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SOYBEAN YIELD AS A FUNCTION OF SOWING SEASON

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ABSTRACT

This study aimed to evaluate the grain yield of soybean cultivars as a function of different sowing seasons and soil types, in the Western region of São Paulo state. Two experiments were performed in the district of Gardênia, municipality of Rancharia-SP in two types of soil (Red Argisol with medium sandy texture and Red Nitosol with very clayey texture). For both studies, a randomized block design in a 5 x 2 factorial scheme arranged in strips was adopted. The factors consisted of five sowing seasons (October 21st; November 4th; November 18th; December 2nd and December 16th) and two soybean cultivars (TMG 7060 IPRO and TMG 7062 IPRO). The sowing seasons performed on October 21th and November 4th showed the highest rates of plant growth and grain yield, regardless of soil texture. Grain yield was similar among the cultivars studied in the Red Argisol with medium sandy texture. In the very clayey Red Nitosol, the TMG 7062 cultivar had higher productivity in the sowing of November 4th and the TMG 7060 cultivar in the sowings of November 18th and December 2nd.

COMPONENTES DE PRODUÇÃO E PRODUTIVIDADE DE CULTIVARES DE SOJA EM FUNÇÃO DA ÉPOCA DE SEMEADURA

RESUMO

O objetivo do trabalho foi avaliar a produtividade de grãos de cultivares de soja em função de diferentes épocas de semeadura e tipos de solo, na região Oeste do Estado de São Paulo. Foram conduzidos dois experimentos no distrito de Gardênia, município de Rancharia-SP em dois tipos de solo (Argissolo Vermelho de textura média arenosa e Nitossolo Vermelho de textura muito argilosa). Para os dois experimentos, adotou-se o delineamento em blocos casualizados em esquema fatorial 5 x 2 arranjado em faixas. Os fatores foram constituídos de cinco épocas de semeadura (21 de outubro; 04 de novembro; 18 de novembro; 02 de dezembro e 16 de dezembro) e duas cultivares de soja (TMG 7060 IPRO e TMG 7062 IPRO). As épocas de semeadura realizadas nos dias 21 de outubro e 04 de novembro apresentaram os maiores índices de crescimento de plantas e produtividade de grãos independente da textura do solo. A produtividade de grãos foi similar entre as cultivares estudadas no Argissolo Vermelho de textura média arenosa. No Nitossolo Vermelho de textura muito argilosa, a cultivar TMG 7062 teve maior produtividade na semeadura de 04 de novembro e a cultivar TMG 7060 nas semeaduras de 18 de novembro e 02 de dezembro.

SECTION EDITOR IN CHARGE

Michael Silveira Thebaldi

INTRODUCTION

Brazil is one of the largest soybean producers in the world, with annual production of 125.4 million tons of grain in an area of 40.5 million hectares (CONAB, 2022). In the last 20 years, there has been a 165% increase in soybean area cultivated in Brazil (CONAB, 2022). This increase was due to several factors, especially good market fundamentals, high liquidity, highly mechanized cultivation, low need for labor and a wide portfolio of available technologies. Furthermore, in the last decade, many areas occupied with perennial pastures, degraded or in degradation process, were cultivated with soybean (FRANCHINI et al., 2016).

Among several regions of Brazil, in São Paulo state there was a considerable increase in soybean cultivation, which had an increase of 34.5% in the cultivated area between 2000 and 2015 (IEA, 2016). The West region stood out due to the increase of 80% in the area planted with soybeans between 2012 and 2018. Soybeans in this region have been used mainly in the Integrated Crop-Livestock (ILP) system, as a strategy for the recovery of degraded pastures (MORO, 2018).

The success of this crop is directly dependent on its adaptation to the edaphoclimatic conditions of the growing region. Soybean is highly sensitive to the photoperiod, which is influenced by the latitude of the place. The adaptation of different cultivars to certain regions, beyond the water and thermal requirements, also depends on the photoperiod requirement, since sensitivity to photoperiod is a variable characteristic among soybean cultivars (FARIAS et al., 2009).

