EJFA Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 36: 1–8
doi: 10.3897/ejfa.2024.118264

RESEARCH PAPER

Intraspecific competition in row spacings in soybean

Vinícius dos Santos Cunha[1], Glauber Monçon Fipke[2], Gerusa Massuquini Conceição[3], Tânia Maria Müller[4], João Leonardo Fernandes Pires[5], Fernando Sintra Fulaneti[4], Thomas Newton Martin[4]

1 *Federal University of Pampa (Universidade Federal do Pampa), Campus Alegrete, Av. Tiaraju, 810, 97546-550, Alegrete, Brazil*
2 *Federal University of Pampa (Universidade Federal do Pampa), Campus Itaqui, Rua Luiz Joaquim de Sá Brito, 97650-000, Itaqui, Brazil*
3 *Northwestern Regional University of the State of Rio Grande do Sul (Universidade Regional do Noroeste do Estado do Rio Grande do Sul) Rua do Comércio, 3000, 98700-000, Ijuí, Brazil*
4 *Federal University of Santa Maria (Universidade Federal de Santa Maria), Santa Maria, RS 97105-905, Brazil*
5 *Brazilian Agricultural Research Company (Empresa de Pesquisa Agropecuária Brasileira, Embrapa Trigo), Rodovia BR 285, km 294, s/n Zona Rural, 99050-970, Passo Fundo, Brazil*

Corresponding author: Thomas Newton Martin (martin.ufsm@gmail.com)

Academic editor: Trong Hieu Luu ♦ **Received** 4 January 2024 ♦ **Accepted** 9 March 2024 ♦ **Published** 27 March 2024

Abstract

The aim of this study is to assess the impact of various row spacings on the morphology, components of grain yield, and overall grain yield of soybean. The experiments were conducted over two planting seasons (2014/2015 and 2015/2016) using two planting dates (November and December) and two cultivars, FPS Urano RR and BMX Tornado RR. The row spacings tested were: 45 cm (wide row), 45 × 45 cm (cross row), 22.5 × 45 cm (twin row), and 22.5 cm (narrow row). Measurements included leaf area index and sunlight interception at R2 stage, as well as grain yield components and overall grain yield. Narrow rows, in addition to achieving canopy closure, also demonstrated enhanced sunlight interception at the R2 stage. However, the positive effect of increased sunlight interception on grain yield was only significant for the December planting date, with no notable difference observed for the November planting date. These findings imply that while narrow rows may offer advantages, particularly in later planting dates, their implementation should be carefully considered and may not consistently lead to increased grain yield, reinforcing the continued preference for conventional row spacing.

Keywords

Intraspecific competition, Grain Yield, *Glycine max*

Introduction

Agriculture must strive for sustainability and increased efficiency to ensure an adequate food supply for people worldwide. In Brazil, the average grain yield of soybeans falls short of its potential by 42%, with 29% attributed to water scarcity and 13% to suboptimal crop management (Sentelhas et al. 2015). To address these challenges, strategies such as irrigation, utilization of modern cultivars, optimal planting dates, soil conservation practices, and appropriate plant distribution are essential (Sentelhas et al. 2015).

Modern soybean cultivars exhibit diverse genetic traits, morphology, and yield potential (Specht et al. 2014). Altering row spacing represents one strategy to optimize crop performance and increase yield potential. Adjusting row spacing modifies the spatial arrangement of plants, thereby reducing or enhancing intraspecific competition and creating a growth environment conducive to crop requirements.

Enhanced sunlight interception resulting from improved plant distribution and branching development has been shown to increase crop yield potential (Slattery et al. 2021). Altering row spacing can facilitate this increase (Kandel et al. 2021). The primary objective of modifying plant distribution is to minimize intraspecific competition (Klimek-Kopyra et al. 2021), often achieved through narrower row configurations. Narrower rows mitigate early leaf abortion in lower canopy regions. However, adjustments in plant distribution may also exacerbate disease incidence (Jaccoud-Filho et al. 2016), as evidenced by increased severity of white mold in narrower rows (35 cm between rows) compared to wider rows (75 cm between rows). This phenomenon is attributed to differences in branching development and spatial occupation between row spacings, leading to prolonged soil surface wetness in narrow rows.

Even so, the narrow rows showed a higher grain yield than the wide rows. In the Jaccoud-Filho et al. (2016) study, the climatic conditions did not favor severity and reduced grain yield in the narrow rows. The narrow rows make disease management a huge problem, it should use wide rows (Jaccoud-Filho et al. 2016). The choice of row spacing must be done to adapt the crop to a specific condition, which may vary among regions or even in planting dates (Lamichhane et al. 2023).

