bar{y} = 1.1$; (7) $\hat{y} = 2E\text{-}06x + 0.82$ ($R^2 = 0.83$).

Soybean lodging was not affected by row spacing in the two sowing dates (Table 2). The cultivar and seeding density also had no effect on soybean lodging in the early sowing date. On the other hand, in the conventional sowing date, lodging was influenced by the interaction between cultivar and seeding density (Table 2). The MG 5.8 cultivar had no raise in lodging due to the increase in seeding density; however, there was an increase in lodging of the MG 6.3 cultivar as a function of the increase in seeding density (Figure 2 b). In situations where cultivars susceptible to lodging are used and environmental conditions are favorable to this problem, the increasing seeding density in soybean can increment lodging rates and grain yield losses can be severe (VILELA; FOLONI; VIEIRA, 2020).

Figure 2. Branches plant-1 (a), lodging (b), pods m-2 (c), 1000-grains weight (d), and grain yield (e and f) of soybean as a function of significant interactions between row spacing, and/or cultivar, and/or seeding density at sowing on October 4th and at sowing on November 8th.



Legend: Lowercase letters in columns compare cultivars inside row spacing, and uppercase letters compare row spacing inside cultivars at $p \leq 0.05$ according to Tukey test. * and ** significant at $p \leq 0.05$ and $p \leq 0.001$ by F-test, respectively. ns: not significant. The vertical bars at points and columns represent the standard errors of means (n = 4).

The number of pods plant-1 was higher at 50-cm row spacing than at 25-cm row spacing, in the early sowing date (Table 3). However, in the conventional sowing date, the row spacing did not affect this yield component. The MG 6.3 cultivar had a higher number of pods plant^{-1} than the MG 5.8 cultivar in the two sowing dates. There was a reduction in the number of pods plant^{-1} due to the increase in seeding density in both sowing dates.

Table 3. Pods plant^{-1}, grains pod^{-1}, and grains plant^{-1} affected by row spacing, cultivar, and seeding density at sowing on October 4th (early date at sowing time) and at sowing on November 8th (conventional date at sowing time) in subtropical region, Ponta Grossa, Paraná state, southern region of Brazil.

Treatment	**Pods plant^{-1}**				**Grains pod^{-1}**				**Grains plant^{-1}**			
	Oct. 4th		**Nov. 8th**		**Oct. 4th**		**Nov. 8th**		**Oct. 4th**		**Nov. 8th**	
Row spacing (cm)												
25	75.5	b	59.4	a	1.9	a	2.2	a	141.7	a	121.5	a
50	104.1	a	64.8	a	1.5	b	2.0	a	147.6	a	127.3	a
Cultivar												
MG 5.8	79.6	b	56.1	b	1.9	a	2.4	a	136.2	b	120.3	a
MG 6.3	99.8	a	68.4	a	1.4	b	1.9	b	149.7	a	129.8	a
Viable seeds ha^{-1}												
Regression equation$^{(1)}$	L$^{(2)}$	**	L$^{(3)}$	**	L$^{(4)}$	**	L$^{(5)}$	**	L$^{(6)}$	**	L$^{(7)}$	**
160000	117.1	a	82.8	a	2.2	a	2.5	a	217.5	a	191.2	a
240000	91.4	b	62.7	b	1.8	b	2.2	b	153.2	b	131.8	b
320000	81.1	c	55.2	c	1.5	c	1.8	c	110.9	c	97.1	c
400000	69.6	d	45.2	d	1.3	d	1.7	c	88.1	d	76.5	d
Variation source	ANOVA (F probability)											
Row spacing (R)	<0.001	**	0.62	ns	<0.001	**	0.84	ns	0.96	ns	0.44	ns
Seed density (S)	<0.001	**	<0.001	**	<0.001	**	<0.001	**	<0.001	**	<0.001	**
Cultivar (C)	<0.001	**	<0.001	**	<0.001	**	0.03	*	0.04	*	0.31	ns
R x S	0.69	ns	0.88	ns	0.37	ns	0.41	ns	0.18	ns	0.87	ns
R x C	0.56	ns	0.74	ns	0.58	ns	0.93	ns	0.34	ns	0.89	ns
S x C	0.33	ns	0.43	ns	0.12	ns	0.90	ns	0.47	ns	0.86	ns
R x S x C	0.11	ns	0.95	ns	0.32	ns	0.81	ns	0.91	ns	0.95	ns
CV (%)	16.28		18.46		19.21		19.15		14.91		18.62	

Means followed by the same letter in a column are not significantly different by Tukey's test at $p < 0.05$. * and ** significant at $p \leq 0.05$ and $p \leq 0.01$ by F-test, respectively. ns = not significant. CV = coefficient of variation. $^{(1)}$ Regression equation: L = linear and Q = quadratic; $^{(2)}$ $\hat{y} = -0.0002x + 143.31$ ($R^2 = 0.96$); $^{(3)}$ $\hat{y} = -0.0002x + 103.55$ ($R^2 = 0.95$); $^{(4)}$ $\hat{y} = -3E\text{-}06x + 2.98$ ($R^2 = 0.96$); $^{(5)}$ $\hat{y} = -4E\text{-}06x + 2.73$ ($R^2 = 0.97$); $^{(6)}$ $\hat{y} = -0.0005x + 293.11$ ($R^2 = 0.95$); $^{(7)}$ $\hat{y} = -0.0005x + 256.68$ ($R^2 = 0.94$).

