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Sowing date changes phenological development, plastochron index, and grain yield of soybeans under Cerrado conditions[1]

Épocas de semeadura alteram o desenvolvimento fenológico, índice de plastocrono e produtividade de soja em condições de Cerrado

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HIGHLIGHTS:

Delayed sowing causes detrimental effects on the development and grain yield of extra-early and early cycle cultivars of soybeans.
Delayed sowing increased the plastochron index and reduced the crop cycle and growth of soybean cultivars.
In the region of Selvíria-MS, sowing in November was the most suitable for soybean.

ABSTRACT: The sowing date is a crop management practice that affects soybean development and grain yield, and is directly related to the genotype and cycle type. Our objective was to evaluate phenological development as a function of photoperiodic responses, plastrochron index, and grain yield in three soybean cultivars with different growth cycles sown on three sowing dates. The study was conducted in Selvíria, Mato Grosso do Sul State, Brazil, using a split-plot design with the main plots arranged in blocks with four replications. The main plots included three sowing dates, 15 days apart, beginning on November 15, and the subplots were composed of three cultivars: BMX Turbo RR (extra-early cycle), BMX Potência RR (early cycle), and TMG 1180 RR (medium cycle). Delayed sowing increased the plastochron index and reduced the growth cycle duration, plant height, node number of the main stem, and pod number per plant. We found that cultivars with longer cycles were more suitable for delayed sowing, had improved vegetative and reproductive development, and had higher grain yields than those with shorter periods. The second sowing date was most suitable for soybean cultivation in this region.

Key words: photoperiod, *Glycine max* L., phenological stages, delayed sowing

RESUMO: A época de semeadura é a prática de manejo cultural com maior interferência no desenvolvimento e na produtividade de grãos de soja, e está diretamente relacionada com o genótipo e tipo de ciclo da cultura. Nosso objetivo foi avaliar o desenvolvimento fenológico em função das respostas fotoperíodicas, índice de plastocrono e produtividade de grãos de três cultivares de soja com ciclos diferentes, semeadas em três épocas distintas O estudo foi realizado em Sevíria, Mato Grosso do Sul e utilizou um delineamento de parcelas subdivididas com as parcelas principais dispostas em blocos com quatro repetições. As parcelas foram compostas por três épocas de semeadura com intervalo de 15 dias, a partir de 15 de novembro, e as subparcelas foram compostas por três cultivares: BMX Turbo RR (ciclo extra-precoce), BMX Potência RR (ciclo precoce) e TMG 1180 RR (ciclo médio). A semeadura tardia aumentou o índice de plastocrono e reduziu a duração do ciclo de crescimento, altura da planta, número de nós no caule principal e número de vagens por planta. Nossos resultados demonstram que cultivares com ciclos mais longos são mais adequadas para semeadura tardia, apresentam melhor desenvolvimento vegetativo e reprodutivo e maior rendimento de grãos. A segunda época de semeadura foi a mais adequada para o cultivo da soja na região.

Palavras-chave: fotoperíodo, *Glycine max* L., estádios fenológicos, semeadura tardia

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Introduction

Many soybean cultivars are grown in tropical regions, and several others are introduced to the market every year (Nath et al., 2017). The evaluation of the development and adaptation of soybean cultivars to different edaphoclimatic conditions and the determination of the optimum sowing date (SD) are essential for improving the efficiency of soybean production and harvest planning (Streck et al., 2008; Zanon et al., 2015).

Higher agricultural yields can be obtained by understanding the dynamics of the production chain (Matoso et al., 2018). The most important management practices for increasing grain yield (GY) are the determination of the optimum sowing date (SD) and selection of genotypes adapted to the agroclimatic region (Ezeaku et al., 2015).

The optimum theoretical period for sowing soybeans is 30-45 days before the summer solstice because these plants are sensitive to the photoperiod and prefer shorter days (Slafer et al., 2015; Zanon et al., 2015).