In Brazil, the prevailing row spacing for soybeans typically ranges around 45 cm between rows, although it may vary from 35 cm to 70 cm (Jaccoud-Filho et al. 2016). Similarly, variations in row spacings are observed in the United States, China, and Argentina. In irrigated systems in the United States, the most common row spacing is 76 cm (Bellaloui et al. 2015), whereas in China and Argentina, row spacing typically ranges from 40 cm to 50 cm (Zhou et al. 2011; Santachiara et al. 2017).

In addition to conventional row spacing, alternative configurations such as cross and twin rows are utilized. Cross-row planting involves two different row orientations, with one set transverse and the other perpendicular to it. Twin rows consist of pairs of rows spaced approximately 20–25 cm apart, positioned 40–50 cm from the next pair of rows. These arrangements can enhance grain yield through the edge effect, promoting increased light interception and air circulation between rows (Slattery et al. 2017).

The primary objective of the present study is to assess soybean morphology, grain yield components, and overall grain yield across two cultivars under four different row spacings and two planting dates.

Materials and methods

Location description

Four experiments were carried out through growing seasons 2014/2015 and 2015/2016, in an experimental area at the Federal University of Santa Maria, located in Rio Grande do Sul state in Brazil at 29°43'05"S, 53°43'59"W, at an altitude of 116 m and flat topography. The climate of the area according to the Köppen classification is Cfa (Alvares et al. 2013). The soil in this area is classified as Argissolo Vermelho-Distrófico típico (Santos et al. 2018) (a sandy clay loam Acrisol in the FAO classification).

Experimental design

Treatments were distributed in a factorial (2 × 4) in a complete randomized block design with four replications. As a first factor, it used two cultivars: FPS Urano RR and BMX Tornado RR. The maturity group (MG) of both cultivars is 6.2. As a second factor, it used four row spacings: wide row (45 cm between rows), cross row (45 cm between rows, with two diagonal passes in opposite directions, 90 degrees to normal field travel), twin rows (two paired rows spaced 22.5 cm apart on 45 cm centers), and narrow row (22.5 cm between rows). The wide row represents the most common row spacing used for soybean in Brazil. Each plot had as total area 2.25 × 7.75 m, where there were five rows in the wide row plots; 5 × 17 rows at cross-row plots; seven rows at twin-row plots; and ten rows at narrow-row plots. Through the 2014/2015 and 2015/2016 growing seasons, the experiments were conducted on two planting dates: normal planting date in November and late plating date in December. The plantings were performed on: November tenth, 2014; December fifteenth, 2014; November fifteenth, 2015; and December seventeenth, 2015. The different planting dates were not considered as a factor and just as a single experiment, analyzed separately.

Fertilizers were applied by broadcast at the last moment, before planters got in the experimental area, using 5 kg of nitrogen ha^{-1}, 20 kg of P_2O_5 ha^{-1}, and 20 kg of K_2O ha^{-1}. Two days prior to planting, phytosanitary seed treatment was performed with pyraclostrobin (25 g L^{-1} a. i.) + thiophanate methyl (225 g L^{-1} a. i.) and fipronil (250 g L^{-1} a. i.). The seed inoculant used was composed of *Bradyrhizobium japonicum* (100 mL 50 kg^{-1} of seed). The inoculation process was done on the same day of planting. Herbicide, insecticide, and fungicide application was performed to maintain weeds, insects, and diseases at a certain level, to avoid grain yield reduction. After emergence stage (VE, Fehr and Caviness 1977) the soybean plants were pulled out to reach the ideal plant population for each cultivar.

Variables measured

The following variables were measured: leaf area index (LAI) are measured using digital images (Martin et al. 2013). For the LAI, all leaves of the three plants plot^{-1} were detached and placed on a white surface for taking photos. The ImageJ calculated the area of every single leaf. The LAI was measured at R2. The sunlight interception was measured using a luximeter when the plants were at R2. At R2, measurements were taken at four heights: On top of the canopy, upper (R2 upper), middle (R2 middle), and lower (R2 lower) portion of the canopy. Sunlight interception was represented as a percentage of the total sunlight reaching the top of the canopy at the time of each point of measurement. The grain yield (GY, kg ha^{-1}) was measured by harvesting 6.25 m^2 in each plot with the mass adjusted to 130 g ka^{-1}, based on the moisture content. The number of pods per plants (NPP) was measured by counting in five plants, collected from the central area of each plot. The mass of 1000 grains was measured by counting and weighing three samples of 1000 grains per plot.

Air temperature and precipitation and statistical analysis

The means of rainfall and air temperature during the experiments were collected in a meteorological station located at the Federal University of Santa Maria, located about 1.4 km away from the experimental area (Fig. 1).

The additivity, homogeneity, normality, and independence of errors were tested using a randomized block model. Analyses of variance (ANOVA) was performed to evaluate the treatment differences in the variables measured. When there was a significant effect of treatment, the means were separated out by conducting the Scott-Knott test or regression analyses. For cultivars and row spacings the means were separated by Scott-Knott with 5% probability. When these additional factors presented a significant effect, the means were evaluated by regression, using TableCurve®.