The number of grains pod^{-1} was higher at 25-cm row spacing than at 50-cm row spacing in the early sowing date (Table 3). However, in the conventional sowing date, the row spacing did not influence this yield component. The MG 5.8 cultivar had a higher number of grains pod^{-1} than the MG 6.3 cultivar in the two sowing dates; meanwhile, for grains plant^{-1} data, there was a significant effect of cultivar only in the early sowing, in which MG 6.3 cultivar obtained the highest values.

The yield components number of pods plant^{-1}, number of grains pod^{-1} and number of grains plant^{-1} decreased as a result of the increase in seeding density in the two sowing dates (Table 3). Decreasing linear adjustment for the number of grains pod^{-1} as a function of the increase in plant population was also verified in another study using a different soybean cultivar and in another production environment (FERREIRA et al., 2020). These results show that there was an intensification of intraspecific competition in soybean crop due to the increase in seeding density. However, it is necessary to calculate the compensation between these yield components to characterize the phenotypic plasticity limits in the context of the interaction between genotype, environment, and management. In this way, it would be possible to generate indexes of reliable yield components to adjust the seeding density to reach the maximum soybean yield potential.

The number of pods m^{-2} was higher at 50-cm row spacing than at 25-cm row spacing in the two sowing dates (Table 4). Still, in both sowing dates, the MG 6.3 cultivar had a greater number of pods m^{-2} than the MG 5.8 cultivar and the increase in seeding density increased the number of pods m^{-2}. In addition, the number of pods m^{-2} was affected by the interaction between row spacing and seeding density in the early sowing date (Figure 2 c). At 50-cm row spacing, soybean had a positive linear response to increase the number of pods m^{-2} as a function of increasing seeding density, and at 25-cm row spacing, soybean had a quadratic response to increase the number of pods m^{-2} as a function of the raise in seeding density.

The number of pods m^{-2} has a great influence on soybean grain yield (BALBINOT JUNIOR et al., 2015; KUMAGAI et al., 2015). In this work, an increase in the number of pods m^{-2} was observed in response to the increase in seeding density in the two sowing dates (Table 4). Therefore, this yield component could be used as a parameter to measure soybean grain yield in phytotechnics works.

The 1000-grains weight was higher at 50-cm row spacing than at 25-cm row spacing in the early sowing date (Table 4). On the other hand, in the conventional sowing date, the 1000-grains weight was higher at 25-cm row spacing than at 50-cm row spacing. The MG 5.8 cultivar had a higher 1000-grains weight than the MG 6.3 cultivar in the early sowing date. However, in the conventional sowing date no difference was observed between cultivars for this yield component. In addition, the 1000-grains weight was increased as a function of the raise in seeding density in the two sowing dates (Table 4).

The 1000-grains weight was affected by the interaction between row spacing and seeding density in the conventional sowing date (Table 4). In the two row spacings of 25 and 50 cm, the 1000-grains weight had positive linear increments as a function of the increase in seeding density (Figure 2 d). However, the 1000-grains weight was higher at all seeding densities at 25-cm spacing than at 50-cm spacing. In a similar study in the soybean crop, an increase in the 1000-grains weight was observed as a function of the raise in seeding density (WERNER et al., 2021).

Table 4. Pods m^{-2}, 1000-grains weight, and grain yield of soybean affected by row spacing, cultivar, and seeding density at sowing on October 4th (early date at sowing time) and at sowing on November 8th (conventional date at sowing time) in subtropical region, Ponta Grossa, Paraná state, southern region of Brazil.