Plant emergence rate and the node number per plant (NNP) are essential parameters of plant development (Martins et al., 2011) that can be estimated by measuring the time necessary for the appearance of two successive nodes in the same stem, and the thermal sum of the period (Jing et al., 2017). In dicotyledons, this interval is known as the plastochron index (PI) (Rockenbach et al., 2016).

The objective of this study was to evaluate the photoperiodic responses related to phenological development, PI, and GY in three soybean cultivars with different growth cycles sown on three sowing dates.

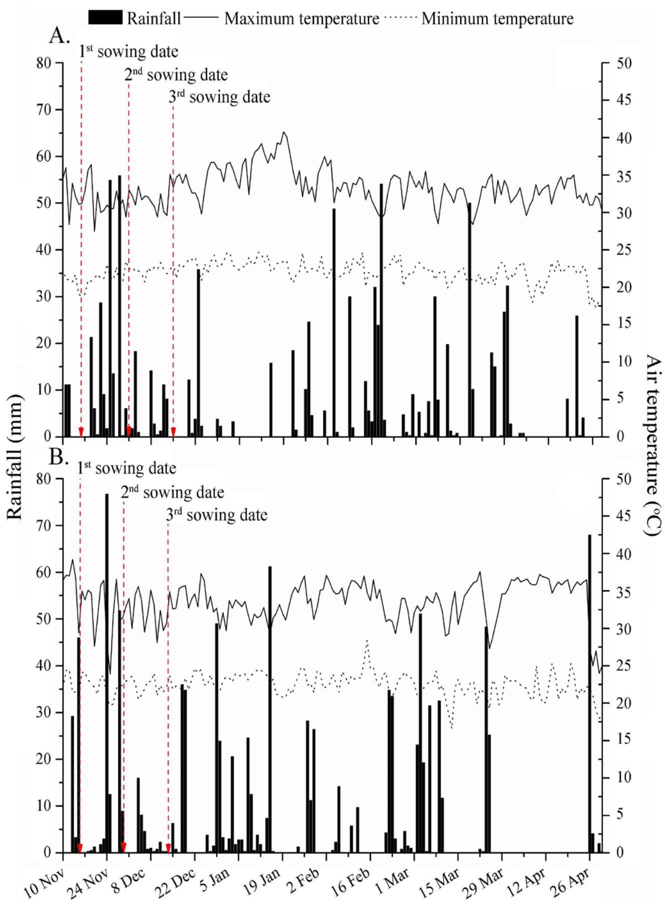

Figure 1. Data of rainfall, maximum and minimum temperatures of the air in the experimental area at Selvíria, Mato Grosso do Sul State, Brazil, during 2015/2016 (A) and 2016/2017 (B)

Material and Methods

The study was conducted over two years in an experimental area located in Selvíria, Mato Grosso do Sul State, in the central-west region of Brazil (51°22' W 20°22' S; 335 m.a.s.l.). The soil of the experimental area was characterized as Typic Haplorthox (USDA, 1999). The rainfall, and maximum and minimum temperatures of the air at the study site are presented in Figure 1.

The sowing system was no-tillage, and the experiments were performed in the same area in spring and summer. In the last 12 years, the experimental area has been cultivated with maize in the off-season (fall/winter) and soybean during the growing season (spring/summer). This sequence of cultivation is most commonly used in Brazil.

Before the installation of the experimental plots, the 0-0.20 m layer of the soil was sampled for chemical analysis according to the methodologies described by van Raij et al. (2001), and presented the following characteristics: phosphorus (P_{resin}): 22 mg dm^{-3}; soil organic matter (SOM): 21 g dm^{-3}; pH ($CaCl_2$): 5.5; exchangeable potassium (K^+): 1.8 mmol$_c$ dm^{-3}; exchangeable calcium (Ca^{2+}): 22 mmol$_c$ dm^{-3}; exchangeable magnesium (Mg^{2+}): 19 mmol$_c$ dm^{-3}; potential acidity at pH 7 (H + Al): 22 mmol$_c$ dm^{-3}; base saturation (BS): 42.8 mmol$_c$ dm^{-3}; cation exchange capacity (CEC): 64.5 mmol$_c$ dm^{-3}; and base saturation (BS, %): 66%.

