Revista em Agronegócio e Meio Ambiente - RAMA
DOI:10.17765/2176-9168.2023v16n2e10012
e-ISSN 2176-9168
Agronegócio

Sowing date and soybean maturity group effects on soybean-corn succession

Data de semeadura e grupos de maturação da soja na sucessão soja-milho

Karine Fuschter Oligini[1], Paulo Fernando Adami[2], Carlos André Bahry[3], Vanderson Vieira Batista[1], Laércio Ricardo Sartor[3], Alvadi Antonio Balbinot Junior[4]

ABSTRACT: This study evaluated the effects of sowing dates and maturation group of soybean on soybean-corn succession in the Southwestern of Paraná state, Brazil, at the 2016/17 and 2017/18 growing season. Experiment was laid out as a randomized complete block design in a 3×3 factorial scheme with three replications, being factor A three soybean cultivars with different maturation group and factor B three soybean sowing dates. Corn sowing periods (nine at total) was a consequence of the soybean harvest date. Soybean cultivars with a maturation cycle between 5.1 and 5.3 sowed in mid-September resulted in better corn performance, but worse technical feasibility for the soybean-maize succession in relation to its sowing on the beginning of October, which results in better total grain yield. Soybean cultivar with maturity group 6.0 was a good option for the mid-September sowing. Soybean sowing in mid-October did not increase its yield and reduce the corn yield.

Keywords: *Glycine max. Zea Mays* L. Early sowing. Yield.

RESUMO: Este estudo avaliou os efeitos das datas de semeadura e do grupo de maturação da soja na sucessão soja-milho no sudoeste do Paraná, Brasil, nas safras 2016/17 e 2017/18. O experimento foi conduzido em delineamento de blocos ao acaso, em esquema fatorial 3 × 3, com três repetições, sendo o fator A três cultivares de soja com diferentes grupos de maturação e o fator B três datas de semeadura. O período de semeadura do milho (nove no total) foi consequência da data da colheita da soja. As cultivares de soja com ciclo de maturação entre 5.1 e 5.3 semeadas em meados de setembro resultaram em melhor desempenho do milho, porém reduziram a viabilidade técnica da sucessão soja-milho em relação à sua semeadura no início de outubro, que resultou em maior rendimento total de grãos. O uso de cultivares de soja de ciclo de maturação 6.0 apresenta-se como uma opção adequada para a semeadura em meados de setembro. A semeadura da soja em meados de outubro não aumentou sua produtividade e reduziu a produção de milho.

Palavras-chave: *Glycine max. Zea Mays* L. Semeadura precoce. Produtividade.

Autor correspondente: Karine Fuschter Oligini
E-mail: karine_oligini@hotmail.com
Recebido em: 01/04/2021
Aceito em: 23/06/2022

INTRODUCTION

Soybean-corn succession is the most adopted cropping system in the Brazilian Midwest, some regions of Southeast and West and North of Paraná state. However, in the South of Paraná, Santa Catarina and Rio Grande do Sul states, this cropping system is still not an option for most

[1] Doutorandos do Programa de Pós-graduação em Agronomia (PPGAG) da Universidade Tecnológica Federal do Paraná (UTFPR), Pato Branco (PR), Brasil.
[2] Docente do Programa de Pós-graduação em Agronomia (PPGAG) da Universidade Tecnológica Federal do Paraná (UTFPR), Pato Branco (PR), Brasil.
[3] Docentes da Universidade Tecnológica Federal do Paraná (UTFPR), Dois Vizinhos (PR), Brasil.
[4] Chefe Adjunto de Pesquisa e Desenvolvimento Embrapa Soja (CNPSO), Londrina (PR), Brasil.

farmers, since low temperature and frost risks are significant. Although the system has been adopted, there is a need to study the best combination between soybean cycle and sowing period aiming to improve the soybean-corn succession. This cropping system increases the utilization of resources (e.g. land, labor, and machinery, etc.) and enables no-till by keeping the soil covered throughout the year.

Moreover, new early maturing soybeans cultivars of indeterminate growth and shorter corn cycle recently launched into the market have increased the possibility of soybean-corn succession adoption at the Brazilian southern. In this way, it is essential to understand how these cultivars behave at different sowing periods, especially considering different maturation group and its effects on corn to optimize the soybean-corn system.

Earlier soybean sowing (mid-September) may affect crop yield once it is more prone to adverse climate conditions, such as low temperature. Moreover, shorter photoperiod may reduce vegetative phase stages, which may affect plant development and its final yield (NÓIA JUNIOR, SENTELHAS, 2019). On the other hand, later soybean sowing increases the risk of disease (*Phakopsora pachyrhizi* Syd. & P. Syd.) and insect pest (*Euschistus heros* Fabricius) pressure.

