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Grain yield of soybean cultivars using different densities and sowing dates in a high-altitude region of south Brazil

Rendimento de grãos de cultivares de soja com diferentes densidades e épocas de semeadura em região de elevada altitude do sul do Brasil

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Abstract

The study aimed to evaluate the performance of soybean cultivars at different sowing dates and plant densities. Two experiments were carried out at FAPA (Fundação Agrária de Pesquisa Agropecuária [Agrarian Foundation for Agricultural and Cattle Research]), located at 25˚33’ S latitude, 51˚29’ W longitude and with 1.100 meters of altitude in Guarapuava, PR [Paraná], Brazil, in two agricultural harvests (2010/2011 and 2011/2012). The experimental design was in randomized blocks and split plots, in which the sowing dates (10/20, 11/18 and 12/10) were allocated by plot, the densities (250, 350 and 450 thousand plants ha^{-1}) by subplot and the cultivars (BMX Energia, BMX Apolo, BMX Ativa, FPS Júpiter, V_Top, NS 6631, TMG 7161 and BRS Tordilha) by sub-subplot. The agronomic characteristics, grain yield and yield components were evaluated. Sowing dates and plant densities affected the agronomic characteristics, grain yield and yield components of soybean. The best sowing dates for lodging-tolerant cultivars are 10/20 and 11/18, and the best densities are 350 and 450 thousand plants ha^{-1}, while lodging-susceptible cultivars respond best for sowing dates of 11/18 and 12/10 and densities from 250 to 350 thousand plants ha^{-1}.
Key words: *Glycine max*, altitude, date, density, productivity

Resumo

O trabalho objetivou avaliar o comportamento de cultivares de soja, em diferentes épocas de semeadura e densidades de plantas. Dois experimentos foram conduzidos na FAPA Fundação Agrária de Pesquisa Agropecuária), localizada na latitude 25˚33’ S, longitude 51˚29’ W e com 1.00 metros de altitude, em Guarapuava, PR, Brasil, em dois anos agrícolas(). O delineamento experimental foi o de blocos ao acaso, com arranjo em parcelas sub-subdivididas, com as épocas (20/10, 18/11 e 10/12) alocadas nas parcelas, as densidades (250 350 e 450 mil plantas ha^{-1}) nas subparcelas e as cultivares (BMX Energia, BMX Apolo, BMX Ativa, FPS Júpiter, V_Top, NS 6631, TMG 7161 e BRS Tordilha) nas sub-subparcelas. Foram avaliados: as características agronômicas, os componentes do rendimento e o rendimento de grãos. A época de semeadura e a densidade de plantas influenciam as características agronômicas, os componentes do rendimento e o rendimento de grãos da soja. As melhores épocas de semeadura para as cultivares tolerantes ao acamamento são 20/10 e 18/11 e as melhores densidades 350 e 450 mil plantas ha^{-1}, enquanto que as cultivares suscetíveis ao acamamento respondem melhor nas épocas 18/11 e 10/12 e com densidades entre 250 e 350 mil plantas ha^{-1}.
Palavras-chave: *Glycine max*, altitude, época, densidade, produtividade

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Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the main agricultural crops of Paraná, significantly contributing to foreign exchange and jobs in all state regions. At 15.8 million tons per year, Paraná is the second largest soybean producer and has the highest productivity (3.336 kg ha^{-1}) among all Brazilian states (CONAB, 2013).

However, there are considerable differences in soybean grain yield among the main producing areas of the state, and the southern region has the lowest productivity (compared to the northern and western regions). In Paraná, among the three largest soybean producing regions, the West and North, usually have higher levels of productivity when compared to state of the South (SEAB, 2013).

These data can be explained by the better adaptation of cultivars in the northern and western regions of the state; most soybean breeding programs are located in those regions, and the development of lines in the northern and western environments favors the selection of cultivars that are better adapted to those areas. However, water availability is considered one of the most significant factors for maximizing the productive potential of soybean (COSTA, 1996), and water availability has been greater historically in the south-central region compared to other regions of the state of Paraná (IAPAR, 2010).

In recent years, however, several breeding programs have begun to select new soybean cultivars that are better adapted to higher altitudes, including the south of Paraná, Planalto, western Santa Catarina and northern Rio Grande do Sul. Night temperatures below 15 ˚C during soybean development, temperatures that are common in these regions (IAPAR, 2010), are usually detrimental to crop yields (SEDIYAMA, 2009).

However, these cultivars have been more successful in higher altitude environments than those selected in other environments with regard to vegetative cycle lengthening, growth enhancement, internode elongation, flower and pod abortion, plant lodging and grain yield reductions (MUNDSTOCK; THOMAS, 2005).

Different characteristics of cultivars developed for the highest altitude region of southern Brazil may be responsible for crop productivity in that environment. However, the data available for streamlining management, including assessing the sowing date and density for maximum productive potential in the region, are not yet conclusive.

The purpose of the study is to evaluate the performance of soybean cultivars with different growth habits and maturity groups in Guarapuava, PR and assess the optimum sowing date and plant density for this cultivars.