The granulometric characteristics of the 0-0.20 and 0.20-0.40 m layers were 545 and 513 g kg^{-1} for clay, 347 and 360 g kg^{-1} for sand, and 108 and 127 g kg^{-1} for silt, respectively.

The soil physical properties (0-0.20 m layer) were as follows: microporosity (34.6%), macroporosity (8.2%), total porosity (42.8%), soil bulk density (1.6 kg dm^{-3}), water retention at field capacity (0.35 g g^{-1}), and permanent wilting point (0.08 g g^{-1}).

The study used a split-plot design with the main plots arranged in blocks with four replications. The main plots included three SDs, and the subplots were composed of three cultivars.

The main plots included November 15, 2015 (1st SD), November 30, 2015 (2nd SD), and December 15, 2015(3rd SD) for the first year; and November 15, 2016 (1st SD), November 29, 2016 (2nd SD), and December 14, 2016 (3rd SD) for the second year. The subplots were composed of three cultivars (BMX Turbo RR [C1], BMX Potência RR [C2], and TMG 1180 RR [C3], Cambé-PR, Brazil).

The first SD corresponded to the commonly recommended time for on-site geoclimatic conditions, while the second SD was considered a marginal period for sowing, and the third SD was considered incompatible with the regional conditions (Ferrari et al., 2015). Each experimental plot consisted of seven 10 m rows with an inter-row spacing of 0.45 m.

This study was conducted over two consecutive years (2015/2016 and 2016/2017). The same amounts of agricultural inputs were used for both years to minimize the random effects. A total of 20 kg ha^{-1} of N, 60 kg ha^{-1} of P_2O_5, and 60 kg ha^{-1} of K_2O were used for fertilization at sowing (Ambrosano et al., 1997).

The plant density per hectare for cultivars C1 and C2 was 380 000, and 360 000, respectively, and 320 000 for C3. Seeds were treated with fungicides (Carboxin + Thiram, each at 100 mL a.i. 100kg^{-1} seeds) before inoculation and sowing. Phytosanitary treatments were performed according to the requirements of soybean crops (Seixas et al., 2020).

The phenological development of soybean cultivars was monitored at each SD using the scale proposed by Fehr et al. (1971), and phenological changes were determined in plots containing 10 plants. The observations were made using the same plants, and the dates of each phenological stage were recorded.

The meteorological data were collected daily from an agrometeorological station located 2 km from the study site and were used to construct graphs of the duration of each phenological stage as a function of the photoperiod.

The daily photoperiod was calculated according to latitude and date. The critical photoperiod for soybean in tropical regions was 13.5 h (Câmara et al., 1997).

In the plants marked for quantification of the phenological stages, the NNP visible in the main stem was counted three times a week, as proposed by Munger (1997). The growing degree-days (GDDs) for each cultivar at each SD were calculated considering 10 °C as the baseline temperature for the emission of nodes on the main stem (Silva et al., 2018a).

For each repetition, linear regression between the NNP in the main stem and GDDs from plant emergence were obtained (Baker & Reddy, 2001; Streck et al., 2005; Zanon et al., 2015). The plastochron index (°C day node^{-1}) was considered the inverse of the slope of the linear regression between the NNP and GDDs (Baker & Reddy, 2001). The PI was determined for each replicate (Streck et al., 2005).

At phenological stage R_2 (full flowering), samples (2 m rows per subplot) were collected to determine the shoot dry matter. The plants were dried in a forced-air oven at 65 °C for 72 hours and weighed to determine the dry matter yield per hectare.

At the end of the growth cycle, 10 plants were randomly collected manually from one row in each plot, and plant height (PH) and insertion height of the first pod (IHFP) were measured and expressed in centimeters. The number of lateral branches per plant (NLBP) and NNP was also determined.

Plants from the plots were harvested at the end of the growth cycle. The pods were dried on a concrete floor, impurities were removed, and the grains were threshed and cleaned using a stationary mechanical thresher.

