Sowing date and maturity group in soybean grown in lowlands

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ABSTRACT

It is projected an increase of about 30% in the world population by 2050 and a food demand increase by 60%, mainly vegetable proteins. Due to this, soybean is being introduced in new production systems, such as in rotation with irrigated rice in lowlands. Irrigated and non-irrigated experiments were conducted in order to determine the influence of irrigation on maturity groups, on yield components and yield in lowlands. Five soybean cultivars with maturity groups (MG) ranging from 4.8 to 7.8 were used, representing the cultivars sowing in southern Brazil, and three sowings were performed (October, November and January). A decrease in the number of pods m^{-2} was observed with the delay in the sowing date in both water regimes and MG, except MG 4.8 and 5.5, which had a higher number of pods m^{-2} when irrigated and sown in November. The leaf area index (LAI) was higher under the irrigated condition, for all MGs and sowing dates. The interaction between the yield components can be maximized by the combination of supplemental irrigation, anticipation of sowing date and the choice for cultivars with MG from 6.2 to 6.8 for lowland environments.

Keywords: *Glycine max* L.; crops system; water regime.

INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] represents more than 60% of vegetable proteins for food and feed global supply (Wilson, 2008). There will be an increase of about 50% in food demand by 2050 and this raises serious concern on soybean yield, as the current trend will not meet this demand (Lobell *et al.*, 2009; Van Ittersum *et al.*, 2013). The high demand for vegetable proteins is putting pressure on the expansion of soybean cultivation in areas that were not traditionally cultivated, for example, lowland areas in southern Brazil rotating with irrigated rice (Sartori *et al.*, 2016; Marques da Rocha *et al.*, 2018; Ribas *et al.*, 2021a; Ribas *et al.*, 2021b; Theisen *et al.*, 2017).

The sowing areas with irrigated rice are called lowlands and are mainly Alfisol, Entisols or the two ones associated (Mundstock *et al.*, 2016). These soils are characterized as hydromorphic with low natural drainage, presenting a surface horizon soil profile with depth of up to 0.50m and underground layer with very limited permeability (Streck *et al.*, 2008). This new soybean production system in rotation with irrigated rice, represents half of the area cultivated in irrigated rice in southern Brazil (Zanon *et al.*, 2018) with an average yield of 1.80 Mg.ha^{-1} (CONAB, 2019), and yield potential around 7 Mg.ha^{-1} (Zanon *et al.*, 2016). Low hydraulic conductivity and water storage capacity in lowlands compared to upland soils (Gomes *et al.*, 1992; Borges *et al.*, 2004) expose soybean plants to water stress,

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even in years of well distributed precipitation during the growing season (Marques da Rocha *et al.*, 2018; Ribas *et al.*, 2021a). During the soybean developmental cycle, there are periods of greater sensitivity to yield loss due to water stress, including initial plant stand, flowering and grain filling, directly affecting the yield components (Mundstock *et al.*, 2016; Zanon *et al.*, 2018). As a result, these yield losses are more frequent in lowlands (Bortoluzzi *et al.*, 2017) contributing to a yield gap of 4.20 $Mgha^{-1}$ in these agroecosystems (Zanon *et al.*, 2016).

Yield potential, growth and development of the crop are strongly influenced by environmental offer (sowing date), genetics (choice of the maturity group) and the occurrence of abiotic stresses (Lobell *et al.*, 2009; Van Ittersum *et al.*, 2013). The right choice for sowing date and maturity group are tools that reduce the risk of loss of yield, considering that the developmental phases in which the yield components are defined coincide with the best climatic conditions for plants (Kantolic, *et al.*, 2008; Zanon *et al.*, 2016). These interactions are well known in upland soybean farms (Zanon *et al.*, 2015a; Tagliapietra *et al.*, 2018; Zanon *et al.*, 2018), but there is still a lack of knowledge on soybeans ecophysiology in lowland environments.

The sustainable intensification of the rice-soybean system requires that basic ecophysiology studies are carried out, seeking to understand the genotype and environment interaction. As a result, experiments were carried out covering the sowing dates and the range of maturity groups currently used in southern Brazil. The objective of this study was to determine the influence of irrigation, sowing date and maturity group on the yield components and the yield of soybeans cultivated in the lowlands.

MATERIAL AND METHODS

Field experiments were conducted with and without irrigation in Santa Maria, state of Rio Grande do Sul, Brazil, during the 2017/2018 growing season. The soil is typical of areas traditionally cultivated with irrigated rice, named as Alfisol. The climate is classified as Cfa according to the Köppen classification (Kuinchtner & Buriol, 2001). A 5x3 factorial scheme was used, with MGs 4.8, 5.5, 6.2, 6.8 and 7.8, and three sowing dates (early October, end of November and early January).

The row spacing was of 0.45 m, and the density was 300,000 $plants.ha^{-1}$. Each plot consisted of seven rows of 4m long each. Seeds were treated with fungicides, insecticides and inoculated with strains of *Bradyrhizobium japonicum* at the time of sowing. Sowing was carried out in corrected soil, according to technical recommendations for soybean, with fertilization aiming to achieve the yield of 7 $Mg.ha^{-1}$. Weeds, insects and diseases were controlled to keep the crop free from biotic stress. In the irrigated experiment, the drip irrigation depth was based on the calculation of soil water balance, using the daily water balance model of Thornthwaite & Mather (1955), that calculates the amount of water in the soil exploitable by the roots from the difference between the entry (precipitation and/or irrigation) and the exit (evapotranspiration) of the water in the soil (Steenhuis & Van Der Molen, 1986). The available soil water capacity (AWC) was maintained between 50 and 100%, considering the root depth.