Materials and Methods

The experiments were conducted at the Agrarian Foundation for Agricultural and Cattle Research (Fundação Agrária de Pesquisa Agropecuária - FAPA), located at 25˚33’ S latitude, 51˚29’ W longitude and 1.100 meters altitude, in the municipality of Guarapuava, south-central region of the state of Paraná, during the 2010/2011 and 2011/2012 agricultural harvests.

A plot seeder was used at the direct planting system. An early soybean cultivar (NS 4990) was sown at the edges of the experimental plots to nullify the edge effect. This cultivar was harvested six days before the experimental plots were harvested, enabling machine movement while harvesting the plots.

Plant density was determined via manual thinning following emergence, followed by counting all plants in each plot.

The soil of the study area is classified as Aluminic Oxisol, clayey texture, subtropical field phase. Fertilization was performed based on the soil analysis, applying 200 kg ha^{-1} NPK 00-25-25 formulation. Desiccation of the cover crop, black oat, was performed 15 days before sowing the soybean using glyphosate (720 g a. e. ha^{-1}). For all plots, the management of weeds, pests and leaf diseases was conducted in accordance with FAPA research recommendations.

The experimental design consisted of randomized blocks, with four replicates, which were arranged in sub-subdivided plots. The factor sowing date (20/10, 18/11 and 10/12) was allocated by plot, the factor density (250, 350 and 450 thousand plants ha^{-1}) by subplot and the RR (Roundup-Ready) cultivars, with different growth types and maturity groups [undetermined: BMX Energia (5.0), BMX Apolo (5.8), V_Top (5.9) and FPS Júpiter (5.9); determined: BMX Ativa (5.6), TMG 7161 (6.1), BRS Tordilha (6.2) and NS 6631 (6.3)], by sub-subplot. The plot size was 1.6 x 5.0 meters, with four rows spaced 0.4 m apart.

Plant lodging was rated (via plot visual scoring; from 1 to 5, with 1 meaning no plant lodging and 5 meaning total plant lodging) at the pre-harvest (at 116 days following emergence). In this phase, all plants found within 0.5 linear meters and located in the middle of the first row and to the left side of each plot were cut at the base to assess plant height (base-to-apex), insertion height of the first pod, number of branches per plant, number of pods per plant and number of seeds per pod.

The harvest was performed using a plot harvester (Wintersteiger, Classic model), such that the whole plot, with a useful area of 8.0 m^2, was harvested. Cleaning was performed after harvesting, removing all impurities and subsequently assessing the thousand grain weight (g) and grain yield (kg ha^{-1}) with moisture content adjusted to 13%.

Analyses of variance were performed using ASSISTAT software, version 7.6 Beta, and mean values were tested for homogeneity using Bartlett's test and then compared via Tukey's test ($p<0.05$).