The study takes the premise that as early as soybean maturation group (5.1–5.3) is sowed, higher is the corn yield, grown as a second summer crop. Although this increase on corn yield may not compensate soybean yield losses when sowed at mid-September. Furthermore, longer soybean maturation group cultivars (6.0-6.3) sowed earlier has higher yield potential than short cycle cultivars, once it has more time to compensate bad weather conditions and to suffer less from short photoperiod.

In this context, it is necessary to adjust the sowing dates of soybeans according to the maturation group of the cultivars considering both crops (soybean and corn) and not only one of them (DO CARMO *et al.,* 2018). Braccini *et al.* (2010) studying the soybean-corn succession on western region of Paraná, reported that the system becomes feasible only if soybean sowing is carried out in October and corn sowing in February, being the yield strongly related to the used soybean cultivars. Likewise, Garcia *et al.* (2018) observed at Southern region of Mato Grosso do Sul that soybean sowing from late September and early October showed higher yields, allowing corn sowing in mid-February.

It is worth noting that these studies were carried out at different regions and these observations do not apply to all regions since soybean maturation cycle is affected by the photoperiod and temperature and this differs among regions. Therefore, it is necessary to define these aspects for each region, relating the maturation cycle to the site of sowing and thus understanding this effect on soybean yield and beyond on soybean-corn succession yield (SOUZA *et al.,* 2015).

This study evaluated the effects of sowing dates and maturation group of soybean on soybean-corn succession in the Southwestern of Paraná state, Brazil.

2 MATERIAL AND METHODS

The study was carried out at UTFPR agronomy experimental area, located at 25º 42' 52" S,53º 03' 94" W and 520 m above sea level, Paraná state, Brazil, at the 2016/17 and 2017/18 growing season. Soil has been manage in a no-tillage system since 2001.According to the Köppen classification, the climate is Cfa (ALVARES *et al.*, 2013) with mean annual rainfall of 2000 mm. Soil at the experimental site is classified as Red Latosol (BHERING *et al.*, 2013). Data for rainfall, temperature, and radiation during the study are shown in Figure 1.

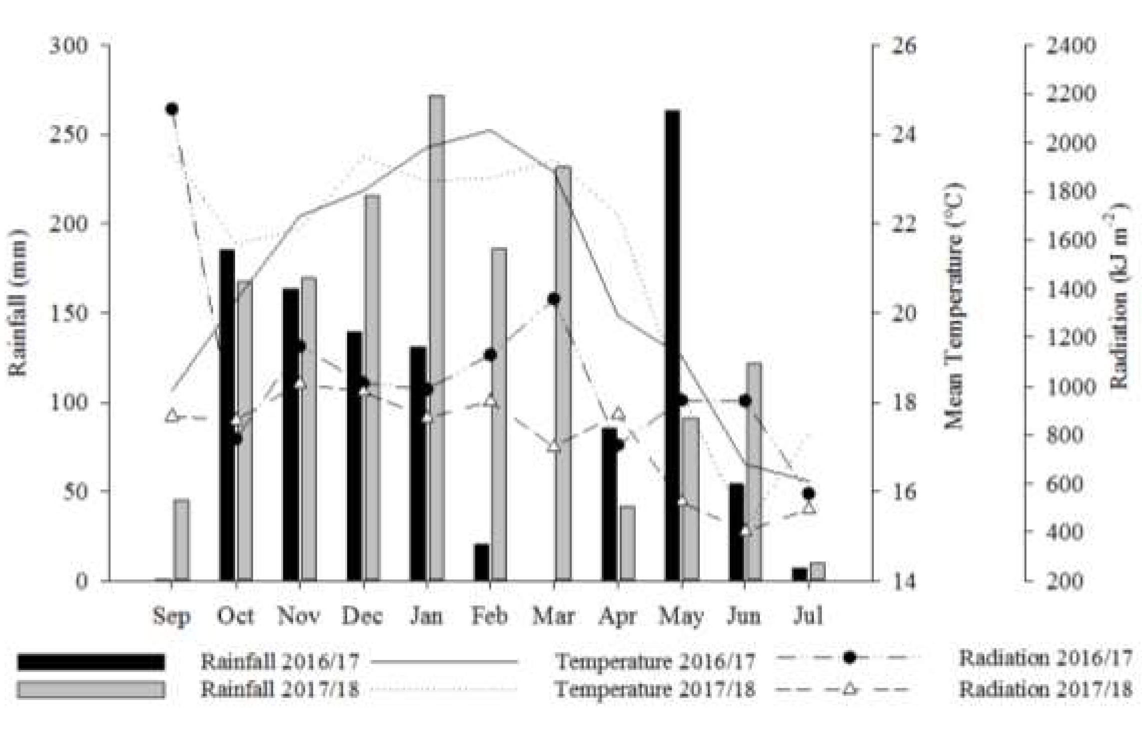

Figure 1. Mean temperature (°C), solar radiation (KJ m^2) and rainfall (mm) data observed along the experimental period at 2016/17 and 2017/18 growing season. INMET - National Institute of Meteorology, Automatic Station at Dois Vizinhos - PR, Brazil, 2021

Soil chemical analysis was performed before treatments establishment collecting a soil sample from a 0 to 20 cm depth layer. The results obtained were: organic matter - 41.1 g dm^{-3}; P-Mehlich: 11.3 mg dm^{-3}; K: 0.18 cm1$_c$dm^{-3}; pH - 5.1; V - 58.8%.