The 100 grain weight (100 GW) was determined by randomly collecting and weighing four samples per subplot, and the values were adjusted to a moisture content of 130 g kg^{-1} of water. The grains obtained by threshing were weighed. GY was transformed into Mg ha^{-1} at a moisture level of 130 g kg^{-1} of water.

The results were subjected to Anderson-Darling normality tests, and homogeneity was evaluated using Levene's test and analysis of variance [F-test ($p \le 0.05$)]. Data were analyzed separately for each year because the weather conditions varied between the years and there was a significant interaction between the years and the effects of treatment. All blocks and block interactions were considered random effects. The SDs and cultivars were considered fixed effects. Differences between treatments were compared using the LSD test ($p \le 0.05$).

Results and Discussion

Many agricultural factors influence the development of soybean crops, but SD is the strongest contributor (Sediyama et al., 2015) and determines the length of plant exposure to climate variations. Therefore, the incorrect choice of sowing period in relation to the cultivar may result in lower GY and crop loss (Silva et al., 2018b).

In this study, delayed sowing (DS) reduced the time required for the plant to change its phenological stage (Table 1). The total GDD tended to decrease until flowering when sowing was delayed (Table 1). Moreover, the GDDs of the extra-early cultivars were strongly affected by SD. Cultivars with longer growth cycles were more sensitive to the duration of phenological stages than those with shorter cycles.

The accumulation of GDDs tended to decrease as sowing was delayed up to stage R_1; however, when observing the accumulation of degree days until the end of the cycle, the results did not show a clear trend, which suggests that the thermal unit approach did not accurately describe the phenological development of soybean. Several other factors, such as air humidity, thermal amplitude, and photoperiod, were likely the more determining factors (Awasthi et al., 2017).

There was a significant effect of SD and cultivar on PI (Table 2). C3 presented the highest PI, independent of the SD. Furthermore, additional GDDs were necessary for the emission of nodes when sowing was later, and this result was observed in all cultivars in both growing seasons (Table 3).

Early-cycle cultivars had smaller PIs, and SD further decreased this index regardless of the cultivar. The PI of cultivar BMX RR Power was more stable in the last two SDs. Later sowing may occur in periods with low regularity of rainfall, which can also influence the development of soybean plants (Silva et al., 2018b). This fact could also be one of the hypotheses of developmental delay (greater plastochron), agreeing with Ma et al. (2021), that the water deficit in the soil, even if slight, delays the vegetative development of soybean.

The analysis of the relationship between the photoperiod and the duration of the phenological stages indicated that the phenological cycle was reduced and flowering occurred sooner with late sowing than early sowing, regardless of the cultivar and year of cultivation (Figure 2). Furthermore, floral induction occurred earlier as the photoperiod was reduced, approaching the critical value for the study region (13.5 h).

In the case of late sowing, the photoperiod conditions for the vegetative growth of soybean were still favorable, although as the sowing date approached the summer solstice (December 21 for the Southern Hemisphere), the period above the critical photoperiod had a shorter duration than when sowing was

Table 1. Duration in calendar days of each phenological subperiod and growing degree-days (GDD) required for flowering (R_1) and physiological maturity (R_7) of soybean cultivars as affected by three sowing dates

Cultivar	Sowing dates	Phenological subperiods						GDD	
		S to VE	VE to R_1	R_1 to $R_{5.1}$	$R_{5.1}$ to R_7	R_7 to R_8	S to R_8	Up to R_1	Up to R_7
First growing season									
BMX Turbo RR	1st	7	31	16	37	14	105	817	1419
	2nd	6	31	18	34	9	98	736	1356
	3rd	6	28	16	32	11	93	690	1225
BMX Potência RR	1st	7	32	15	51	13	118	831	1539
	2nd	6	29	16	48	12	111	768	1504
	3rd	6	27	16	45	10	104	895	1536
TMG 1180 RR	1st	7	41	30	58	8	144	1210	1842
	2nd	6	37	26	53	12	134	1329	1989
	3rd	7	31	17	52	12	119	1042	1909
Second growing season									
BMX Turbo RR	1st	7	31	16	37	14	105	793	1617
	2nd	6	30	18	36	8	98	736	1518
	3rd	6	30	14	31	9	88	656	1200
BMX Potência RR	1st	7	32	15	56	16	126	781	1753
	2nd	6	29	16	50	23	124	735	1535
	3rd	6	27	16	45	10	104	670	1501
TMG 1180 RR	1st	7	41	30	62	14	154	1007	1690
	2nd	7	34	26	56	14	137	904	1586
	3rd	7	28	19	53	10	117	952	1587