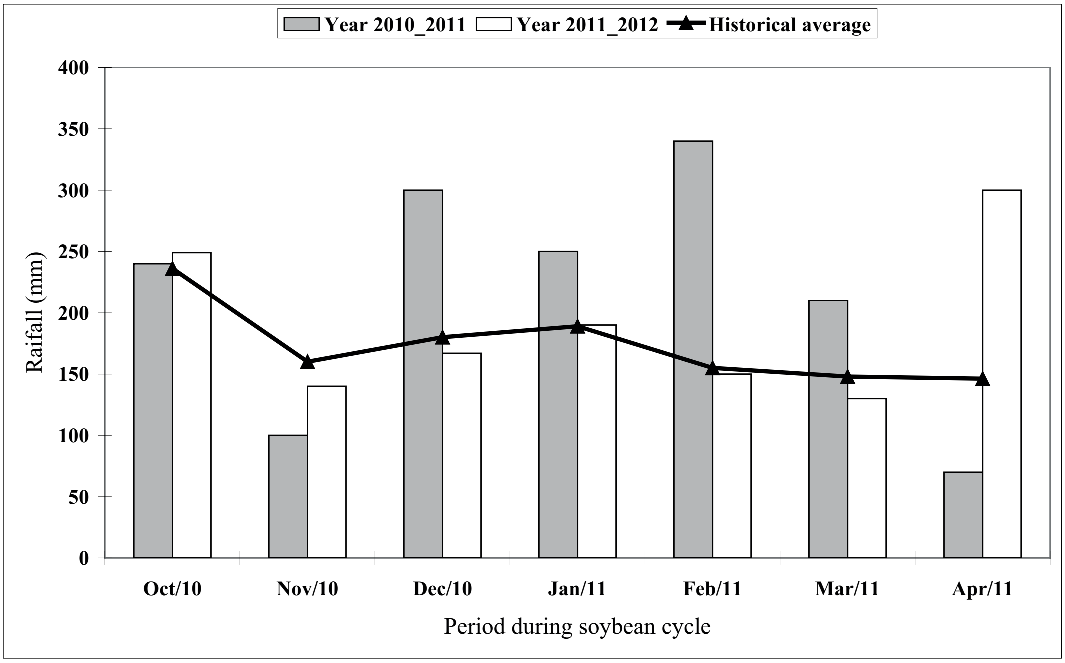
Results and Discussion

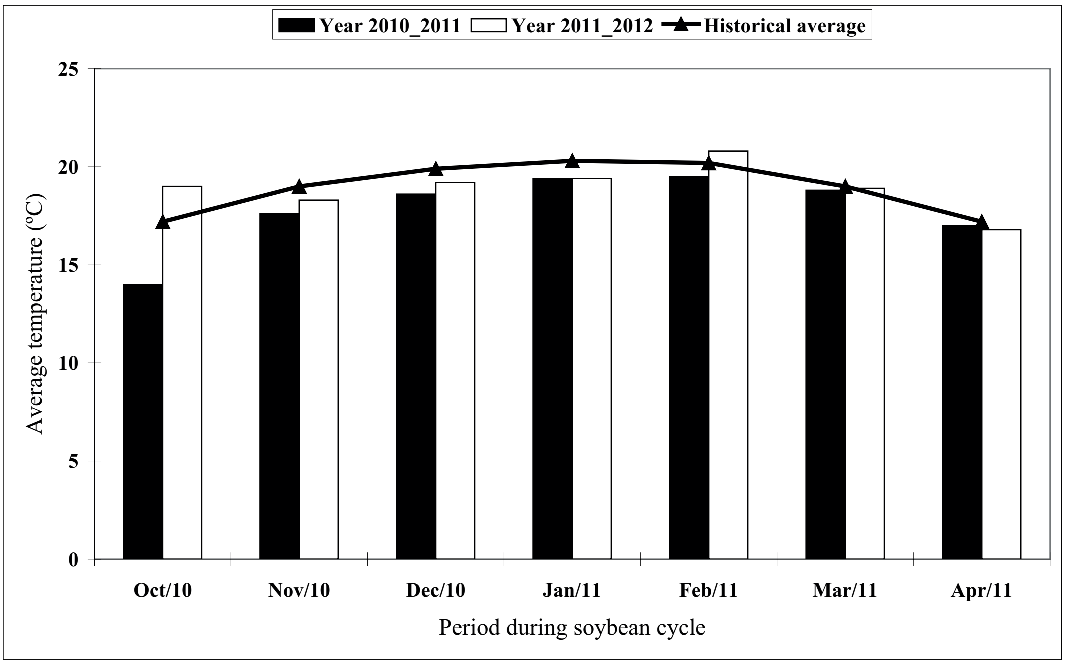
In general, soybean plant development was normal, enabling the assessed cultivars to reveal their adaptation to the study area. Rainfall in the 2010/2011 harvest was higher than the historical average, while in the following harvest, it was slightly below average, thus characterizing different regimes between the two harvests (Figure 1A). Average temperatures were similar during the development cycles of soybean plants in both harvests (Figure 1B).

Regarding average plant height (Table 1), increasing plant density noticeably caused significant increases in height for most cultivars assessed in both harvests, particularly for the first sowing date (October 20). In general, the earlier cultivars (BMX Energia, BMX Apolo, FPS Júpiter and BMX Ativa) had lower plant heights than the medium-cycle cultivars (TMG 7161 and BRS Tordilha), regardless of date, plant density and/or assessment year (Table 2).

There were no interactions between factors regarding the insertion height of the first pod. Both harvests performed similarly, with the highest means found for the first sowing date (October 20) and at the highest plant density (Table 2).

Figure 1. (A) Rainfall (mm) and (B) temperature (˚C) during soybean cycle at 2010/2011, 2011/2012 harvests and historical average recorded at FAPA meteorological station, Guarapuava, Paraná.





Source: Elaboration of the authors with data obtained meteorology station of FAPA.

These results enabled us to establish a rather close relationship between plant height and response to lodging, with the cultivars with highest plant heights (Table 1) showing the highest lodging scores (Table 3). Compared to the other dates and densities, the V_Top, TMG 7161 and BRS Tordilha cultivars increased lodging when sown on October 20 and at the highest plant density. Conversely, compared to previous harvests, both harvests of BMX Apolo, BMX Energia, BMX Ativa, FPS Júpiter and NS 6631 cultivars exhibited the lowest plant lodging indices, regardless of date or plant density (Table 3).

Table 1. Plant height (cm) of soybean cultivars sowed in three times and densities, in two agricultural harvests (2010/2011 and 2011/2012). FAPA, Guarapuava, Paraná, 2012.