The trial was laid out as a randomized complete block design in a 3×3 factorial scheme with three replications. Factor A was related to three soybean cultivars: P95Y72 RR® (MG = 5.0), P95R51 RR® (MG = 5.1) and P95Y52 RR® (MG = 5.3) in the 2016/2017 growing seasons.

There was a change on experimental treatments at the 2017/2018 growing season (2nd year), being the P95Y72 RR® soybean cultivar switched for the P96Y90 RR® (MG= 6.0). Factor B was related to three soybean sowing periods: period 1 - mid-September (09/12 to 09/15); period 2 - the beginning of October (10/01 to 10/03); and period 3 – mid-October (10/11 to 10/14).

Soybean cultivars were sown with a seed rate of 20, 15.6, and 13.7 seeds m^{-1} respectively for mid-September, beginning of October and mid-October for all cultivars, according the technical indications. Cultivar P96Y90 RR® was sowed at a density of 13.2 seeds m^{-1} at the first two periods and with 14 seeds m^{-1} for the last season. Both crops (soybean and corn) were sowed in no-till system. Experimental units consisted of 10 rows (0.45 m apart) of 30 m long.

Soybean soil fertilization was performed using a phosphorous source know as Top-Phos® (23% of P_2O_5) at a rate of 350 kg ha^{-1}. Potassium was broadcast at the sowing day using 120 kg of Kcl per ha^{-1} (60% of K_2O) aiming to produce 5 Mg ha^{-1} of grains. At both growing seasons, soybean prior crop was black oat (*Avena strigosa*).

Aiming to uniform maturation and have an earlier harvest, soybean was desiccated with 400 g a.i of paraquat (200 $g.L^{-1}$) at the soybean phenological stage R7.2. Harvesting was performed between seven and nine days after soybean desiccation, and then yield components and final yield was assessed.

Harvesting took place at an average of 122 to 128 days after emergence with cultivars P95Y72, P95R51, P95Y52 and 140 days with P96Y90. At harvest, based on a sample of 10 plants per plot, the total height of plants (cm) and thousand-grain weight (TGW) were determined.

Soybean was manually harvest in two samples of three rows with 5 meters long (sample area 6.75 m^2 per point) per plot. Total area of the plot was also harvested manually, threshed and biomass/straw spread evenly over the plot. Moisture content of the seeds was evaluated using the oven-drying method at 105 ºC for 24h and TGW and final yield ($kg.ha^{-1}$) were adjusted to a moisture content of 13%.

Corn (Hybrid P3431VYH used at both years) sowing periods (nine at total) was a consequence of soybean harvest with differed according to soybean maturation group. Corn sowing was performed at the same day, as soybean was harvest in both years, with a seed density of 66,000 seeds ha^{-1}.

At both growing seasons, corn fertilization consisted of 327 $kg.ha^{-1}$ of 02-18-18 (N-P_2O_5-K_2O) applied to the sowing furrow opener. Nitrogen (100 kg ha^{-1}) was sidedress at V3-V4 phenological stage, using urea as a source (46% of N) in order to reach 9,000 kg ha^{-1}.

Regarding to corn traits, were evaluated: number of grains per row (NGR) (in 10 ears per plot), thousand grains mass (corrected for moisture content of 13%) and height of first ear.

Corn yield was assessed by harvesting two samples per plot collecting the ears at three central rows of the plot 5 m long. Corn was harvest at later June and beginning of July at both growing seasons and grain yields were adjusted to a moisture content of 13%.

The data were submitted to analysis of variance using the F test (p<0.05) and the means compared by the Tukey test (p<0.05), using the Sisvar® statistical software (FERREIRA, 2011).

3 RESULTS AND DISCUSSION

Weather conditions allowed good and quickly seed emergence for both crops and growing seasons. There were significant effects and interactions between sowing dates and soybean genotypes for several variables. Soybean genotypes sown at the beginning of October had higher average heights when compared to the genotypes sown in September (Table 1).