Therefore, the sowing season also influences the soybean development and yield, mainly due to the sensitivity to photoperiod. Depending on the sowing season, plant flowering can be anticipated or delayed, causing major changes in crop yield (BRACCINI et al., 2004; STÜLP et al., 2009; MEOTI et al., 2012). At the same time, the type of soil has a high participation in the productive potential, since soils of medium to sandy texture have low water retention (MORO et al., 2020). Thus, production environments that have soils with low water storage associated with inadequate sowing seasons can result in plants with reduced growth, resulting in low grain yield.

In this sense, more studies are needed on the soybean sowing season in the Western region of São Paulo in order to maximize agricultural yield of the producer. In addition, the definition of the best sowing season can help the producer in planning the area to be cultivated, avoiding the installation of the culture at seasons that are not recommended.

Thus, the objective of this study was to evaluate production and yield components of soybean cultivars according to different sowing seasons and soil types, in the Western region of São Paulo state.

MATERIAL AND METHODS

Two experiments were performed under field conditions in the district of Gardênia, municipality of Rancharia-SP from October 2016 to March 2017. The soils were classified as Red Argisol with medium-sandy texture in Experiment 1 and Red Nitosol with very clayey texture in Experiment 2. The experimental areas were located 18 km away from each other, in a region classified as Aw, according to the Köppen classification. The chemical attributes of the soil can be seen in Table 1.

Table 1. Soil chemical analysis in the layer from 0 to 0.2 m depth in two soil types. Gardenia District, Rancharia-SP (2018)

Experiment	pH	M.O.	P_{resina}	H+Al	Ca	Mg	K	SB	CEC	V
	$CaCl_2$	g dm^{-3}	mg dm^{-3}			mmol$_c$ dm^{-3}				%
Red Argisol	5.0	11.3	9.8	1.86	1.16	0.5	0.13	1.79	3.65	49
Red Nitosol	5.1	24.1	44.6	3.68	4.28	1.55	0.77	6.60	10.28	64.2

Clay content in the 0 - 0.8 m layer: Red Argisol (17.9%) and Red Nitosol (66.7%). pH (hydrogen potential); M.O. (organic matter); SB (sum of bases); CEC (cation exchange capacity); V (base saturation)

For both studies, a randomized block design in a 5 x 2 factorial scheme arranged in strips was adopted. The factors consisted of five soybean sowing seasons (October 21st; November 4th; November 18th; December 2nd and December 16th) and two soybean cultivars (TMG 7060 IPRO and TMG 7062 IPRO). The experimental plot consisted of 11 sowing lines spaced 0.45 m apart and 15 m long, with four repetitions per treatment.

Sowing took place in the direct sowing system under the corn crop residues and liming was performed in the crop prior to the experiment (2015/16). For both experiments, the seeder was adjusted to 11 seeds per meter with fertilization of 200.0 kg ha^{-1} of NPK 07-40-00 fertilizer with seeds treated through TSI (industrial seed treatment).

The TMG 7060 IPRO cultivar belongs to the relative maturity group 6.0, with indeterminate growth, a cycle of 110 to 120 days and the sowing recommendation for the region is between October 14th and November 30th. The TMG 7062 IPRO cultivar belongs to the relative maturity group (GMR) 6.2, with semi-determined growth, a cycle of 110 to 120 days and sowing recommendation between October 14th and December 7th. Weather conditions during the experimental period can be seen in Figure 1.

In both experiments, at the harvest time, five plants were collected per experimental plot to evaluate plant height (m), number of pods (NPP), grains (NGP) per plant and mass of 100 grains (g). Yield was evaluated by collecting 1.0 m^{-2} of plants using a template, in which the grain separation was performed manually with humidity standardization at 13%.

The results were submitted to analysis of variance and Tukey's mean comparison test ($p<0.05$) was performed using the SISVAR program, version 5.3 (FERREIRA, 2011).