	Sowing dates (E) x Densities (D)								
	Year 2010/2011								
Cultivars	E1D1	E1D2	E1D3	E2D1	E2D2	E2D3	E3D1	E3D2	E3D3
BMX Energia	69 CDe	74 Bd	78 Ad	66 DEc	71 BCd	71 BCe	61 Fd	59 Ff	65 Ee
BMX Apolo	75 ABcd	77 Ad	76 Ad	64 Dc	69 Cd	72 BCe	54 Fe	58 Ef	64 De
V_TOP	95 Aa	96 Ab	96 Ab	83 Db	85 CDc	91 Bc	85 CDa	84 CDb	87 Cb
FPS Júpiter	88 Cb	92 Bc	99 Ab	86 Cb	85 Cc	86 Cd	75 Ec	75 Ec	79 Dc
BMX Ativa	72 BCde	75 ABd	78 Ad	53 Ed	61 De	60 Df	63 Dd	63 De	70 Cd
TMG 7161	97 ABa	96 ABCb	99 Ab	92 DEa	93 CDEb	95 BCDb	81 Gb	88 Fa	91 EFa
BRS Tordilha	89 Cb	100 ABa	103 Aa	91 Ca	98 Ba	99 Ba	80 Eb	82 Deb	85 Db
NS 6631	78 Bc	77 Bd	88 Ac	65 Ec	68 DEd	70 CDe	72 Cc	71 CDd	78 Bc
C.V. (%): 2,90									
	Year 2011/2012								
Cultivars	E1D1	E1D2	E1D3	E2D1	E2D2	E2D3	E3D1	E3D2	E3D3
BMX Energia	92 Bc	100 Ab	97 ABd	84 Cb	82 Cc	85 Cc	66 Dc	64 De	68 Dd
BMX Apolo	88 Bcd	95 Ab	100 Acd	80 Cb	84 BCc	85 BCc	67 Dc	70 Dde	65 Dd
V_TOP	113 Aa	111 Aa	100 Bcd	99 Ba	99 Bab	99 Bb	87 Cb	82 Cab	82 Cbc
FPS Júpiter	103 Bb	112 Aa	105 Bbc	99 Ba	100 Bab	99 Bb	81 Cb	82 Cab	84 Cbc
BMX Ativa	85 Bd	95 Ab	100 Acd	80 BCb	86 Bc	85 Bc	72 Dc	73 Dcd	78 CDc
TMG 7161	114 Ba	114 Ba	123 Aa	95 Da	105 Ca	107 Ca	95 Da	79 Ebc	95 Da
BRS Tordilha	110 Aa	109 ABa	111 Ab	97 Ca	102 Cab	103 BCab	85 Db	88 Da	98 Ca
NS 6631	102 Bb	114 Aa	110 Ab	98 Ba	96 Bb	97 Bb	84 Cb	86 Ca	88 Cb
C.V. (%): 3,66									

Means followed by same capital letter within the rows and small letter within the column are not significantly different by Tukey´s test at P<0,05.

Sowing dates: E1 (first: 20/10); E2 (second: 18/11); E3 (third: 10/12); Densities (plants ha^{-1}): D1 (250.000); D2 (350.000); D3 (450.000).

Source: Elaboration of the authors.

Table 2. Insertion height of first pod (cm) of soybean cultivars sowed in three times and densities, in two agricultural harvests (2010/2011 and 2011/2012). FAPA, Guarapuava, Paraná, 2012.

	Year 2010/2011	Year 2011/2012
Cultivars	Insertion height of 1° pod	
BMX Energia	15,7 c	19,5 c
BMX Apolo	15,1 c	20,3 bc
V_TOP	19,0 ab	20,7 bc
FPS Júpiter	20,3 a	22,1 b
BMX Ativa	15,8 c	20,3 bc
TMG 7161	19,8 ab	20,2 bc
BRS Tordilha	19,9 ab	26,1 a
NS 6631	18,9 b	26,2 a
Sowing times	Insertion height of 1° pod	
20/october	19,1 a	24,0 a
18/november	17,8 b	21,2 b
10/december	17,3 b	20,2 b
Densidades	Insertion height of 1° pod	
250 thousand plants ha^{-1}	16,7 c	20,0 c
350 thousand plants ha^{-1}	18,1 b	22,0 b
450 thousand plants ha^{-1}	19,4 a	23,4 a
C.V. (%):	9,09	13,89

Means followed by same letter within the rows are not significantly different by Tukey´s test at P<0,05.
Source: Elaboration of the authors.

Table 3. Plant lodging (scores 1 to 5) of soybean cultivars sowed in three times and densities, in two agricultural harvests (2010/2011 and 2011/2012). FAPA, Guarapuava, Paraná, 2012.