Table 2. F values and averages for plastochron index (°C day node^{-1}) according to the treatments

Treatments	Plastochron index (°C day node^{-1})	
	First growing season	Second growing season
Sowing dates (SD)		
1st	122.0 a†	101.6 a
2nd	120.0 a	91.2 b
3rd	109.4 b	87.5 c
LSD	2.1	1.5
Cycle (C)		
Extra-early	116.0 b	84.5 c
Early	98.6 c	89.7 b
Medium	138.5 a	106.1 a
LSD	2.9	1.1
F test		
p value (SD)	< 0.001	< 0.001
p value (C)	< 0.001	< 0.001
p value (SD x C)	< 0.001	< 0.001
CV (%) plot	1.39	1.21
CV (%) split-plot	2.44	1.13

† Values followed by the different letters in the columns are statistically different at ($p < 0.05$) according to the LSD test

Table 3. Interactions between cultivar and sowing dates for plastochron (°C day node^{-1}) in first and second year

Cultivar (C)	Sowing dates (SD)			LSD
	1st	2nd	3rd	
First growing season				
C1	121.9 bA†	116.2 bB	109.89 bC	4.4
C2	105.2 cA	95.2 cB	90.1 cC	
C3	138.9 aA	148.5 aB	128.2 aC	
LSD		5.1		
Second growing season				
C1	92.6 cA	83.3 bB	77.5 cC	1.9
C2	101.0 bA	84.0 bB	84.0 bB	
C3	111.1 aA	106.4 aB	101.0 aC	
LSD		1.8		

† Values followed by the same lowercase letter in the columns and uppercase letters in the rows are statistically different at ($p < 0.05$) according to the LSD test

performed earlier, which can cause early flowering induction in greater or lesser intensity, depending on the sensitivity of the cultivar (Martins et al., 2011).

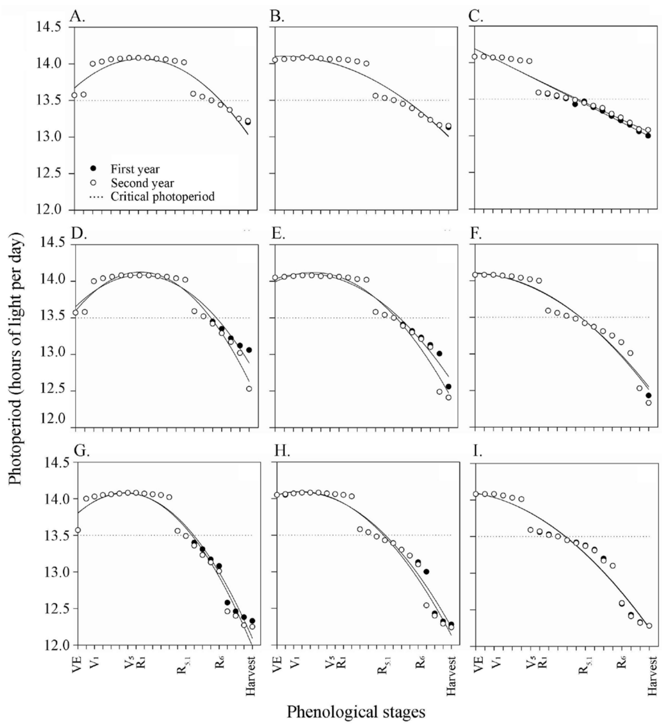

Figure 2. Influence of photoperiod in the experimental site in relation to soybean growth stages, for extra-early maturing cycle soybean in 1st (A), 2nd (B) and 3rd (C) sowing dates, for early maturing cycle soybean in 1st (D), 2nd (E) and 3rd (F) sowing dates and medium maturing cycle soybean for 1st (G), 2nd (H) and 3rd (I) sowing dates during two consecutive years (2015/2016 and 2016/2017)