List of abbreviations

ANOVA	Analyses of variance;
C	cultivar;
D	days after planting;
GY	Grain yield;
LAI	leaf area index at R2;
MG	maturity group;
NGP	Total number of grains plant^{-1};
NPP	Total number of pods plant^{-1};
PORT	portion of the plant;
R	row spacing;
TGM	1000 grains mass;
VE	Emergence stage.

Results and discussion

At Table 1 there is the synopsis of ANOVA, showing the interaction among factors. Grain yield showed a significant effect for the interaction (CxR; cultivar × row spacing) when cultivated in November (14/15). And for the second year (November 15/16) only the Cultivar main effect showed significance. For the December cultivation (14/15 and 15/16) only the main row spacing effect was observed. The LAI (R2) was significant for the double interaction (CxR; cultivar × row spacing) in all evaluations, indicating that the LAI changes according to row spacing for all evaluations. Changes in row spacing are capable of modifying the leaf area of plants. This occurs because the way the plants are distributed alters the growth and development of the leaves.

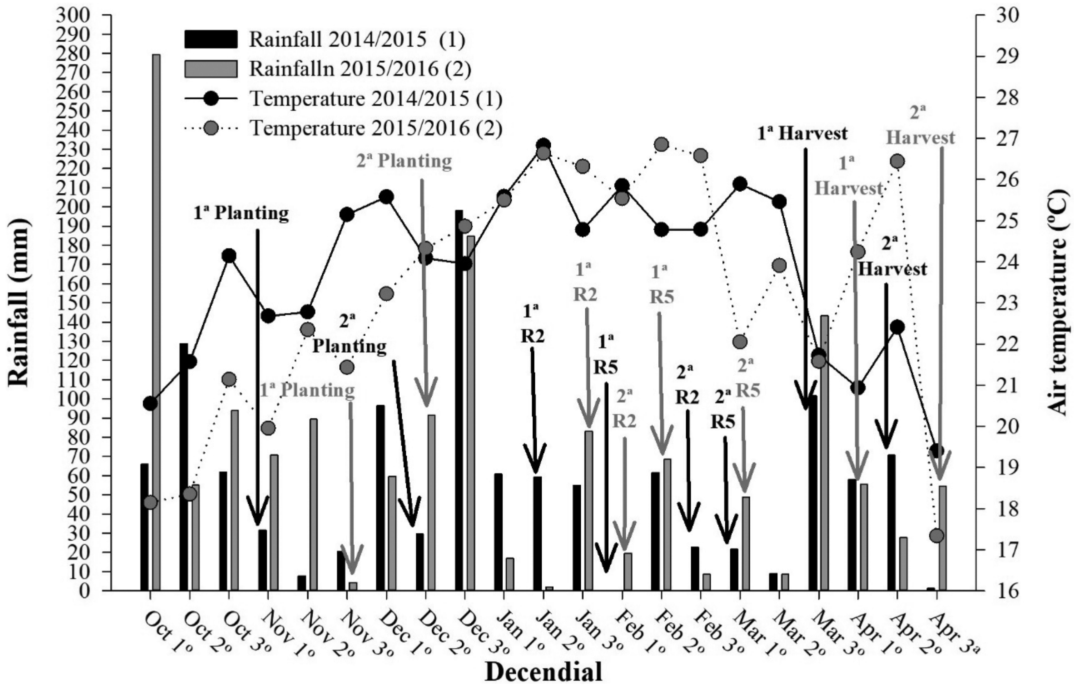

Figure 1. Rainfall and air temperature during the experiments. The line arrows indicate the moment where planting, R2, R5, and harvest happened. The black line arrows represent those experiments carried out in 2014/2015 growing season and gray line arrows represent those experiments carried out in 2015/2016 growing season. Those line arrows with 1ª and 2ª mean November and December planting date, respectively.

Table 1. Main effect, double and triple interaction observed in the analyses of variance for the following variables: grain yield (GY, kg ha^{-1}), light intercepation at R2 in the upper part (R2 upper), middle part (R2 middle) and lower part (R2 lower); leaf area index at R2 (LAI R2); total number of pods plant^{-1} (NPP); total number of grains plant^{-1} (NGP); 1000 grains mass (1000, g).

Variables	November 14/15	December 14/15	November 15/16	December 15/16
GY	CxR	R	C	R
R2 upper	-**	-	C	CxR
R2 middle	-	-	C; R	CxR
R2 lower	-	-	C; R	CxR
LAI R2	CxR	CxR	CxR	CxR
NPP	C	C	C	R
NGP	C	C	C	C
1000	C	CxR	C	C

*C = cultivar; R = row spacing; D = days after planting; PORT = portion of the plant. **there was no evaluation.