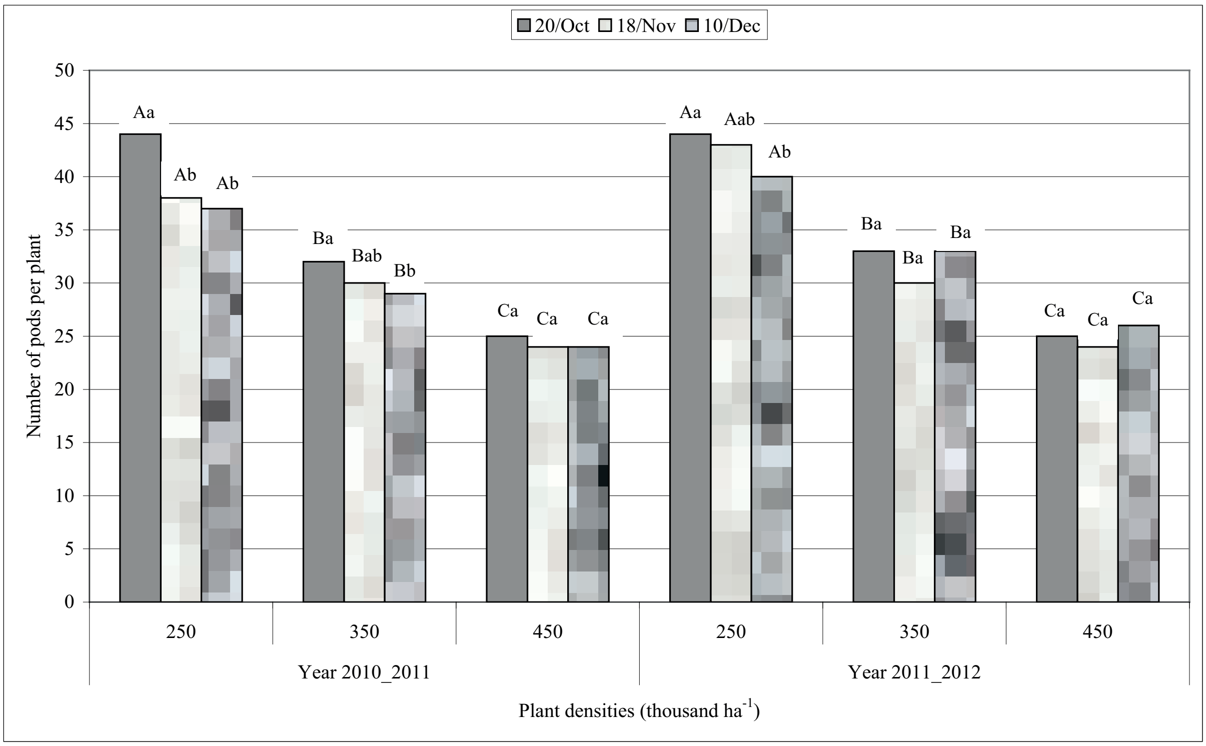
	2010/2011			2011/2012		
	Average: densities within sowing dates			Average: densities within sowing dates		
Cultivars	20/Oct	18/Nov	10/Dec	20/Oct	18/Nov	10/Dec
BMX Energia	1,1 Ac	1,0 Ad	1,0 Ab	1,1 Ad	1,0 Ad	1,0 Ac
BMX Apolo	1,2 Ac	1,0 Ad	1,0 Ab	1,2 Ad	1,0 Ad	1,0 Ac
V_TOP	2,3 Ab	1,8 Bb	1,3 Cab	2,6 Ab	2,3 Bb	1,2 Cbc
FPS Júpiter	1,4 Ac	1,3 Acd	1,0 Bb	1,5 Ac	1,6 Ac	1,0 Bc
BMX Ativa	1,1 Ac	1,0 Ad	1,0 Ab	1,1 Ad	1,0 Ad	1,0 Ac
TMG 7161	2,3 Ab	1,7 Bbc	1,1 Cab	2,7 Ab	2,0 Bb	1,4 Cab
BRS Tordilha	3,0 Aa	2,7 Aa	1,5 Ba	3,1 Aa	3,0 Aa	1,7 Ba
NS 6631	1,4 Ac	1,3 Ad	1,1 Aab	1,1 Ad	1,1 Ad	1,0 Ac
	Average: sowing dates within densities (thousand plants ha^{-1})			Average: sowing dates within densities (thousand plants ha^{-1})		
Cultivars	250	350	450	250	350	450
BMX Energia	1,0 Ab	1,0 Ac	1,1 Ad	1,0 Ad	1,0 Ad	1,1 Ad
BMX Apolo	1,0 Ab	1,0 Ac	1,2 Acd	1,0 Ad	1,0 Ad	1,2 Ad
V_TOP	1,1 Cb	1,9 Bb	2,4 Ab	1,4 Cbc	2,2 Bb	2,6 Ab
FPS Júpiter	1,0 Bb	1,3 Abc	1,5 Acd	1,1 Bcd	1,4 Ac	1,6 Ac
BMX Ativa	1,0 Ab	1,0 Ac	1,2 Acd	1,0 Ad	1,0 Ad	1,2 Ad
TMG 7161	1,2 Cab	1,8 Bb	2,3 Ab	1,5 Cb	2,0 Bb	2,6 Ab
BRS Tordilha	1,6 Ca	2,5 Ba	3,0 Aa	1,9 Ca	2,5 Ba	3,4 Aa
NS 6631	1,0 Bb	1,3 Ac	1,6 Ac	1,0 Bd	1,0 Bd	1,3 Acd
C.V. (%): 19,80				C.V. (%): 15,21		

Means followed by same capital letter within the rows and small letter within the column are not significantly different by Tukey´s test at P<0,05.
Source: Elaboration of the authors.