Table 1. Plant height (cm) and thousand grain - weight (g) of three soybean cultivars grown at three sowing periods at 2016/17 and 2017/18 growing season at Dois Vizinhos - PR, Brazil

GS[1]	SC[2]	Plant height (cm)			TGW (g)		
		----------------------Sowing dates---------------------					
		Mid-September	Early October	Mid-October	Mid-September	Early October	Mid-October
2016/17	P95Y72	68.6 Ab[3]	77.8 Aa	74.3 Bab	186.6 Aa	180.0 Aa	183.3 Ba
	P95R51	66.6 Ab	80.9 Aa	79.6 Aba	180.0 Ab	156.6 Bc	200.0 Aa
	P95Y52	69.3 Ac	77.8 Ab	82.9 Aa	180.0Ab	173.3ABb	196.6 Aa
CV (%)			2.6			2.48	
2017/18	P95R51	54.1 Bc	85.4 Bb	106.3 Ba	141.1 Bb	134.1 Bb	186.5 Aa
	P95Y52	59.1 Bc	89.6 Bb	103.2 Ba	167.9 Aa	186.5 Aa	200.1 Aa
	P96Y90	117.1 Ab	137.3 Aa	136.3 Aa	138.9 Ba	139.5 Ba	127.5 Ba
CV (%)			3.38			4.86	

[1]GS: Growing season; [2]SC: soybean cultivars; [3]Means in the same row followed by different lowercase letters and in the column followed by capital letters differ by Tukey test at 5%.

Soybean plant behavior may be explained by both temperature and photoperiod effects. Lower or milder temperatures at September, with averages below 10 °C (Figure 1) may have affected soybean growth. Thus, daylight length increases from July to December. According to Sediyama, Silva, Borém (2015), short daylight at September may stimulate earlier soybean flowering, resulting in shorter plants with less number of reproductive nodes, number of pods per plant and, consequently, lower grain yield.

These findings are consistent with those reported by Braccini *et al.* (2010), which also reported shorter soybean plants when sown in September compared to the later sowing being the plant growth reduction attributed to low temperature and reduced. Meotti *et al.* (2012)

studying the effect of sowing periods on six soybean cultivars in the state of Santa Catarina, reported that weather conditions such as temperature, solar radiation, and photoperiod allowed better growth traits and soybean development to the October sowing period.

Soybean cultivar P96Y90 used in the 2017/2018 growing season showed a strong relationship between maturation groups (MG) and final plant height. This cultivar with MG of 6.0 presented the highest average height independent of sowing period, showing that its longer cycle allows plants to grow taller which also shows a smaller influence of the photoperiod.

Soybean thousand grain-weight was affected by sowing dates (Table 1) which may be explained by climatic conditions. Cultivar P95R51, showed for both years, lower TGW when sowed at the beginning of October, although, this productive yield component might have been offset by other yield components since grain yield was higher at this sowing period (Table 2).

Table 2. Soybean grain yield (kg ha^{-1}) of three soybean cultivars grown at three sowing periods at 2016/17 and 2017/18 growing season at Dois Vizinhos - PR, Brazil

GS[1]	SC[2]	Soybean yield (kg ha^{-1})		
		----------Sowing dates----------		
		Mid-September	Early October	Mid-October
2016/17	P95Y72	3,358 Bb[3]	3,772 Ba	4,075 Ba
	P95R51	4,124 Aa	4,468 Aa	4,065 Ba
	P95Y52	4,196 Ab	4,423 Ab	5,014 Aa
CV (%)			4.2	
2017/18	P95R51	3,399 Bb	5,841 Aa	5,184 Aa
	P95Y52	4,697 Aba	5,596 Aa	4,778 Aa
	P96Y90	5,972 Aab	6,205 Aa	4,917 Ab
CV (%)			5.2	

[1]GS: Growing season; [2]SC: soybean cultivars; [3]Means in the same row followed by different lowercase letters and in the column followed by capital letters differ by Tukey test at 5%.

Soybean cultivar P95Y52 presented the most stable TGW along the sowing dates and growing seasons, while cultivar P95R51 showed a greater variation for this variable, with lighter TGW for the 2017/18 in relation to the prior growing season. This result may be explained due to environmental growing conditions, such as reduced water availability, which has an impact on photosynthesis rates and reduces the accumulation of photoassimilates (HEIFFIG *et al.*, 2006; NÓIA JÚNIOR *et al.*, 2018). On the other hand, P96Y90, showed the lowest average of TGW, with a mean of 135.3 g, without differences among sowing periods (Table 1). Longer maturation group, taller plants and a higher number of pods and grain per plant of this cultivar may explain lower TGW of this cultivar, without however affect grain yield.

Soybean cultivars P95R51 and P95Y52 sowed in mid-October showed a tendency of heavier grains (TGW), both in 2016/17 and 2017/18. Bornhofen *et al.* (2015), evaluating four sowing periods and six soybean cultivars with different maturity group showed that the thousand grain-weight was strongly influenced by the sowing season and genetic constitution of the cultivars. Spader and Deschamps (2015) also observed similar effects on this variable when studying soybean cultivars with different sowing periods and plant densities.

There was a strong relationship between sowing period and soybean maturity group for the first sowing period (mid-September), in a way that grain yield increased as long as the maturity group of the cultivars increased. These differences are so evident, that cultivar P96Y90 yielded 2,573 kg. ha^{-1} more than P95R51.

Furthermore, it is noticed for the first sowing period that grain yield differences between cultivars are reduced as maturity group of cultivars get closer and there may even be no differences, as observed between cultivar P95R51 and P95Y52 (mean of 10 days of difference between cultivars harvest time). The difference for the same comparison between years is due to climatic conditions (drought in September of the second growing season).