According to Rockenbach et al. (2016), the shortening of the cycle and the precocity for flowering are characteristics that occur due to the reduction of the photoperiod and the occurrence of high temperatures, as observed in the years studied, mainly in the vegetative growth phase.

In the first SD, floral induction occurred when daylight hours increased. Floral induction occurred earlier in the first

SD than in the two later SDs, that is, flowering began when the number of daylight hours began to decrease, although the daylight period was longer than the critical photoperiod.

The cultivar C3 had the most pronounced change in the duration of the phenological stages relative to the other cultivars; in the first and second SDs (Figures 2G and H), the plants reached growth stage V_7, whereas in the third SD (Figure 2I), flowering occurred after V_5, resulting in the shortening of the growth cycle. Changes in the vegetative period as a function of the SDs were observed only for this cultivar, which had a comparatively longer growth cycle.

Regarding the duration of the phenological stages, cultivars with longer cycles were more sensitive to the duration of subperiods than those with shorter cycles (Rockenbach et al., 2016). This variation was more evident from the vegetative period to the beginning of grain filling ($V_E – R_{5.1}$). For the other subperiods, this change was not as evident. The same was true for the other materials during the three study periods.

The PI decreased when sowing was delayed, that is, the rate of node production increased at the later sowing dates. The decrease in the PI with SD may be a response to the duration of daylight hours, because the increase in the rate of plant development in shorter photoperiods is a typical response of short-day plants (Lu et al., 2017). Furthermore, soybean crops sown late may undergo periods of irregular rainfall, which may affect plant development.

There was clearly an increasing tendency in the PI in the medium-cycle cultivar (C3), while the extra-early and early cultivars alternated their responses between the two years. The growth cycle is not a reliable indicator of the PI because the development of soybean is not affected by the rate of development of nodes, but by the final number of nodes (Streck et al., 2008).

The relationship between the photoperiod and the duration of phenological stages demonstrates that the vegetative growth of soybean in the first and second SDs was within the period in which the average amount of daylight was greater than the critical photoperiod. This condition is considered optimal for the crop because it allows the plants to reach maximum PH with as many nodes as possible (Streck et al., 2008).

The photoperiodic conditions for the vegetative growth of soybeans were still favorable for DS. However, as the date of sowing was close to the summer solstice in the Southern Hemisphere, the favorable amount of daylight above that of the critical photoperiod was smaller than that with early sowing, which may lead to a greater or lesser extent of early flowering, depending on the sensitivity of the cultivar (Martins et al., 2011).

This factor, together with high temperatures during the soybean harvest period, increases the risk of early flowering.

In the first year, cultivar C3 plants were taller than those of the early cultivar, which in turn were taller than plants from the extra-early cultivar (Table 4). The NNP in both years was different between the cultivars and followed the same trend as that of PH.

The NNP was highest in cultivar C3 and lowest in cultivar C1. Furthermore, in the second year, SD resulted in the development of plants with a small NNP in the main stem, indicating that SD affected the NNP and, consequently, PH.