These results indicate that sowing performed from mid-November and with densities between 250 and 350 thousand plants ha^{-1} can become a problem in cultivars with excessive plant growth and consequently higher susceptibility to lodging. Indeed, the choices of sowing date and plant density can significantly affect several morphological features as well as soybean grain yields in different regions of South Brazil (PEIXOTO et al., 2000; LUDWIG et al., 2007).

For all sowing dates and for both harvests, the number of pods per plant in the cultivars assessed significantly decreased as the plant density increased (Figure 2). At a density of 250 thousand plants ha^{-1}, the first sowing date resulted in the highest number of pods per plant, while at the other densities, no pods per plant differences were observed among sowing dates, regardless of harvest (Figure 2). In all cultivars, the number of branches per plant diminished with increasing plant density, which certainly contributed to the reduction in pods per plant. Increasing plant density decreases the space and resources available for each plant and increases intraspecific competition, causing further flower and pod abortion and decreasing production per specimen within the community (COSTA, 1996; MARTINS, 1999; RAMBO et al., 2002; MUNDSTOCK; THOMAS, 2005).

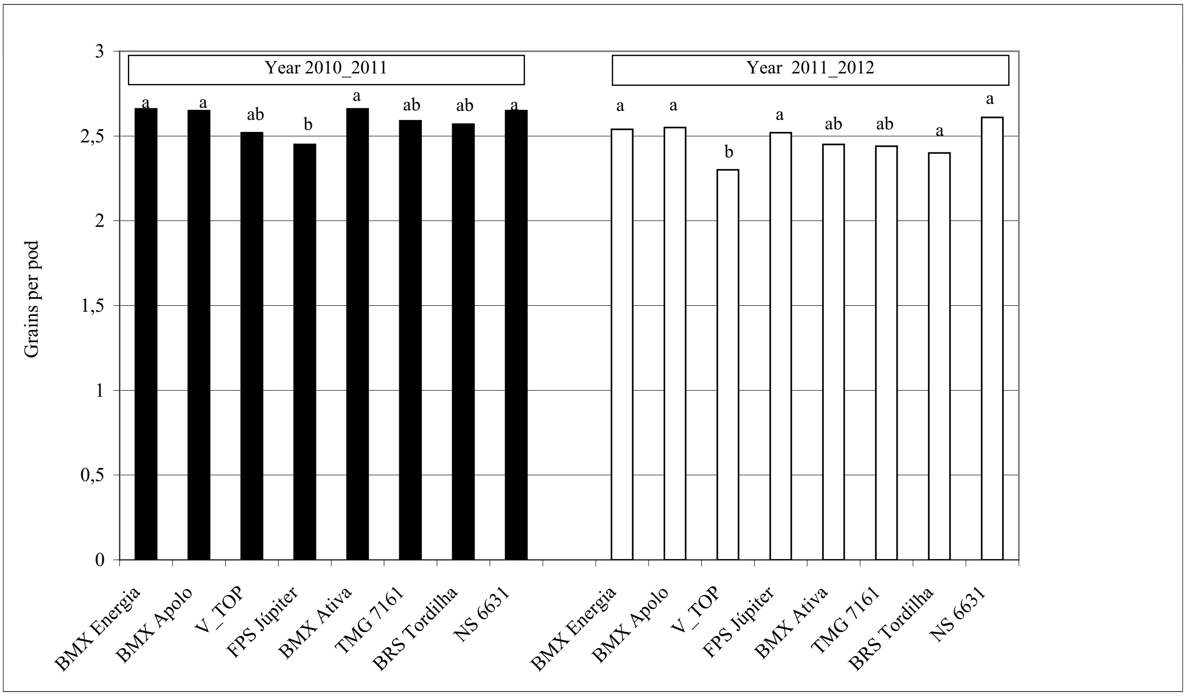
Figure 2. Pods number of soybean cultivars sowed in three times and densities, in two agricultural harvests (2010/2011 and 2011/2012). FAPA, Guarapuava, Paraná, 2012.



Means followed by same capital letter within the densities and small letter within the sowing time are not significantly different by Tukey´s test at P<0,05.
Source: Elaboration of the authors.

Neither sowing date nor plant density affected the number of grains per pod. The FPS Júpiter cultivar exhibited the lowest number of grains per pod, while the other cultivars showed no differences (in both harvests) regarding the (mean of the) three sowing dates and three densities evaluated (Figure 3). Because the number of grains per pod is a genetically determined characteristic, the environment has less effect on this characteristic (COSTA, 1996), which may explain the results reported herein.

Figure 3. Grain number by pod of soybean cultivars sowed in three times and densities, in two agricultural harvests (2010/2011 and 2011/2012). FAPA, Guarapuava, Paraná, 2012.



Means followed by same letter within the year are not significantly different by Tukey´s test at P<0,05.
Source: Elaboration of the authors.