Grain yield

The narrow rows showed similar or better results related to wide rows (YG). Narrow rows reached the highest yield in both December 2014/2015 and 2015/2016 (Fig. 2). Twin rows showed lower grain yield compared to the wide rows in November 2014/2015 for the BMX Tornado RR cultivar. The cross row did not show any increase in grain yield in any experiment. Besides that, the cross row had a higher operational cost, up to 34% higher than the wide row (Silva et al. 2015). Also, to get the planting done in time, in the cross row it needs more tractors and planters to accomplish it in an adequate time.

The low intraspecific competition imposed by the narrow row does not increase grain yield when planting occurs on the normal date. According to the "Zoneamento Agrícola de Risco Climático da Soja" for Rio Grande do Sul, the normal planting date is usually during October and November. Increase in grain yield with narrow rows usually occurs in late planting dates (Lee 2006). This must be due to sunlight interception during the reproductive stages, mainly between R1 and R5 (Santachiara et al. 2017).

On the normal planting dates, the sunlight availability during the vegetative stage is sufficient for plants develop an adequate canopy, to intercept a sufficient amount of sunlight during the reproductive period, for high yields. In these cases, there is no necessity to change row spacing for improving resource use and increasing grain yield (Basso et al. 2021). On late planting dates, there is less availability of factors such as, sunlight, photoperiod, and heat units,

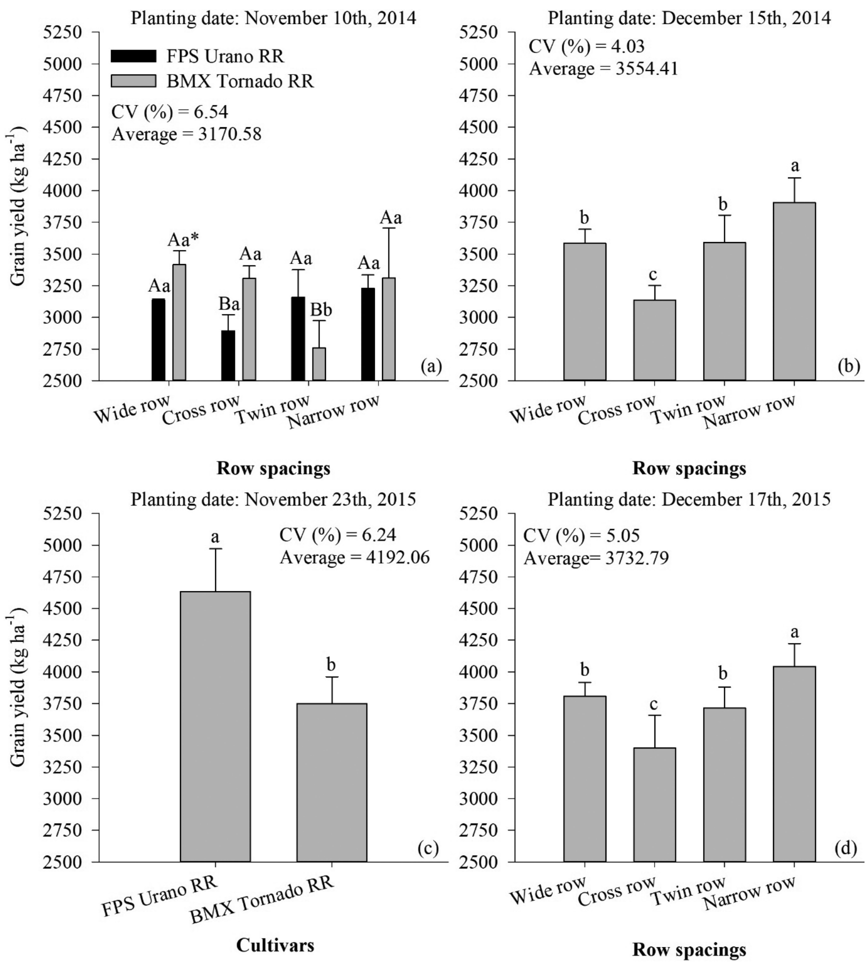

Figure 2. Means of grain yield according to interaction between cultivars and row spacings (**a**), main effect of row spacings (**b**), main effect of cultivars (**c**) and main effect of row spacings (**d**). *Lower-case letters differ means of row spacings and upper-case letters differ means by of cultivars by the Scott-Knott test with 5% of probability.