Grain yield differences among cultivars at the 2nd sowing period showed a similar tendency reported for the first one, but grain yield differences among cultivars tend to be reduced, once climatic conditions (photoperiod and temperature) allows better plant development, affecting more the shorter maturity group soybean cultivars. The same observation is valid to the 2nd growing season, where soybean grain yield was similar at the 2nd sowing period.

Soybean grain yield at the 3rd sowing dates differed between cultivars at the 1st growing season and showed similar results at the 2nd growing season, where yields were higher than the first year. In this case, shorter maturity group cultivar may escape from higher disease pressure of *Phakospera pakhiryzi,* while longer maturity group tends to suffer more with disease and the neotropical brown stink bug (*Euschistus heros Fabricius*) pressure as reported by Garcia *et al.* (2018). Furthermore, better weather conditions of the second year may explain higher yields.

When compared soybean cultivars within the sowing periods, it is possible to observe that P95Y72 sowed in mid-September showed lower yield than when sowed in October (Table 2). This result is attributed to longer photoperiod and higher temperatures of October, which allows better growth and plant development, resulting in higher yield. These differences tend to be reduced for longer maturity group cultivars, once they compensate growth due to longer vegetative stage.

Cultivar P95R51 showed lower grain yield at the 2nd crop year in relation to the first year to the September sowing period. It is important to report that plant vulnerability to biotic effects reduces as plant maturity group increases and this fact may explain higher yield of the other cultivars from the same sowing period (early September).

Soybean yield in the second year (2017/2018), showed higher values than the first year, especially when soybean was sowed at the beginning of October (Table 2). High precipitation rates, especially in December and January (Figure 1), which coincided with an important phenological stage of soybean (flowering period) contributed to the higher yields.

The highest yield was achieved at the 2017/18 crop season with the P96Y90 cultivar sown at the beginning of October (Table 3). Longer cycle (GM 6.0) allows the soybean plants to recover from possible damage and generate high yields. However, harvesting took place 15 days after other cultivars sowed in the same period. Later sowing on October of later maturity group cultivars turn out as latter harvest, what exposes the cultivars to higher diseases and pests pressure. This cultivar also showed very good performance when sowed at the mid-September, which also allows corn sowing within the agroclimatic zoning (February 20th) and turns out with a satisfactory production (6,869 kg ha^{-1}) (Table 3).

Table 3. Corn yield components in relation to different sowing periods at the 2016/17 and 2017/18 growing season at Dois Vizinhos-PR, Brazil

GS[1]	MSD	After Soybean	NGR	TGW (g)	SHI (cm)	YIELD (kg ha^{-1})
	1-01/16/2017	1ºSC-95Y72	39.5 a[2]	360.6 a	0.98 ab	9,385 a
	2-01/22/2017	1ºSC-95R51	38.0 ab	365.8 a	1.01 a	9,204 a
	3-01/26/2017	1ºSC-95Y52	36.6 ab	343.4 a	0.98 bc	8,450 ab
	4-01/30/2017	2ºSC-95Y72	36.7 ab	355.3 a	0.98 ab	7,692 ab
2016/17	5-02/06/2017	2ºSC-95R51	36.6 ab	336.8 a	1.01 a	6,616 bc
	6-09/02/2017	2ºSC-95Y52	37.3 ab	328.2 ab	1.03 a	6,477 bc
	7-02/15/2017	3ºSC-95Y72	35.1 bc	229.3 c	0.82 e	2,577 d
	8-20/02/2017	3ºSC-95R51	32.1 d	210.8 c	0.85 cd	2,316 d
	9-02/23/2017	3ºSC-95Y52	35.3 bc	269.1 bc	0.84 cd	4,770 c
	CV (%)		3.73	11.41	5.57	2.81
	1- 23/01/2018	1º SC-95R51	38.0 a	347.0 a	0.90 a	8,461 a
	2- 06/02/2018	1º SC-95Y52	37.3 ab	312.6 b	0.80 ab	7,208 ab
	3- 09/02/2018	2º SC-95R51	36.2 ab	326.5 b	0.76 bc	7,608 ab
	4- 15/02/2018	2º SC-95Y52	36.1 ab	313.3 b	0.73 bc	7,039 ab
2017/18	5-18/02/2018	1º SC-96Y90	35.6 ab	311.3 b	0.75 bc	6,869 bc
	6-23/02/2018	3º SC-95R51	35.3 bc	276.8 c	0.73 bc	6,121 c
	7- 28/02/2018	3º SC-95Y52	34.5 c	254.5 d	0.67 c	6,046 c
	8-03/03/2018	2º SC-96Y90	32.2 d	220.1 e	0.62 c	5,670 c
	9- 15/03/2018	3º SC-96Y90	30.8 d	210.8 e	0.60 c	4,800 d
	CV (%)		3.08	2.01	4.38	6.77