RESULTS AND DISCUSSION

Experiment 01 – Red Argisol with medium-sandy texture

The sowing season presented an effect on all evaluated variables (Table 2). The cultivar effect occurred only on plant height and on the number of grains per plant. Sowing season x cultivar interaction was observed in plant height, number of pods (NPP) and grains (NGP) per plant and mass of 100 grains.
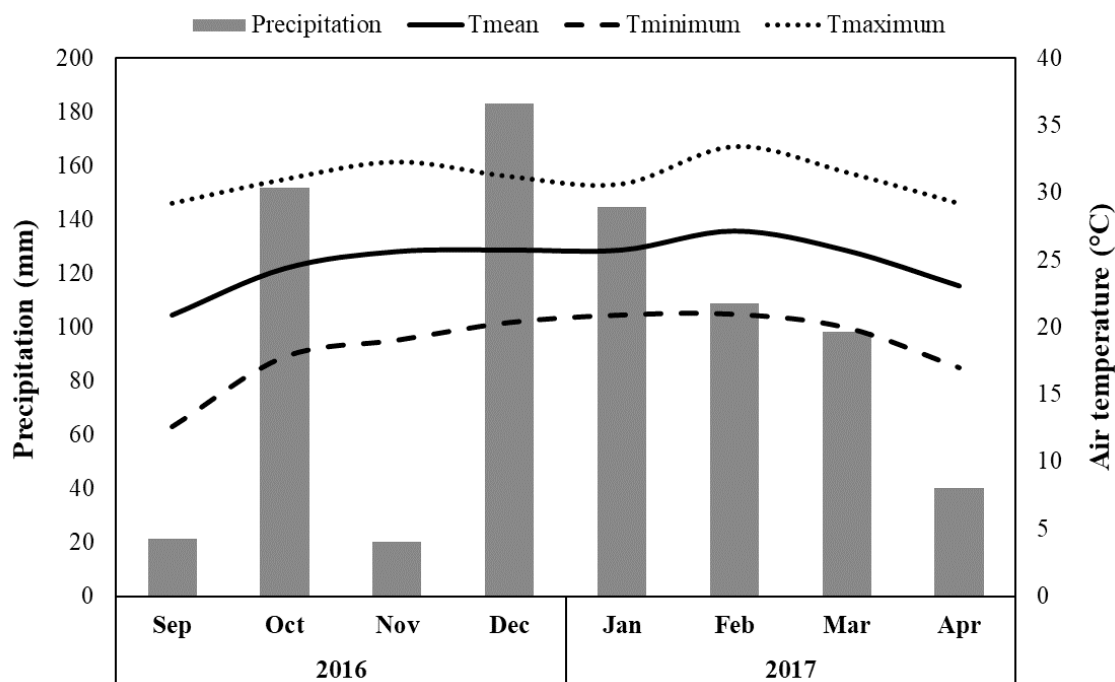

Figure 1. Precipitation (mm) and maximum (Tmaximum), minimum (Tminimum) and mean (Tmean) temperature of air (°C) from September 2016 to April 2017

Table 2. Analysis of variance of experiment 01 (sandy). Plant height (m), number of pods (NPP) and number of grains (NGP) per plant, mass of 100 grains (g) and grain yield (kg ha^{-1}) of two soybean cultivars (TMG 7060 and TMG 7062) in five sowing seasons. Gardenia District, Rancharia-SP (2018)

Treatments	Height	NPP	NGP	Mass of 100 grains	Yield
	(m)			(g)	(kg ha^{-1})
Season (S)	**	**	**	**	**
October 21st	0.91 A	63.77 AB	150.07 A	16.77 A	4,564.86 A
November 4th	0.85 A	77.87 A	189.40 A	16.04 A	4,577.59 A
November 18th	0.62 B	58.30 B	156.22 AB	14.45 B	4,009.56 AB
December 2nd	0.64 B	54.22 B	131.30 B	13.70 B	3,406.32 BC
December 16th	0.58 B	61.57 B	125.52 B	14.02 B	2,825.90 C
Cultivar (C)	**	ns	*	ns	ns
TMG7060	0.77 a	61.00 a	140.24 b	15.06 a	3,925.71 a
TMG7062	0.67 b	65.30 a	160.77 a	14.94 a	3,827.99 a
Interaction S x C	*	*	*	*	ns
CV (%)	8.45	15.79	17.05	4.87	15.74