for crop growth. In this situation the probability to increase grain yield with narrow rows is greater (Jaccoud-Filho et al. 2016). The increase in grain yield provided by narrow rows in relation to wide rows was 320.50 kg ha^{-1} (8.93%) and 234.55 kg ha^{-1} (6.16%), in 2014/2015 and 2014/2015, respectively. These values result in an average increase of 277.52 kg ha^{-1} (7.54%). Moreover, for the grain yield differences, it is necessary to look at the implications imputed by narrow rows. The number of rows that a planter would need to perform the process is doubled, which can increase the cost of get the planting done. With cross rows, a 54% increase in the cost of this operation was found by (Silva et al. 2015). Depending on the increase in the cost of planting soybean in narrow rows, the observed grain yield increase in this study may not represent an increase in the economic yield. However, there is a possibility of using the same drill used to plant small grains like wheat. These authors have concluded that the purchase is economically worthwhile in areas greater than 144 ha, in the state of Iowa-USA, where 30% or more is covered by soybean. However, it is necessary to investigate if this option is feasible in Brazilian conditions. It is also important to state that the plant population in the narrow rows cannot be increased to keep intraspecific competition at an adequate level, to allow increases in grain yield (Jaccoud-Filho et al. 2016).

Sunlight interception at R2

The sunlight interception at R2 had a great effect on cultivars and row spacings in November and interaction between these factors in December. In November all row spacings were intercepting 92% of the sunlight at lower portion of the canopy, on an average. In December, in the same portion of the canopy, these values decreased to 87%, on an average. Sunlight interception at R2 in December was higher in the narrow and cross rows, where both intercepted more than 88% of the sunlight, 2% more than in the wide and twin rows, on an average (Table 2). This result worked only for narrow rows, which showed higher grain yield in the December planting dates (Fig. 2).

The plant distribution in cross rows probably does not improve biomass accumulation even though it intercepts more sunlight at R2 than that in the wide and twin rows. Perhaps there is more variability in the field due to the crossing of the rows. Intraspecific competition must be higher at row intersections. The crossing of the rows can also make air circulation difficult which has an impact on biomass accumulation via evapotranspiration, and aids disease infection due to the wetness of leaves (Zhou et al. 2011). In the narrow rows the plant distribution is more uniform (Zhou et al. 2011) showing a positive impact on biomass accumulation. It is a little different with wide and twin rows. Both wide and twin rows showed less potential to intercept sunlight at R2, but they reached a higher grain yield than cross rows. Even these row spacings present high intraspecific competition, both plant distributions allow enough air circulation to improve biomass accumulation (Jaccoud-Filho et al. 2016).

Leaf area index

The leaf area index (LAI) had an effect of cultivars and row spacings (Table 3). Because of the availability of sunlight, photoperiod, and heat units, soybean reaches higher values of LAI in early or normal planting dates than late planting dates (Tagliapietra et al. 2018). However, in the 2014/2015 growing season the LAI at R2 showed similar results in both November and December planting dates. According to Fig. 1, there was a lack of rainfall around R2 in the soybean planted in November, in that growing

Table 2. Means of the main effect and the interaction between cultivars and row spacings for the light interception at R2 in Upper part, Middle part, and Lower part of the canopy in November and December 2015/2016 growing season.

	November		
	Upper part	**Middle part**	**Lower part**
FPS Urano RR	75.74 A*	88.72 A	92.28 A
BMX Tornado RR	74.02 B	87.82 B	92.07 B
Wide row	74.45	88.02 B	91.97 B
Cross row	75.15	87.75 B	92.14 B
Twin row	74.57	88.48 A	92.20 B
Narrow row	75.38	88.82 A	92.39 A
CV (%)	2.3	1.38	0.37
Average	74.88	88.27	92.18

	December					
	Upper part		**Middle part**		**Lower part**	
	Urano**	**Tornado*****	**Urano**	**Tornado**	**Urano**	**Tornado**
Wide row	70.66 Ab	69.51 Bc	80.08 Ab	79.55 Bc	85.77 Ab	85.65 Ac
Cross row	72.12 Aa	72.47 Aa	82.50 Aa	82.09 Aa	88.30 Aa	88.14 Aa
Twin row	70.37 Ab	70.54 Ab	80.02 Ab	80.30 Ab	85.91 Bb	86.23Ab
Narrow row	72.38 Aa	72.11 Aa	82.31 Aa	82.47 Aa	88.23 Aa	88.29 Aa
CV (%)	1.11		0.62		0.29	
Average	71.27		81.17		87.07	

*Means followed by the same letter do not differ themselves by the Scott-Knott test with 5% of probability. Absence of letters next to the numbers means no difference among the means. Upper-case letter on vertical and lower-case letter on the horizontal differ means by the Scott-Knott test with 5% of probability.

Table 3. Means of the main effect and the interaction between cultivars and row spacings for the leaf area index at R2.