[1]GS: Growing season; SC: Soybean cultivar; CSD: Corn sowing date; NGR: Number of grains per row; TGW: Thousand-grain weight; SHI: Spike height insertion; [2]Means followed by the same letter do not differ by Tukey test, 5% probability

Grain yield results from P95R51 and P95Y52 cultivars at the 2016/17 and 2017/18 growing season showed them to be good options for early October sowing periods and, depending on the year and the expected value paid for commodities, are suitable cultivars for the soybean-corn double summer crop arrangement (Table 2). P95Y52 cultivar showed certain productive stability (mean of 4,446 kg ha^{-1}) in relation to the agricultural years when sowed in September. In addition, it allows corn sowing at the beginning of February, which enables good corn development and grain yield (6,912 kg ha^{-1}) (Table 3). Garcia *et al.* (2018) reported similar results, with soybean genotypes showing better productive performance when sown in early October, not justifying early sowing for short cycle cultivars.

Thus, there is a tendency of higher grain yield of soybean sowed at the beginning of October in relation to the sowing at mid-September. In this case, it is suggested the sowing of cultivars P95Y72, P95R51, and P95R52 at the beginning of October, which allows corn sowing at 01/30, 02/02, and 02/15. Similarly, soybean cultivar P96Y90 sowed in mid-September (Table 2) allows corn sowing on 02/21 (Table 3), which also allows good corn yield results. Therefore, it is recommended to the farmers to adopt the best combination (maturation group and sowing season) in most of his areas, but, at the same time, it is suggested a combination of more than one cultivar to reduce production risks.

Soybean sowing at the middle of October did not increase its yield in relation to the sowing at the beginning of October (except for P95Y52 at the first growing season) (Table 2). On the other hand, this sowing period turns corn second summer crop unfeasible, once its sowings periods happen in the second half of February (outside of crop zoning/not allowed agricultural financial), increasing corn productions risks (frosts) and affecting its yields due to worsen weather conditions (shorter days with lower mean temperature and solar radiation – Figure 1).

Regarding the corn yield components, according to Balbinot Júnior *et al.* (2005), the number of grains per row is one of the most significant yield components of grain yield definition. At the experiment, this variable decreased as sowing period was delayed at both growing seasons (Table 3). As time pass by, from January to June, days get shorter, temperature and solar radiation decreases (Figure 1) and these weather conditions may impair plant growth, resulting in lower leaf area and photosynthesis index, what turns out as lower grains per rows.

Regarding to the corn TWG at the first growing year (Table 3), sowing from 01/16 up to 30/01 did not differ from each other, decreasing as time pass by, being 73 g lighter at early February. From the first sowing period (01/16) to the last one (02/23), TGW decreased 25%. Plant lodging (due to strong wind) resulted in lower TGW at the 7th and 8th sowing period in relation to the 9th sowing period. A similar trend was reported at the 2nd growing season to the TGW, where there was a 40% decrease on the TGW when comparing the 1st and 9th sowing period (from 01/23/18 to 03/15/18). Later sowing periods at this growing seasons (sowing at March) help to explain the differences between years. TGW had a greater contribution to grain yield reduction.

According to Magalhães *et al.* (2002), TGW is the grain yield component that most limits corn yield since it is highly influenced by the photosynthetic rate, as well as, temperature, water availability, and incident solar radiation. Thus, cloudy days (normal at autumn/winter) may reduce light intensity by 30 to 40%, directly affecting photosynthesis, what in turn lead to delays in maturation and lower grain yield (CRUZ *et al.*, 2006). Since photosynthesis is dependent on the corn plants solar radiation use efficiency, these TGW results are possibly explained by the solar radiation reduction as sowing period was delayed from January to March.

Corn sown in January is exposed to higher rates of solar radiation and temperature (Figure 1), resulting in higher rate of photosynthesis, higher accumulation of dry mass to fill the grains and, therefore, higher grain yield. This does not happen for late sowing, where the radiation is reduced and temperatures are already milder, which may result in less photosynthetic and productive potential (Figure 1), as observed in the present study.

According to Yang *et al.* (2017), the interception efficiency is influenced by genotype, time of the year and farm site, and it is necessary whenever possible to carry out regionalized studies with the aim of verifying the best performance of the genotypes available on the market at different sowing periods.

Corn development, expressed by spike height insertion was influenced by sowing period, being shorter as sowing was delayed from January to February. These differences for this variable were more evident in the second experimental year, where the difference from corn sowing from January to March reached 30 cm. Later sowing periods in relation to the first experimental year explain these differences between years. This result corroborated with Uate *et al.* (2015) which reported that corn seeded after January 30th resulted in lower mean values of spike insertion height, and the climatic conditions (rain, temperature, and radiation) were determinants for the expression of this variable.

Based on the yield difference between the 1st and 9th sowing period divided by the number of days among these sowing dates, it is possible to observe that, for each day of delay in the corn sowing, there was a yield reduction of 143 and 159 kg ha^{-1} for the first and second growing years (Table 3). These results highlight how important and how sowing period affect corn yield, showing that there are great yield losses due to sowing delay (ANDREA *et al.*, 2020).