Uppercase letters compare sowing seasons and lowercase letters compare cultivars. Means followed by the same uppercase or lowercase letter in the column do not differ statistically by the Tukey test at 5% significance level

Plant height of TMG 7060 and TMG 7062 cultivars reduced in sowing performed from November 18th. The average height of plants of the two cultivars was 0.91 and 0.85 m for sowings performed on October 21st and November 4th, respectively; and 0.62; 0.64; 0.58 m in sowing performed on November 18th; December 2nd and December 16th respectively. Regarding the cultivars, greater plant height was observed in the TMG 7060 cultivar in the sowings of October 21st, November 4th and December 16th (Table 3).

The NPP and NGP of the TMG 7060 cultivar were higher at sowing on November 4th compared to later seasons. Regarding the TMG 7062 cultivar, the NPP and NGP were similar at all sowing seasons. In relation to the difference between cultivars, it was observed that NPP was higher in TMG 7062 cultivar at sowing on December 16th and that NGP was higher in TMG 7062 cultivar at sowing on November 18th.

The mass of 100 grains of TMG 7060 cultivar was higher in sowings on October 21st and November 4th, with a reduction in sowings performed after November 18th. Regarding the TMG 7062 cultivar, the mass of 100 grains was higher in the sowing on October 21st compared to sowings after November 18th. Among the cultivars, at sowing on November 18th, the highest mass of 100 grains was obtained by TMG 7062 cultivar and at sowing on December 16th, by TMG 7060 cultivar.

Regarding grain yield, a reduction in yield in later sowing in both cultivars (TMG7060 and TMG7062) was observed (Figure 2). The highest grain yield of the TMG 7060 cultivar occurred in the first two sowing seasons, October 21st (4,703 kg ha^{-1}) and November 4th (4,706 kg ha^{-1}), in relation to the two later seasons, which were 3,225 kg ha^{-1} (December 2nd) and 3,151 kg ha^{-1} (December 16th).

In relation to the TMG 7062 cultivar, similar results were observed for the cultivar TMG 7060, in which there was a reduction in grain yield in the sowing performed at the later season, compared to the first three seasons. Grain yield from sowings performed on October 21st, November 4th, November 18th, December 2nd and December 16th were 4,425 kg ha^{-1}, 4,445 kg ha^{-1}, 4,180 kg ha^{-1}, 3,587 kg ha^{-1} and 2,500 kg ha^{-1}, respectively.

Table 3. Breakdown of the sowing season x soybean cultivars interaction in experiment 01 (sandy). Plant height (m), number of pods (NPP) and number of grains (NGP) per plant and mass of 100 grains (g) of two soybean cultivars (TMG 7060 and TMG 7062) in five sowing seasons. Gardenia District, Rancharia-SP (2018)

Sowing seasons	Cultivars	Height	NPP	NGP	Mass of 100 grains
October 21st	TMG 7060	1.00 Aa	65.50 ABa	150.95 ABa	16.72 Aa
	TMG 7062	0.82 Ab	62.05 Aa	149.20 Aa	16.83 Aa
November 4th	TMG 7060	0.94 Aa	81.60 Aa	196.25 Aa	16.27 Aa
	TMG 7062	0.76 Ab	74.15 Aa	182.55 Aa	15.81 ABa
November 18th	TMG 7060	0.62 Ba	56.90 Ba	122.55 Bb	13.76 Bb
	TMG 7062	0.62 Ba	59.70 Aa	189.90 Aa	15.15 Ba
December 2nd	TMG 7060	0.65 Ba	50.60 Ba	122.25 Ba	13.95 Ba
	TMG 7062	0.62 Ba	57.85 Aa	140.35 Aa	13.45 Ca
December 16th	TMG 7060	0.63 Ba	50.40 Bb	109.20 Ba	14.62 Ba
	TMG 7062	0.52 Bb	72.65 Aa	141.85 Aa	13.43 Cb