Espaçamentos	November 2014/15		December 2014/15		November 2015/16		December 2015/16	
	R2							
	Urano**	Tornado***	Urano	Tornado	Urano	Tornado	Urano	Tornado
Wide row	2.98 Ab	3.49 Aa	3.51 Aa	2.79 Bb	5.78	5.47	3.83 Ab	3.81 Aa
Cross row	2.40 Bc	3.29 Aa	3.24 Ba	3.71 Aa	5.38	5.90	2.65 Ac	2.74 Ab
Twin row	3.02 Bb	3.59 Aa	3.39 Aa	3.59 Aa	6.60	5.71	4.58 Aa	3.63 Ba
Narrow row	3.15 Aa	3.32 Aa	3.66 Aa	3.41 Aa	6.05	5.68	5.03 Aa	3.63 Ba
CV (%)	7.54		5.92		11.33		9.94	
Average	3.20		3.41		5.82		3.74	

*Means followed by the same letter do not differ themselves by the Scott-Knott test with 5% of probability. Absence of letters next to the numbers means no difference among the means. Upper-case letter on vertical and lower-case letter on the horizontal differ means by the Scott-Knott test with 5% of probability. **Urano = FPS Urano RR. ***Tornado = BMX Tornado RR.

season (Fehr and Caviness 1977). The lack of water caused reduction in leaf expansion. Probably that lack of rainfall during R2 decreased the LAI in November and it showed a negative impact in grain yield as well (Fig. 2).

The LAI at R2 show a good relationship with grain yield (Tagliapietra et al. 2018), but sometimes that does not occur. The angle and shape of the leaves must allow light interception and absorption along all the portions of the canopy (Hu and Wiatrak 2012). When a canopy shows a very high LAI those leaves located at the upper portions of the canopy will be shading those leaves at the lower portions. The leaves located at the lower portion will not form photoassimilates and hence the soybean yield is decreased (Müller et al. 2017). Photoassimilates are also stored in other parts of the plant like stem and branches. In some cases where fields show the same LAI, grain yield can vary according to its ability for redistributing of photoassimilates. In early or normal planting dates there is enough water and solar radiation available. In this situation the ability to redistribute photoassimilates is higher. However, in late planting dates there are less resources available and the ability to redistribute is poor.

Grain yield components

Among the grain yield components, the number of plants area^{-1} is only adjusted by direct action, with seeding rate. The most malleable grain yield component, which usually presents a greater impact in grain yield, is the number of pods plant^{-1} or even grains plant^{-1} (Silva et al. 2020). The lowest values of the number of pods plant^{-1} have been in December (Table 4), where also the lowest grain yield has also been observed (Fig. 2). As for the row spacings, the number of pods plant^{-1} is not always the most important component in grain yield differences.

Table 4. Means of the main effect and the interaction between cultivars and row spacings for the number of pods plant^{-1}, number of grains pod^{-1}, and 1000 grains mass.

Espaçamentos	November 2014/2015		December 2014/2015		November 2015/2016		December 2015/2016	
	Urano**	Tornado***	Urano	Tornado	Urano	Tornado	Urano	Tornado
	Number of Pods Plant^{-1}							
Wide row	42.40 B	63.27 A	49.55 B	52.65 A	61.62	62.18	44.83 Ba	60.00 Ab
Cross row	36.20 B	63.85 A	47.65 B	57.25 A	57.10	54.89	40.17 Ba	53.50 Ab
Twin row	39.30 B	58.30 A	46.10 B	58.65 A	64.87	56.63	43.14 Ba	57.25 Ab
Narrow row	38.35 B	63.10 A	41.55 B	54.75 A	60.59	67.4	51.10 Ba	69.75 Aa
CV (%)	7.74		10.39		13.23		10.81	
Average	50.59		51.01		60.65		52.49	
	Number of Grains Pod^{-1}							
Wide row	1.93 B	2.36 A	2.27 B	2.49 A	2.23 B	2.47 A	2.27 B	2.55 A
Cross row	1.98 B	2.34 A	2.18 B	2.44 A	2.29 B	2.55 A	2.29 B	2.47 A
Twin row	2.02 B	2.40 A	2.23 B	2.56 A	2.27 B	2.51 A	2.23 B	2.51 A
Narrow row	2.04 B	2.32 A	2.23 B	2.51 A	2.26 B	2.53 A	2.26 B	2.53 A
CV (%)	2.54		3.17		3.29		3.17	
Averag	2.17		2.36		2.39		2.39	
	1000 grains mass							
Wide row	191.51 A	147.31 B	129.26 Bc	136.41 Aa	141.04 B	148.22 A	143.61 A	133.54 B
Cross row	179.02 A	144.46 B	129.58 Ac	129.08 Ab	146.11 B	153.63 A	140.45 A	130.08 B
Twin row	172.47 A	154.13 B	132.95 Ab	130.63 Ab	142.16 B	151.09 A	139.23 A	130.46 B
Narrow row	174.71 A	160.19 B	137.78 Aa	133.89 Ba	139.73 B	151.19 A	146.80 A	133.80 B
CV (%)	9.87		1.62		3.44		3.40	
Average	165.47		132.45		146.65		137.18	

*Means followed by the same letter do not differ themselves by the Scott-Knott test with 5% of probability. Absence of letters next to the numbers means no difference among the means. Upper-case letter on vertical and lower-case letter on the horizontal differ means by the Scott-Knott test with 5% of probability. **Urano = FPS Urano RR. ***Tornado = BMX Tornado RR.