It also means that it is a good idea to start soybean sowing with cultivars of a longer cycle (96Y90) and let the shorter ones to be sowed later in October. The fact is that short-cycle soybean cultivar sowed early in September has its yield potential impaired and the gains obtained on corn yield do not compensate its losses, when agronomic and economic point of view are considered (PIRES *et al.*, 2016).

Thus, in order to balance the yield potential of the soybean/corn crop succession, soybean P95R51 and P95R52 sowed at the beginning of October allows corn second summer crop sowing at the first half of February, with a good productive balance for the double summer crop, making corn less susceptible to climatic adversities. However, this arrangement does not apply to cultivar P96Y90, which has a long cycle which must be sown in September to enable the second corn summer crop. This represents an arrangement with productive stability for long-cycle soybean genotype.

4 CONCLUSIONS

There is a strong relationship between sowing date and soybean maturity group on soybean-corn succession, in a way that soybean yield tends to increase as sowing is delayed from mid-September to early October, although, corn yield decrease as its sowing is delayed from January to March.

Soybean with a maturation group between 5.1 and 5.3 shows better results for the soybean-corn succession when sowed in early October. Longer maturation group (6.0) may be sowed earlier at mid-September, allowing corn sowing at mid-February, resulting in adequate soybean-corn performance.

5 ACKONOWLEGMENTS

The first author thanks the Coordenação de Aperfeiçoamento Pessoal de Nível Superior (CAPES) for granting the scholarship. The authors declare that have no conflicts of interest.

REFERENCES

ANDREA, M. C. S.; DALLACORT, R.; TIEPPO, R. C.; BARBIERI, J. D. Assessment of climate change impact on double-cropping systems. **SN Applied Sciences**, v. 2, n. 4, p. 1-13, 2020.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; DE MORAES, G.; LEONARDO, J.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, n. 6, p. 711-728, 2013.

BALBINOT JUNIOR, A. A.; BACKES, R. L.; ALVES, A. C.; OGLIARI, J. B.; FONSECA, J. A. Contribuição de componentes de rendimento na produtividade de grãos em variedades de polinização aberta de milho. **Revista Brasileira Agrociência**, v. 11, n. 2, p. 161-166, 2005. Available at: https://doi.org/10.18539/cast.v11I2.1184. Accessed on: dez. 15, 2020.

BHERING, S. B.; SANTOS, H. G.; BOGNOLA, I. A.; CÚRCIO, G.; CARVALHO JUNIOR, W. D.; CHAGAS, C. D. S.; SILVA, J. D. S. **Mapa de Solos do Estado do Paraná**. Rio de Janeiro: Embrapa Solos, 2013. 73 p. Available at: https://ainfo.cnptia.embrapa.br/digital/bitstream/item/79053/1/doc96-2007-parana-final.pdf> Accessed on: out. 29, 2020.

BORNHOFEN, E.; BENIN, G.; GALVAN, D.; FLORES, M. F. Épocas de semeadura e desempenho qualitativo de sementes de soja. **Pesquisa Agropecuária Tropical**, v. 45, n. 1, p. 46-55, 2015. Available at: https://doi.org/10.1590/1983-40632015v4529143. Accessed on: dez. 15, 2020.

BRACCINI, A. L.; STULP, M.; ALBRECHT, L. P.; ÁVILA, M. R.; SCAPIM, C. A.; RICCI, T. T. Agronomic traits and seed yield produced in the soybean-maize crop in succession cropping. **Acta Scientiarum Agronomy**, v. 32, n. 4, p. 651-661, 2010. Available at: https://doi.org/10.4025/actasciagron.v32i4.8064. Accessed on: dez. 02, 2020.

CRUZ, J. C.; PEREIRA FILHO, I. A.; ALVARENGA, R. C.; GONTIJO NETO, M. M.; VIANA, J. H. M.; OLIVEIRA, M. F.; de SANTANA, D. P. Manejo da cultura do milho em sistema plantio direto. **Informe Agropecuário**, v. 27, p. 42-53, 2006. Available at: https://www.alice.cnptia.embrapa.br/handle/doc/490278. Accessed on: dez. 02, 2020.

DO CARMO, E. L.; BRAZ, G. B. P.; SIMON, G. A.; DA SILVA, A. G.; ROCHA, A. G. C. Desempenho agronômico da soja cultivada em diferentes épocas e distribuição de plantas. **Revista de Ciências Agroveterinárias**, v. 17, n. 1, p. 61-69, 2018. Available at: https://doi.org/10.5965/223811711712018061. Accessed on: nov. 11, 2020.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. **Ciência e Agrotecnologia**, v. 35, n. 6, p. 1039-1042, 2011. Available at: http://dx.doi.org/10.1590/S1413-70542011000600001. Accessed on: nov. 19, 2020.