Uppercase letters compare sowing seasons and lowercase letters compare cultivars. Means followed by the same uppercase or lowercase letter in the column do not differ statistically by the Tukey test at 5% significance level
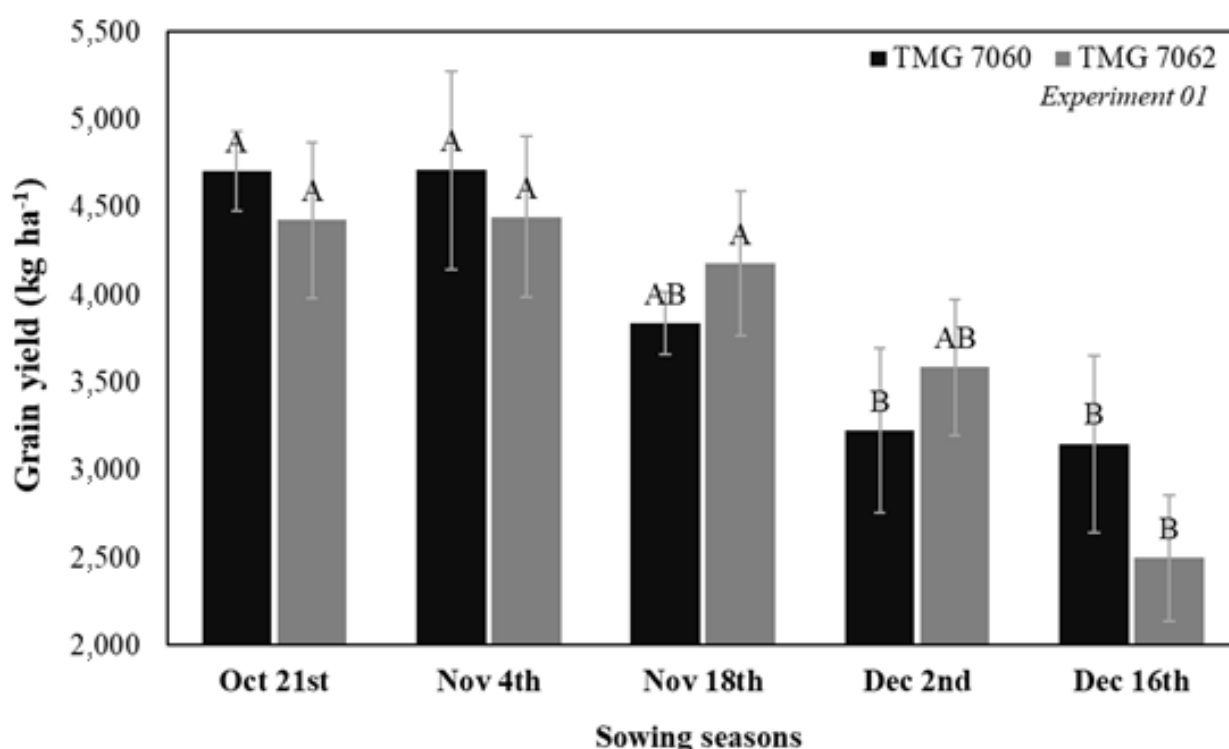

Figure 2. Grain yield (kg ha^{-1}) of two soybean cultivars (TMG 7060 and TMG 7062) in five sowing seasons. Gardenia District, Rancharia-SP. (Experiment 01). (Uppercase letters compare sowing seasons). Means followed by the same uppercase letter do not differ statistically by the Tukey test at 5% significance level

Experiment 02 – Red Nitosol with very clayey texture

In relation to experiment 02, the sowing season influenced plant height, NGP and mass of 100 grains. The cultivar interfered only in plant height and there was interaction between the factors only for grain yield (Table 4).