There were significant interaction between cultivars and sowing dates on thousand grain weight (TGW), but no effects of plant density was observed. The BRS Tordilha cultivar had the highest mean TGW values on the three sowing dates of the 2010/2011 harvest, when rainfall levels were high (Table 4). In general, the third sowing date was the most detrimental for grain weight, as most cultivars experienced a TGW reduction on that date (Table 4). The BMX Energia and BMX Apolo cultivars performed better than the others on the first date and did not differ from the V_Top, FPS Júpiter and BRS Tordilha cultivars on the second and third sowing dates of the 2011/2012 harvest, under lower rainfall conditions (Table 4).

Delaying the sowing date shortened each cultivar's growth cycle, an effect that was particularly noticeable when comparing the first and third dates (data not shown). Thus, the smaller concentration of photoassimilates, and, therefore grain weight reduction, was likely caused by the lower number of days available for grain formation following the third sowing date. Indeed, in addition to temperature and water stress, shortening the grain-filling period affects plant structure, size, weight and soybean grain yield during this period (ODA; SEDIYAMA; BARROS, 2009).

Although increasing plant density reduced the number of pods per plant (Figure 2), it contributed to an increase in grain yield, particularly in lodging-tolerant cultivars (Tables 3 and 5). In this case, the higher numbers of plants per area offset reductions in the numbers of individual pods. Similar results were obtained by Rezende et al. (2004), whose highest grain yields were found in lodging-tolerant cultivars at a density of 400 thousand plants ha^{-1}. However, these results contrast those obtained by Capenter and Board (1997) and Pires (1998), which reflect no differences in soybean grain productivities for densities between 100 and 600 thousand plants ha^{-1}. These differences may be due to characteristics that are specific to the old cultivars, which exhibited higher growth and branching and high lodging levels compared to the new cultivars assessed in the present study (the latter exhibited lower plant height and were tolerant to lodging).

Table 4. Thousand grain weight (TGW) of soybean cultivars sowed in three times and densities, in two agricultural harvests (2010/2011 and 2011/2012). FAPA, Guarapuava, Paraná, 2012.

	2010/2011			2011/2012		
	Densities within sowing dates			Densities within sowing dates		
Cultivars	20/Oct	18/Nov	10/Dec	20/Oct	18/Nov	10/Dec
BMX Energia	172 Ac	168 Ab	156 Bbcd	176 Aa	166 Bab	157 Ca
BMX Apolo	175 Abc	172 Ab	160 Bbc	179 Aa	167 Ba	156 Ca
V_TOP	171 Ac	166 Ab	155 Bcd	165 Ab	165 Aab	144 Bb
FPS Júpiter	181 Ab	172 Bb	160 Cbc	159 Abc	160 Aab	148 Bab
BMX Ativa	176 Abc	166 Bb	162 Bb	168 Ab	156 Bbc	148 Cab
TMG 7161	152 Ae	156 Ac	152 Ade	155 Ac	152 Ac	145 Bb
BRS Tordilha	199 Aa	196 Aa	184 Ba	159 Abc	160 Aab	148 Bab
NS 6631	162 Ad	157 Ac	148 Be	155 Ac	152 Ac	143 Bb
	C.V. (%): 2,82			C.V. (%): 5,02		

Means followed by same capital letter within the rows and small letter within the columns are not significantly different by Tukey´s test at P<0,05.
Source: Elaboration of the authors.

In lodging-susceptible cultivars (including BRS Tordilha and TMG 7161), densities above 350 thousand plants ha^{-1} resulted in lower grain yields in both harvests (Table 5). In this case, as shown in Table 3, increasing plant density increased plant height (Table 1), contributing to increased lodging (which, especially for the first and second sowing dates, was initiated at the onset of flowering). In general, lodged plants presented higher flower and legume abortion, resulting in lower grain production per plant (COSTA, 1996; RAMBO et al., 2002; MUNDSTOCK; THOMAS, 2005; ODA; SEDIYAMA; BARROS, 2009; LUDWIG et al., 2007).

Thus, the appropriate plant density primarily depends on the cultivar's characteristics and the environmental conditions wherein it will be grown. In general, under climate conditions favoring lodging, as in high-altitude regions of South Brazil, plant densities between 280 and 350 thousand plants ha^{-1} enable high grain yields combined with acceptable levels of lodging (GAUDÊNCIO et al., 1990). Furthermore, density is a key factor for determining plant arrangement patterns in the production system. This parameter directly affects soybean plant growth and development and, consequently, the time required to cover an area. In turn, higher or lower rates of leaf coverage are directly related to the use of solar radiation, especially early in the cycle (EVANS; FISCHER, 1999). Therefore, the optimal plant density should maximize grain yield, enabling appropriate plant and first-pod insertion heights for mechanized harvesting and minimizing plant lodging (GAUDÊNCIO et al., 1990).

Table 5. Grain yield of soybean cultivars sowed in three times and densities, in two agricultural harvests (2010/2011 and 2011/2012). FAPA, Guarapuava, Paraná, 2012.