GARCIA, R. A.; CECCON, G.; SUTIER, G. A. S.; DOS SANTOS, A. L. F. Soybean-corn succession according to seeding date. **Pesquisa Agropecuária Brasileira**, v. 53, n. 1, p. 22-29, 2018. Available at: http://dx.doi.org/10.1590/s0100-204x2018000100003. Accessed on: ago. 13, 2020.

HEIFFIG, L. S.; CÂMARA, G. M. S.; MARQUES, L. A.; PEDROSO, D. B.; PIEDADE, S. M. S. Fechamento e índice de área foliar da cultura da soja em diferentes arranjos espaciais. **Bragantia**, v. 65, n. 2, p. 285-295, 2006. Available at: http://dx.doi.org/10.1590/S0006-87052006000200010. Accessed on: dez. 01, 2020.

MAGALHÃES, P. C.; DURÃES, F. O. M.; CARNEIRO, N. P.; PAIVA, E. **Fisiologia do milho**. Circular Técnica, 22. Sete Lagoas, Embrapa/Centro Nacional de Milho e Sorgo. 2002. 23 p. Available at: http://docsagencia.cnptia.embrapa.br/milho/circul22.pdf. Accessed on: dez. 01, 2020.

MEOTTI, G. V.; BENIN, G.; SILVA, R. R.; BECHE, E.; MUNARO, L. B. Épocas de semeadura e desempenho agronômico de cultivares de soja. **Pesquisa Agropecuária Brasileira**, v. 47, n. 1, p. 14-21, 2012. Available at: https://doi.org/10.1590/S0100-204X2012000100003. Accessed on: dez. 03, 2020.

NÓIA JÚNIOR, R. S.; DO AMARAL, G. C.; PEZZOPANE, J. E. M.; TOLEDO, J. V.; XAVIER, T. M. T. Ecophysiology of C3 and C4 plants in terms of responses to extreme soil temperatures. **Theoretical and Experimental Plant Physiology**, v. 30, n. 3, p. 261-274, 2018. Available at: https://link.springer.com/article/10.1007/s40626-018-0120-7. Accessed on: dez. 01, 2020.

NÓIA JÚNIOR, R. S.; SENTELHAS, P. C. Soybean-maize off-season double crop system in Brazil as affected by El Niño Southern Oscillation phases. **Agricultural Systems**, v. 173, p. 254-267, 2019. Available at: https://doi.org/10.1016/j.agsy.2019.03.012. Accessed on: nov. 09, 2020.

PIRES, G. F.; ABRAHÃO, G. M.; BRUMATTI, L. M.; OLIVEIRA, L. J. C.; COSTA, M. H.; LIDDICOAT, S.; KATO, E.; LADLE, R. J. Increased climate risk in Brazilian double cropping agriculture systems: Implications for land use in Northern Brazil. **Agricultural and forest meteorology**, v. 228, p. 286-298, 2016. Available at: https://doi.org/10.1016/j.agrformet.2016.07.005. Accessed on: nov. 09, 2020.

SEDIYAMA, T.; SILVA, F. L.; BORÉM, A. **Soja do plantio a colheita**. 1.ed. editora UFV, 2015. 333 p.

SOUZA, V. Q.; BELLÉ, R.; FERRARI, M.; PELEGRIN, A. J.; CARON, B. O.; NARDINO, M.; FOLLMANN, D. N.; CARVALHO, I. R. Componentes de rendimentos em combinações de fungicidas e inseticidas e análise de trilha em soja. **Global Science and Technology**, v. 8, n. 1, p. 167–176, 2015. Available at: https:// doi.org/10.14688/1984-3801/gst.v8n1p167-176. Accessed on: nov. 27, 2020.

SPADER, V.; DESCHAMPS, C. Rendimento de grãos de cultivares de soja com diferentes densidades e épocas de semeadura em região de elevada altitude do sul do Brasil. **Semina: Ciências Agrárias**, v. 36, n. 3, p. 1823-1834, 2015. Available at: http://dx.doi.org/10.5433/1679-0359.2015v36n3Supl1p1823. Accessed on: nov. 30, 2020.

UATE, J. V.; PINHO, R. G. V.; CANCELLIER, L. L.; CAMILO, A.; BERNADO JÚNIOR, L. A. Y. Épocas de semeadura e distribuição espacial de plantas na produção de milho. **Revista Brasileira de Milho e Sorgo**, v. 14, n. 3, p. 346-357, 2015. Available at: https://doi.org/10.18512/1980-6477/rbms.v14n3p346-357. Accessed on: nov. 18, 2020.

YANG, H.; GRASSINI, P.; CASSMAN, K. G.; AIKEN, R. M.; COYNE, P. I. Improvements to the Hybrid-Maize model for simulating maize yields in harsh rainfed environments. **Field Crops Research**, v. 204, p. 180-190, 2017. Available at: https://doi.org/10.1016/j.fcr.2017.01.019. Accessed on: out. 5, 2020.