Regarding the sowing seasons, a reduction in plant height with the delay in sowing was observed. The height in the first planting dates was 1.01 m (October 21st) and 1.06 m (November 4th), with a decrease of approximately 0.25 m in the last sowing (December 16th), which reached plant height values of 0.75 m. A reduction in NGP and in the mass of 100 grains was also observed when late sowings were performed. Regarding the cultivars, a difference was verified only in the average height of plants of 0.97 m for the TMG 7060 cultivar and 0.91 m for the TMG 7062 cultivar.

The highest grain yield of the TMG 7060 cultivar occurred in the first and third sowing seasons (4,781 kg ha^{-1} on October 21st; and 4,740 kg ha^{-1} on November 14th), compared to sowings performed on December 2nd (3,731 kg ha^{-1}) and December 16th (3,052 kg ha^{-1}).

In relation to TMG 7062 cultivar, the highest yield occurred in the sowing performed on November 4th (5,191 kg ha^{-1}), with a significant yield reduction from the sowing performed on November 18th (3,791 kg ha^{-1}). The lowest yields of 2,993 and 3,382 kg ha^{-1} were observed in the sowings performed on December 2nd and December 16th, respectively.

Regarding the differences between the cultivars, on November 4th, the TMG 7062 grain yield was 18.4% higher than that of TMG 7060. In the sowing on November 18th and December 2nd, the TMG 7060 grain yield was 25.0% and 24.6% higher than that of TMG 7062, respectively.

In experiments 1 and 2, we can observe that the soybean yield components (plant height, NPP, NGP and mass of 100 grains) presented higher values in the first three sowing seasons (October 21st, November 4th and November 18th), with a reduction in late sowings (December 2nd and December 16th).

The reduction in soybean development in late sowings is related to the type of plant response to the environmental photoperiod. Several studies have shown that photoperiod is one of the environmental factors that most affect soybean development (RODRIGUES et al., 2001; WU et al., 2006; WU et al., 2015; YANG., 2019). Physiologically, soybean is classified as a short-day plant (PDC) (PURCELL et al., 2014) and they bloom when kept in photoperiods lower than the critical photoperiod

Table 4. Analysis of variance of experiment 02 (clay). Plant height (m), number of pods (NPP) and number of grains (NG) per plant, mass of 100 grains (g) and grain yield (kg ha^{-1}) of two soybean cultivars (TMG 7060 and TMG 7062) in five sowing seasons. Gardenia District, Rancharia-SP (2018)

Treatments	Height	NPP	NGP	Mass of 100 grains	Yield
	(m)			(g)	(kg ha^{-1})
Season (S)	**	ns	**	**	**
October 21st	1.01 A	59.75	123.92 AB	15.74 A	4,648.72 A
November 4th	1.06 A	57.47	137.50 A	15.39 A	4,787.62 A
November 18th	0.95 B	49.7	109.97 B	14.97 A	4,266.04 A
December 2nd	0.93 B	55.87	109.10 B	13.09 B	3,362.61 B
December 16th	0.75 C	54.72	103.95 B	11.91 B	3,217.87 B
Cultivar (C)	**	ns	ns	ns	ns
TMG 7060	0.97 a	55.20 a	112.60 a	14.24 a	4,138.10 a
TMG 7062	0.91 b	55.81a	121.52 a	14.20 a	3,975.04 a
Interaction S x C	ns	ns	ns	ns	**
CV (%)	3.90	13.70	16.11	6.27	10.96