	2010/2011			2011/2012		
	Densities within sowing dates			Densities within sowing dates		
Cultivars	20/Oct	18/Nov	10/Dec	20/Oct	18/Nov	10/Dec
BMX Energia	4949 Aab	4732 ABab	4063 Cc	4955 Aab	4680 Ba	3696 Ce
BMX Apolo	5149 Aa	4771 Bab	4202 Cbc	4956 Aab	4804 Aa	3919 Bd
V_TOP	4696 Ab	4516 Ab	4129 Bbc	4645 Ad	4373 Bc	4395 Bab
FPS Júpiter	5031 Aa	4660 Bab	4343 Cb	4808 Abc	4748 Aa	4498 Ba
BMX Ativa	5136 Aa	4790 Ba	4363 Cb	5175 Aa	4617 Bab	4240 Cbc
TMG 7161	4132 Bd	4232 Bc	4671 Aa	4080 Be	4204 ABcd	4345 Aab
BRS Tordilha	3998 Bd	4254 Ac	4172 ABbc	4090 Be	4217 ABcd	4382 Aab
NS 6631	4428 Ac	4109 Bc	3961 Bc	4731 Acd	4413 Bbc	4066 Ccd
	Sowing dates within densities (thousand plants ha^{-1})			Sowing dates within densities (thousand plants ha^{-1})		
Cultivars	250	350	450	250	350	450
BMX Energia	4199 Bbc	4680 Aab	4765 Ab	3828 Ce	4121 Bd	4382 Ac
BMX Apolo	4522 Ba	4686 Bab	4914 Aab	4599 Ba	4880 Aa	4675 Bab
V_TOP	4427 Aab	4536 Abc	4378 Acd	4018 Bde	4443 Ac	4476 Abc
FPS Júpiter	4430 Bab	4616 Bab	4988 Aab	4533 Bab	4682 ABab	4840 Aa
BMX Ativa	4441 Cab	4794 Ba	5053 Aa	4376 Bbc	4808 Aa	4848 Aa
TMG 7161	4391 Aabc	4489 Abc	4154 Bde	4329 Abc	4369 Ac	3931 Bd
BRS Tordilha	4169 Abc	4280 Acd	3975 Be	4372 Abc	4390 Ac	3927 Bd
NS 6631	3904 Cd	4143 Bd	4451 Ac	4183 Bcd	4518 Abc	4509 Abc
C.V. (%): 4,67				C.V. (%): 3,48		

Means followed by same capital letter within the rows and small letter within the columns are not significantly different by Tukey´s test at P<0,05.
Source: Elaboration of the authors.

According to Peixoto et al. (2000), a reduction in soybean plant density can be offset by a higher number of pods per plant, such that the yield remains constant. This observation is particularly applicable in lodging-susceptible cultivars because reducing density for these cultivars also reduces plant lodging. Soybean cultivars with high vegetative development usually have high abilities for branching and space-compensation when densities are low. This ability is due, at least in part, to the high phenotypic plasticity soybean plants show for certain morphological characteristics and yield components (PIRES et al., 2000).

The sowing date significantly affected soybean grain yield for all cultivars, albeit differently. The grain yields of the TMG 7161 and BR Tordilha cultivars, both of medium cycle, were higher for the third sowing date (December 10), particularly compared to the October 20 sowing date. Meanwhile, for most cultivars assessed (including all early-cycle cultivars), the best yields were found for the first and second sowing dates (October 20 and November 18) (Table 5). These results were similar for both harvests assessed (Table 5), showing that although all dates assessed are within the agricultural zoning period recommended by the official agencies for each crop in the region (MAPA, 2011), the performance is variable among cultivars, particularly when they are sown at the beginning and end of that period (Table 5). According to Ludwig et al. (2007), although it may still be within the agricultural zoning period, delaying the sowing date reduces soybean grain yield; however, increasing plant density may minimize this grain-yield reduction.

Thus, understanding the response(s) of each cultivar at the regional level, particularly as a result of different sowing dates and crop densities, is fundamental to maximizing the yield potential of soybean cultivars. To take advantage of all the benefits, the producer must plan the sowing date for each cultivar prior to choosing the cultivars to be sown in each harvest. Subsequently, in regions where winter cereals or pastures are grown before soybean, the sowing date and cycle of each crop should be determined prior to choosing the soybean cultivars that will be sown in each area.

The results of the present study indicate that soybean grain yield in high-altitude regions, including southern Paraná, can be maximized by adopting cultivars that are better adapted to these conditions and by considering the most effective sowing date and plant density, among other factors, for each cultivar within the productive farm systems.

Conclusions

Sowing dates and plant densities affected the agronomic characteristics, grain yield and yield components of soybean.

The best sowing dates for lodging-tolerant cultivars are 10/20 and 11/18, and the best densities are 350 and 450 thousand plants ha^{-1}, while lodging-susceptible cultivars respond best for sowing dates of 11/18 and 12/10 and densities from 250 to 350 thousand plants ha^{-1}.

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