In December 2014/2015, the narrow row showed higher than a 1000-grain mass than other row spacings. In this specific situation, the 1000-grain mass was the grain yield component responsible for the grain yield differences among row spacings. However, a 1000-grain mass usually did not vary according to the row spacing modifications. The 1000-grain mass had a trait more influenced by cultivar genetics (Santachiara et al. 2017) or environmental conditions during seed filling. The greatest 1000-grain mass, in this case, could be related to factors such as longer duration of seed filling, temperature in the canopy during seed filling, and greater ability to redistribute photoassimilates from source to the seeds, in narrow rows. However, in December 2015/2016 the difference in the 1000-grain mass has not occurred again and the number of pods plant^{-1} was the most important component for the grain yield. In this situation there was no difference between row spacings for FPS Urano RR and narrow rows showed higher values for BMX Tornado RR (Table 4).

Regarding cultivars, they have a different adjustment for grain yield components. The plant population recommended by the breeders of the two cultivars is different due to their ability for branching. Indeterminate cultivars have more grain yield stability. BMX Tornado RR maintains a value for number of pods plant^{-1} close to 60, which maintains its grain yield level above 3500 kg ha^{-1}. FPS Urano RR when planted in better growth conditions (Fig. 1), reached values of number of pods plant^{-1} close to those of the BMX Tornado RR, increasing its grain yield level (Fig. 2), as in November 2015/2016. As the narrow rows were the ones that showed the highest sunlight interception at the lower portion of the canopy in December, this resulted in the highest number of grains and consequently the highest grain yield. In November, FPS Urano RR and BMX Tornado RR showed the same number of grains at the lower and upper middle and lower at upper portion of the canopy. It drove both cultivars to reach the same number of grains and increase FPS Urano RR grain yield due to its higher number of plants area^{-1}. In the December planting date BMX Tornado RR showed a higher number of grains in all portions of the canopy than FPS Urano RR, which made both cultivars reach the same grain yield.

Conclusions

The narrow row configuration demonstrates superior canopy closure, persisting up to 40 days post-planting, coupled with heightened sunlight interception at the R2 stage. Conversely, the cross-row arrangement exhibits a reduction in soybean grain yield relative to alternative row spacings. Similarly, the twin-row configuration yields comparable or diminished grain output compared to wider row configurations. Both narrow and wide row spacings consistently yield higher grain outputs across varying planting dates. Specifically, the narrow row configuration emerges as the optimal choice for late planting scenarios, outperforming alternative configurations trialed in this study. Conversely, the wide row configuration is recommended for standard planting dates.

Author contributions

All authors contributed equally to the research and discussion of the obtained data of the manuscript. Additionally, all authors further contributed to the writing of the different sections of the paper.

Acknowledgements

To the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq - Processes 312480/2020-2), the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brasil - Finance code 001, and the Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul (FAPERGS – Processes 22/2551-0001644-8) for granting scholarships to the authors. To the scholarship students and volunteers for helping in data collection.

References

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JL, Sparovek G (2013) Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 22: 711–728. https://doi.org/10.1127/0941-2948/2013/0507

Basso CJE, Pertile WB, Sangiovo MJR, Souza FM, Diecson (2021) Impact of row spacing on soybean morphological parameters and yield. African Journal of Agricultural Research 17: 998–1002.

Bellaloui N, Bruns HA, Abbas HK, Mengistu A, Fisher DK, Reddy KN (2015) Effects of row-type, row-spacing, seeding rate, soil-type, and cultivar differences on soybean seed nutrition under U.S Mississippi Delta conditions. PLOS ONE 10: e0129913. https://doi.org/10.1371/journal.pone.0129913

Fehr W, Caviness C (1977) Stages of soybean development. 11. https://dr.lib.iastate.edu/handle/20.500.12876/90239

Hu M, Wiatrak P (2012) Effect of planting date on soybean growth, yield, and grain quality. Agronomy Journal 104: 785–790. https://doi.org/10.2134/agronj2011.0382

de Souza Jaccoud-Filho D, Sartori FF, Manosso-Neto M, Vrisman, Cunha CM, Pierre ML, Berger-Neto A, Zanon S (2016) Influence of row spacing and plant population density on management of "white mould" in soybean in southern Brazil. Australian Journal of Crop Science 10: 161–168.