Uppercase letters compare sowing seasons and lowercase letters compare cultivars. Means followed by the same uppercase or lowercase letter in the column do not differ statistically by the Tukey test at 5% significance level
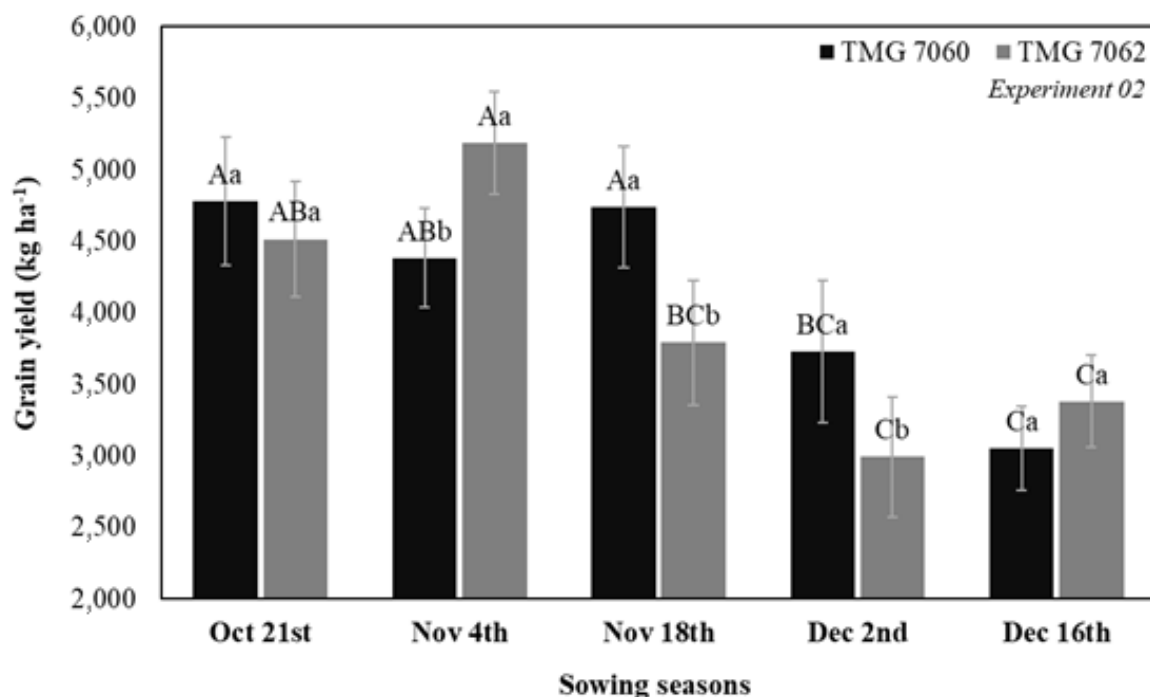
Figure 3. Grain yield (kg ha⁻¹) of two soybean cultivars (TMG 7060 and TMG 7062) in five sowing seasons. Gardenia District, Rancharia-SP. (Experiment 02). (Uppercase letters compare sowing seasons and lowercase letters compare cultivars). Means followed by the same uppercase or lowercase letter do not differ statistically by the Tukey test at 5% significance level

(VAZ et al., 2019). Critical photoperiod refers to a certain number of hours of light, in which below or above this number, the plant is induced to blossoming. This value is characteristic of each species and even of each cultivar within the species (CAMARA and HEIFFIG, 2000).

The yield variation of different cultivars in a given region also occurs as a function of the photoperiodic requirement of the genotype. Photoperiod sensitivity is a variable characteristic among cultivars, which means that each material has its own critical photoperiod (FARIAS et al., 2009). Due to this photoperiod sensitivity of each cultivar and its interactions with the environment, especially the photoperiod of each region, cultivars have been classified into relative maturity groups (RMG) (ALLIPRANDINI et al., 2009; ZANON et al., 2015).

In this study, the yield variation may be related to the classification of cultivars according to the GMR, in which the TMG 7060 cultivar is classified as GMR 6.0 and TMG 7062 cultivar is classified as GMR 6.2. The GMR is the duration of the soybean development cycle (from seeding to physiological

maturity), being determined by the response to photoperiod, management practices and general area of adaptation of soybean cultivars. This new classification in GMRs allowed to represent in a more realistic way the factors that affect the duration of the development cycle (BEXAIRA et al., 2018).