Table 4. F values and averages for plant height (PH), insertion height of the first pod (IHFP), number of nodes per plant (NNP) and number of lateral branches per plant (NLBP) according to the treatments

Treatments	PH	IHFP	NNP	NLBP
	(cm)			
First growing season				
Sowing dates (SD)				
1st	90.2 a†	15.8 a	19.3 a	2.5 a
2nd	83.7 a	14.2 a	18.4 a	2.3 a
3rd	81.8 a	13.5 a	19.6 a	2.2 a
LSD	9.9	3.6	1.4	0.9
Cycle (C)				
Extra-early	73.0 c	11.4 b	17.0 c	2.4 a
Early	85.3 b	15.8 a	19.4 b	2.6 a
Medium	97.5 a	16.2 a	20.9 a	2.0 a
LSD	8.2	2.2	1.3	0.7
F test				
p value (SD)	0.1563	0.3015	0.1428	0.6453
p value (C)	< 0.001	< 0.001	< 0.001	0.1209
p value (SD x C)	0.6532	0.1033	0.0675	0.3682
CV (%) plot	8.86	19.04	5.58	18.10
CV (%) split-plot	9.39	14.67	6.54	13.49
Second growing season				
Sowing dates (SD)				
1st	80.3 a	14.6 a	19.6 a	3.15 a
2nd	82.0 a	11.3 b	19.8 a	3.66 a
3rd	66.5 b	10.7 b	17.5 b	2.5 b
LSD	1.7	1.9	1.0	0.54
Cycle (C)				
Extra-early	57.0 c	8.4 c	15.9 c	3.65 a
Early	73.8 b	12.0 b	17.9 b	3.15 a
Medium	98.1 a	16.2 a	23.1 a	2.51 b
LSD	5.4	1.3	1.3	0.6
F test				
p value (SD)	< 0.001	< 0.001	0.0032	0.0099
p value (C)	< 0.001	0.0047	< 0.001	0.0020
p value (SD x C)	0.1860	0.0855	0.6082	0.6804
CV (%) plot	2.30	15.51	5.69	16.81
CV (%) split-plot	8.28	12.67	8.16	13.60

† Values followed by the different letters in the columns are statistically different at ($p < 0.05$) according to the LSD test

There were significant differences in the NLBP between the cultivars, but only in the second year, and the mean NLBP was comparatively higher in the first and second SDs. C1 presented the highest NLBP, followed by C2 and C3.

The lowest values of PH and the IHFP were obtained with later SDs, which was directly associated with the shorter vegetative period, as observed by Câmara et al. (1997). The climatic conditions during the vegetative stage, especially the shorter photoperiod and higher temperature, reduced PH and the phenological cycle, which directly affected vegetative growth and biomass accumulation.

Although cultivars C2 and C3 had longer growth cycles relative to C1, and were consequently more sensitive to photoperiodic variations, their juvenile period was longer than that of extra-early cultivars, which was compensated for with increased vegetative growth and accumulation of plant biomass.

Shoot dry matter was higher in the first year in cultivars C2 and C3 than in C1 (Table 5). However, there were no significant differences in this variable between the SDs and cultivars in the second year. In both growing seasons, the NNP was significantly higher in the second SD than in the third SD.

Table 5. F values and averages for aboveground dry matter (ADM), number of pods per plant (NPP), 100-grain weight (100GW) and grain yield (GY) according to the treatments

Treatments	ADM (Mg ha^{-1})	NPP	100GW (g)	GY (Mg ha^{-1})
First growing season				
Sowing dates (SD)				
1st	3.88 a†	62 ab	13.83 b	2.84 a
2nd	3.63 b	66 a	13.94 b	2.97 a
3rd	3.62 b	50 b	14.95 a	2.13 b
LSD	0.08	15	0.81	0.24
Cycle (C)				
Extra-early	3.29 b	55 a	15.58 a	2.12 c
Early	3.93 a	62 a	13.91 b	3.24 a
Medium	3.90 a	62 a	13.23 b	2.57 b
LSD	0.10	9	0.87	0.19
F test				
p value (SD)	< 0.001	0.0449	0.0270	< 0.001
p value (C)	< 0.001	0.1626	< 0.001	< 0.001
p value (SD x C)	0.1898	0.1588	< 0.001	0.0430
CV (%) plot	1.84	19.32	5.68	9.04
CV (%) split-plot	2.77	14.68	7.12	8.67
Second growing season				
Sowing dates (SD)				
1st	3.12 a	54 ab	14.33 ab	2.82 b
2nd	3.19 a	67 a	13.97 b	3.82 a
3rd	3.21 a	50 b	14.44 a	2.33 c
LSD	0.63	13	0.44	0.30
Cycle (C)				
Extra-early	3.19 a	44 b	16.68 a	2.68 b
Early	3.42 a	63 a	13.34 b	3.28 a
Medium	2.92 a	63 a	12.72 b	3.01 a
LSD	0.68	14	0.63	0.31
F test				
p value (SD)	0.3223	0.0121	< 0.001	0.0027
p value (C)	0.9199	0.0488	0.0496	< 0.001
p value (SD x C)	0.1597	0.5534	0.0170	< 0.001
CV (%) plot	19.97	22.87	3.1	15.43
CV (%) split-plot	15.32	13.92	5.21	12.17