Kandel HJ, Samarappuli DP, Johnson KL, Berti MT (2021) Soybean relative maturity, not row spacing, affected interseeded cover crops biomass. Agriculture 11: 441. https://doi.org/10.3390/agriculture11050441

Klimek-Kopyra A, Bacior M, Lorenc-Kozik A, Neugschwandtner RW, Zając T (2021) Intraspecific competition as a driver for true production potential of soybean. Italian Journal of Agronomy 16(1): 1709. https://doi.org/10.4081/ija.2020.1709

Lamichhane JR, Alletto L, Cong WF, Dayoub E, Maury P, Plaza-Bonilla D, Reckling M, Saia SE, Tison G, Debaeke P (2023) Relay cropping for sustainable intensification of agriculture across temperate regions: Crop management challenges and future research priorities. Field Crops Research 291: 108795. https://doi.org/10.1016/j.fcr.2022.108795

Lee CD (2006) Reducing row widths to increase yield: Why it does not always work. Crop Management 5: 1–7. https://doi.org/10.1094/CM-2006-0227-04-RV

Martin TN, Marchese JA, de Sousa AKF, Curti GL, Fogolari H, Vinícius SC (2013) Uso do software ImageJ na stimativa de área foliar para a cultura do feijão. Interciencia 38: 843–848.

Müller M, Rakocevic M, Caverzan A, Chavarria G (2017) Grain yield differences of soybean cultivars due to solar radiation interception. American Journal of Plant Sciences 8: 2795–2810. https://doi.org/10.4236/ajps.2017.811189

Santachiara G, Borrás L, Rotundo JL (2017) Physiological processes leading to similar yield in contrasting soybean maturity groups. Agronomy Journal 109: 158–167. https://doi.org/10.2134/agronj2016.04.0198

Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreras JF, Coelho MR, Almeida JA, Filho JCA, Oliveira JB, Cunha TJF (2018) Sistema Brasileiro de Classificação de Solos 5 ed. Brasília, DF: Embrapa, 356.

Sentelhas PC, Battisti R, Câmara GMS, Farias JRB, Hampf AC, Nendel C (2015) The soybean yield gap in Brazil–magnitude, causes and possible solutions for sustainable production. The Journal of Agricultural Science 153: 1394–1411. https://doi.org/10.1017/S0021859615000313

Silva AG, Sena Martins PD, Carmo EL, Procópio SO, Barcellos LC, Ferreira CJB, Bessa OR (2020) Plant arrangement in soybean crops with indeterminate growth in brazilian Cerrado. Research Society and Development 9: e1789119639–e1789119639. https://doi.org/10.33448/rsd-v9i11.9639

Silva PR, Tavares LA, Sousa SF, Correia TPDS, Riquetti NB (2015) Rentabilidade na semeadura cruzada da cultura da soja. Revista Brasileira de Engenharia Agrícola e Ambiental 19: 293–297. https://doi.org/10.1590/1807-1929/agriambi.v19n3p293-297

Slattery RA, Ort DR (2021) Perspectives on improving light distribution and light use efficiency in crop canopies. Plant Physiology 185: 34–48. https://doi.org/10.1093/plphys/kiaa006

Slattery RA, Van Loocke A, Bernacchi CJ, Zhu XG, Ort DR (2017) Photosynthesis, light use efficiency, and yield of reduced-chlorophyll soybean mutants in field conditions. Frontiers in Plant Science 8: 549. https://doi.org/10.3389/fpls.2017.00549

Specht JE, Diers BW, Nelson RL, de Toledo JFF, Torrion JA, Grassini P (2014) Soybean. Yield Gains in Major US Field Crops 33: 311–355. https://doi.org/10.2135/cssaspecpub33.c12

Tagliapietra EL, Streck NA, da Rocha TSM, Richter GL, da Silva MR, Cera JC, Guedes JVC (2018) Optimum leaf area index to reach soybean yield potential in subtropical environment. Agronomy Journal 110: 932–938. https://doi.org/10.2134/agronj2017.09.0523

Zhou XB, Chen H, Ouyang Z (2011) Row spacing effect on leaf area development, light interception, crop growth and grain yield of summer soybean crops in Northern China. African Journal of Agricultural Research 6: 1430–1437.

E-mail and ORCID

Vinícius dos Santos Cunha (viniciuscunha@unipampa.edu.br)
Glauber Monçon Fipke (glauberfipke@unipampa.edu.br)
Gerusa Massuquini Conceição (gerusa.conceicao@unijui.edu.br)
Tânia Maria Müller (mullertania@hotmail.com)
João Leonardo Fernandes Pires (joao.pires@embrapa.br)
Fernando Sintra Fulaneti (fernando.sintrafulaneti@gmail.com)
Thomas Newton Martin (Corresponding author, martin.ufsm@gmail.com), ORCID: https://orcid.org/0000-0003-4549-3980