In São Paulo state, soybean sowing is recommended between September and December (CONAB, 2019). However, our results show a reduction in plant development and yield for sowings performed from December onwards with TMG 7060 and TMG 7062 cultivars in the West of the state, in both types of soil (Experiment 1 and Experiment 2).

In the Southern Hemisphere, the spring equinox occurs around September 23rd. The photoperiod increases daily from spring onwards, reaching its maximum value on December 22nd (summer solstice), where the day with the longest photoperiod of the year is observed and extends until December 31st. The photoperiod reduction begins from January onwards (PEREIRA et al., 2007). Sowing performed between September and November promotes greater vegetative growth

of plants, which increases their leaf area and the number of ramifications, thus increasing the number of nodes, where flowers will be formed in the future.

Therefore, under conditions of favorable water availability, the greater number of nodes favors the insertion of the raceme with the pods, resulting in the greatest potential for grain yield. In late sowings, the plant will have a shorter period of vegetative growth, so blossoming will occur more quickly, which in turn will result in plants with low yield potential due to smaller branching and leaf area. Such effects were observed by several authors in late sowings of soybean (MARTINS et al., 1999; PEIXOTO et al., 2000; BRACCINI et al., 2004; MEOTTI et al., 2012).

The lower biometric development of plants resulted in lower grain yield. The average yield reduction in sowings performed in December when compared to the first three sowing seasons was 27.9% and 28.9% in experiments 1 and 2, respectively. The reduction in soybean grain yield was observed by several authors, being in the order of 48.0% (BRACCINI et al., 2004), 57.8% (RODRIGUES et al., 2008), 72.8% (STÜLP et al., 2009) and 30.6% (SILVA et al., 2018).

The production components NPP and NGP of the TMG 7062 cultivar were not influenced by the sowing season in experiment 01. However, a reduction of 20% in the mass of 100 grains was observed when comparing the first and the last sowing season. According to Zanon et al. (2018), the mass of 100 grains is a primary production component and any change directly impacts soybean yield. Therefore, although there was no change in NPP and NGP, the reduction in the mass of 100 grains contributed to the reduction of grain yield.

Another factor that deserves attention in relation to sowing season is water availability. According to Figure 1, the months of December and January had good water availability, with an average of 180 and 140 mm, respectively. These months coincided with the bloom period and grain filling of the sowings performed between October and early November, favoring the water supply to the plant. On the other hand, in the late sowings occur drops in the water supply to the plants, caused by the reduction of precipitation.

At the same time, the type of soil had a strong influence on the yield rates, as the average yields for the sowing seasons were 3.876 kg ha^{-1} and 4.052 kg

ha^{-1}, respectively for the medium-sandy textured soil area (Experiment 1) and clayey soil (Experiment 2), respectively. Sandy soils have lower water retention, accentuating the degree of water deficit, especially in regions with a history of dry spells, such as the West Paulista region (MORO et al., 2020), making the productive success of the crop even more dependent on the proper sowing season.

CONCLUSIONS

- Sowing performed between October 21th and November 4th promoted higher components of production and yield of soybean grains regardless of soil texture. Grain yield was similar among the cultivars studied in the Red Argisol with medium-sandy texture. In the very clayey Red Nitosol, the TMG 7062 cultivar had higher yield in the sowing of November 4th and the TMG 7060 cultivar had higher yield in the sowings of November 18th and December 2nd.

AUTHORSHIP CONTRIBUTION STATEMENT

BARBOSA, A.M.: Conceptualization, Formal Analysis, Methodology, Writing – original draft; **SILVA, G.B.:** Data curation, Formal Analysis, Methodology; **SANTOS, S.E.S.:** Data curation, Formal Analysis, Methodology; **CATUCHI, T.A.:** Conceptualization, Writing – original draft; **TIRITAN, C.S.:** Conceptualization, Writing – original draft.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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