† Values followed by the different letters in the columns are statistically different at ($p < 0.05$) according to the LSD test

Moreover, in the second year, the NNP was higher in cultivars C2 and C3 than in C1.

GY was affected by the interaction between SDs and cultivars (Table 6). GY was comparatively higher in the second SD, and cultivar C2 presented the highest GY in both years. SD reduced the GY of all three cultivars, regardless of the duration of the growth cycle. Nonetheless, GY in the early and medium-cycle cultivars was higher than that in the extra-early cultivar (C1).

Similarly, for this cultivar, GY was highest in the second SD, especially in the second year, when GY was similar to that of C2 and higher than that of C3. SD strongly compromised GY in this cultivar, and should not be performed in practice. In contrast, long-cycle cultivars were more indicated for DS, as was the case for C2 and C3 in both growing seasons.

Among the sowing dates in our study, accumulated rainfall during the growth cycle was reduced as sowing was delayed, independent of the year (Figure 2), and was more pronounced in early- and medium-cycle cultivars, especially between the first and third SD.

Cultivars with longer growth cycles remained in the field for longer than early cycle cultivars and, consequently, had a higher capacity to recover from abiotic stresses, including water stress, leading to higher GYs (Silva et al., 2018a).

Table 6. Interactions between cultivar and sowing dates for weight of 100 grains (100GW) and grain yield (GY) in first and second growing season

Cultivar (C)	Sowing dates (SD) 1st	2nd	3rd	LSD
100GW (g) - First growing season				
C1	13.86 aB†	14.68 aB	18.21 aA	1.39
C2	13.42 aA	13.20 aA	13.01 bA	
C3	14.22 aA	13.96 aA	13.56 bA	
LSD		1.51		
GY (Mg ha^{-1}) - First growing season				
C1	2.33 bA	2.51 cA	1.50 cB	0.34
C2	3.63 aA	3.47 aA	2.62 aB	
C3	2.55 bB	2.92 bA	2.26 bC	
LSD		0.34		
100GW (g) - Second growing season				
C1	16.30 aB	16.22 aB	17.52 aA	0.96
C2	13.96 cA	12.52 bB	13.54 cA	
C3	12.75 bA	13.17 bA	12.25 bA	
LSD		1.10		
GY (Mg ha^{-1}) - Second growing season				
C1	1.92 cB	4.47 aA	1.67 bB	0.50
C2	2.93 bB	4.02 aA	2.88 aB	
C3	3.62 aA	2.96 bB	2.45 aC	
LSD		0.53		

† Values followed by the same lowercase letter in the columns and uppercase letters in the rows are statistically different at ($p < 0.05$) according to the LSD test

High temperatures occurred during soybean development, especially in the flowering and grain filling periods with late sowing, which may increase the probability of pod abortion (Awasthi et al., 2017) and photorespiration, ultimately leading to a decrease in the net concentration of photoassimilates directed to grain filling.

Conclusions

Our results demonstrated that delayed sowing changed less the phenological development of longer-cycle cultivar, being more indicated for late sowing. Regardless of the cultivar, the duration of the phenological cycle was strongly reduced by sowing dates and affected the plastochron index. The second sowing date was the optimum period for soybean cultivation in the studied latitude, resulting in higher grain yield.

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