Treatment	**Pods m^{-2}**				**1000-grains weight**				**Grain yield**			
	Oct. 4th		**Nov. 8th**		**Oct. 4th**		**Nov. 8th**		**Oct. 4th**		**Nov. 8th**	
Row spacing (cm)					g				kg ha^{-1}			
25	1714	b	1415	b	164.1	b	173.2	a	4925	a	4706	a
50	2370	a	1574	a	168.7	a	161.3	b	5046	a	4439	b
Cultivar												
MG 5.8	1817	b	1389	b	169.8	a	166.3	a	5051	a	4503	a
MG 6.3	2266	a	1599	a	162.1	b	168.2	a	4965	a	4642	a
Viable seeds ha^{-1}												
Regression equation(1)	Q(2)	*	Q(3)	*	L(4)	**	L(5)	**	Q(6)	**	L(7)	**
160000	1399	c	1090	b	161.3	c	164.7	b	4406	b	4210	c
240000	1934	b	1466	a	165.6	b	166.1	b	5110	a	4613	b
320000	2352	a	1696	a	167.4	ab	168.0	ab	5147	a	4643	ab
400000	2482	a	1724	a	169.6	a	170.2	a	5278	a	4819	a
Variation source	ANOVA (F probability)											
Row spacing (R)	<0.001	**	0.03	*	0.03	*	<0.001	**	0.23	ns	0.005	**
Seed density (S)	<0.001	**	<0.001	**	0.008	**	0.02	*	<0.001	**	<0.001	**
Cultivar (C)	<0.001	**	0.006	**	<0.001	**	0.13	ns	0.68	ns	0.14	ns
R x S	0.02	*	0.68	ns	0.63	ns	0.04	*	0.86	ns	0.007	**
R x C	0.41	ns	0.57	ns	0.24	ns	0.44	ns	0.52	ns	0.29	ns
S x C	0.56	ns	0.42	ns	0.07	ns	0.91	ns	0.04	*	0.35	ns
R x S x C	0.21	ns	0.84	ns	0.64	ns	0.63	ns	0.47	ns	0.76	ns
CV (%)	20.36		19.42		4.30		3.77		7.16		7.91	

Means followed by the same letter in a column are not significantly different by Tukey's test at $p < 0.05$. * and ** significant at $p \leq 0.05$ and $p \leq 0.01$ by F-test, respectively. ns = not significant. CV = coefficient of variation. (1) Regression equation: L = linear and Q = quadratic; (2) $\hat{y} = -2E\text{-}08x^2 + 0.013x - 356$ ($R^2 = 0.99$); (3) $\hat{y} = -1E\text{-}08x^2 + 0.01x - 206$ ($R^2 = 0.99$); (4) $\hat{y} = 3E\text{-}05x + 157$ ($R^2 = 0.95$); (5) $\hat{y} = 2E\text{-}05x + 161$ ($R^2 = 0.99$); (6) $\hat{y} = -2E\text{-}08x^2 + 0.02x + 2480$ ($R^2 = 0.94$); (7) $\hat{y} = 0.0023x + 3920$ ($R^2 = 0.90$).

Soybean grain yield was not affected by the row spacing in the early sowing date. On the other hand, in the conventional sowing date, grain yield was higher at 25-cm spacing than at 50-cm spacing (Table 4).

In the early sowing date, soybean yield was influenced by the interaction between cultivar and seeding density (Table 4). The MG 5.8 cultivar (shortest cycle) had a quadratic response of yield increase as a function of the raise in seeding density, and the MG 6.3 cultivar (longer cycle) had a positive linear response of yield increase as a function of the raise in seeding density (Figure 2 e).

In the conventional sowing date, the interaction between row spacing and seeding density had an effect on soybean grain yield (Table 4). At 50-cm spacing, there was no increase in yield due to the raise in seeding density. On the other hand, at 25-cm spacing, there was a quadratic response of yield increase as a function of the increase in seeding density. Maximum grain yield was observed in the crop installed with a spacing of 25 cm and densities of 320,000 and 400,000 viable seeds ha^{-1} in the conventional sowing date (Figure 2 f).

In the two sowing dates, an increment in soybean yield was observed in response to the increase in seeding density (Table 4; Figures 2 e and 2 f). However, these results differ from others obtained in studies conducted using other soybean cultivars and in different environments (PROCÓPIO et al., 2014; RIBEIRO et al., 2017; FERREIRA et al., 2018; MARTINS et al., 2020). Therefore, it is essential to understand that phytotechnical positioning procedures in soybean crop, which involve spatial arrangement between plants in the scope of row spacing adjustment and seeding density, need to be validated in the context of the interaction between genotype, environment and management so that have effective agronomic results.

When soybean row spacing is reduced and the plant population is maintained, there is a more equidistant spatial distribution between plants in the crop, which results in less intraspecific competition (PROCÓPIO et al., 2014) and, consequently, it is can increase yield potential.

4 CONCLUSIONS

Morphological attributes and yield components are altered by spatial arrangement between plants and cultivar, with variable responses according to the sowing date.

In the early sowing date (October 4th), soybean has grain yield raise due to the increase in seeding density with different responses between cultivars.

In the conventional sowing date (November 8th), soybean installed with a 25-cm row spacing has an increase in 1000-grains weight, which can be important for certain agronomic purposes, such as for seed production fields in subtropical regions of southern Brazil.

In the conventional sowing date (November 8th), there is an increase in soybean grain yield installed with 25-cm row spacing associated with a seeding density of 320,000 to 400,000 viable seeds ha^{-1}, which does not happen for 50-cm spacing.

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