The daily meteorological data necessary for the calculation of water balance were measured by an automatic station belonging to Instituto Nacional de Meteorologia (INMET), located approximately 100m from the experiment. To estimate the potential evapotranspiration (ETo), the Penman-Monteith method was used (Allen *et al.*, 1998). The crop coefficient (Kc) along the soybean development cycle was calculated by linear interpolation between the values reported by Berlato *et al.* (1986). During the crop developmental cycle, 19 irrigations were performed during the sowing in October 26 in November and 10 in January, as shown on Table 1, being relatively low values when compared with the climatological normal data of Santa Maria-RS, where the potential evapotranspiration for the months of October to May is of 64.9, 98.8, 131.3, 139.3, 116.1, 103.5, 68.1 and 48.0 mm, respectively.

The developmental stages was observed every two days following the scale of Fehr *et al*. (1971). The primary yield components evaluated at harvest time were: number of pods per square meter ($pods.m^{-2}$); number of grains per pod and dry mass of thousand grains. The secondary yield components evaluated were: the final height of the plant, the evolution of the node number (NN) and the leaf area index (LAI). The evaluations of leaf area throughout the cycle were performed using a non-destructive method, measuring the length and width of the central leaflet of all leaves, and the leaf area was calculated by the method described by Richter *et al.* (2014). To determine the grain yield (13% moisture), an area of 4 m^2 was harvested. Analysis of variance and multiple comparison of the means with the t test ($p < 0.05$) were performed using the Sisvar program.

Table 1: Number of irrigations and total amount of water irrigated (mm) during the three sowing dates

Sowing date	Estage	Number of irrigations	Total amount of water irrigated (mm)
October	Vegetative	2	11
	R1 - R5	10	64,3
	R5 - R7	7	29,1
	TOTAL	19	104,4
November	Vegetative	15	80,8
	R1 - R5	4	24,9
	R5 - R7	4	14
	TOTAL	23	119,7
January	Vegetative	4	27,2
	R1 - R5	5	21,1
	R5 - R7	1	4,5
	TOTAL	10	52,8

RESULTS AND DISCUSSION

The periods with a volume of water in the soil lower than 60% of the FC in October sowing date matched with the reproductive phase and the same periods occurred in the vegetative phase (Figure 1) in the sowing date of November and January. Therefore, at early sowing dates (September and October), extra care is required due to the increased risk of water deficit during the reproductive phase, as the critical periods of soybean crop coincide with the time of the year when the vapor pressure deficit and evapotranspiration are maximum (December and January) (Figure 2) (Bortoluzzi *et al.*, 2017). This information is relevant for lowland crops that aim to achieve yield potential up to the of early sowing date (Zanon *et al.*, 2016).

In addition to the sowing date, another important factor to reach the soybean yield potential is the leaf area index (LAI), which directly affects the solar interception, the production of photo-assimilates and therefore the yield (Tagliapietra *et al.*, 2018). In Figure 3, the LAI was higher under the irrigated condition, since the start of the cycle for all MGs and sowing dates. The LAI was higher during the sowing in October, decreasing with the delay in the sowing date, due to the decrease in the photoperiod, in agreement with the results obtained by Zanon, *et al.* (2015a). Only MG 4.8 without irrigation responded differently, having a higher LAI when sown in November (Figure 3A). In addition to MG 4.8 having the cycle considered short for the region when submitted at an early sowing (October) in the lowlands and without irrigation, a small water deficit caused a reduction in the growth rate, which led to a drop in the LAI (Winck *et al.*, 2022). The LAI under the irrigated condition (Figure 3), except for the January sowing, which was higher than the optimal LAI (6.3) to achieve high yields (Tagliapietra *et al.*, 2018). Under the non-irrigated condition, except for MG 7.8 in October sowing, the cultivars did not reach the optimal LAI (Figure 3). In this sense, it can be inferred that irrigation assures the reach of optimal crop LAI, in order to achieve high yield in lowland environments.

The evolution of the node number (Figure 4) and the final node number (FNN) (Figure 4A) showed a similarity between the irrigated and the non-irrigated experiments in the October sowing, due to regular precipitation in the vegetative phase, which did not compromise the development of the cultivars (Figure 1). With the occurrence of water deficit, plants use strategies to minimize this stress, ranging from stomatal closure under small stresses and evolving until stopping growth and development in case of more severe stress (Winck *et al.*, 2022). In Figure 3 it can be seen that the water deficit caused the reduction of LAI by the production of abscisic acid, during all periods of sowing. However, the decrease in node emissions was observed mainly at the time of sowing in November and at the end of sowing date in January (Figure 4), demonstrating in practice that the leaf growth process has stopped, while the emission of nodes (development) was only affected in more severe water deficiency in the soil. A similar response to that was found in cassava by Baker *et al.* (1989).

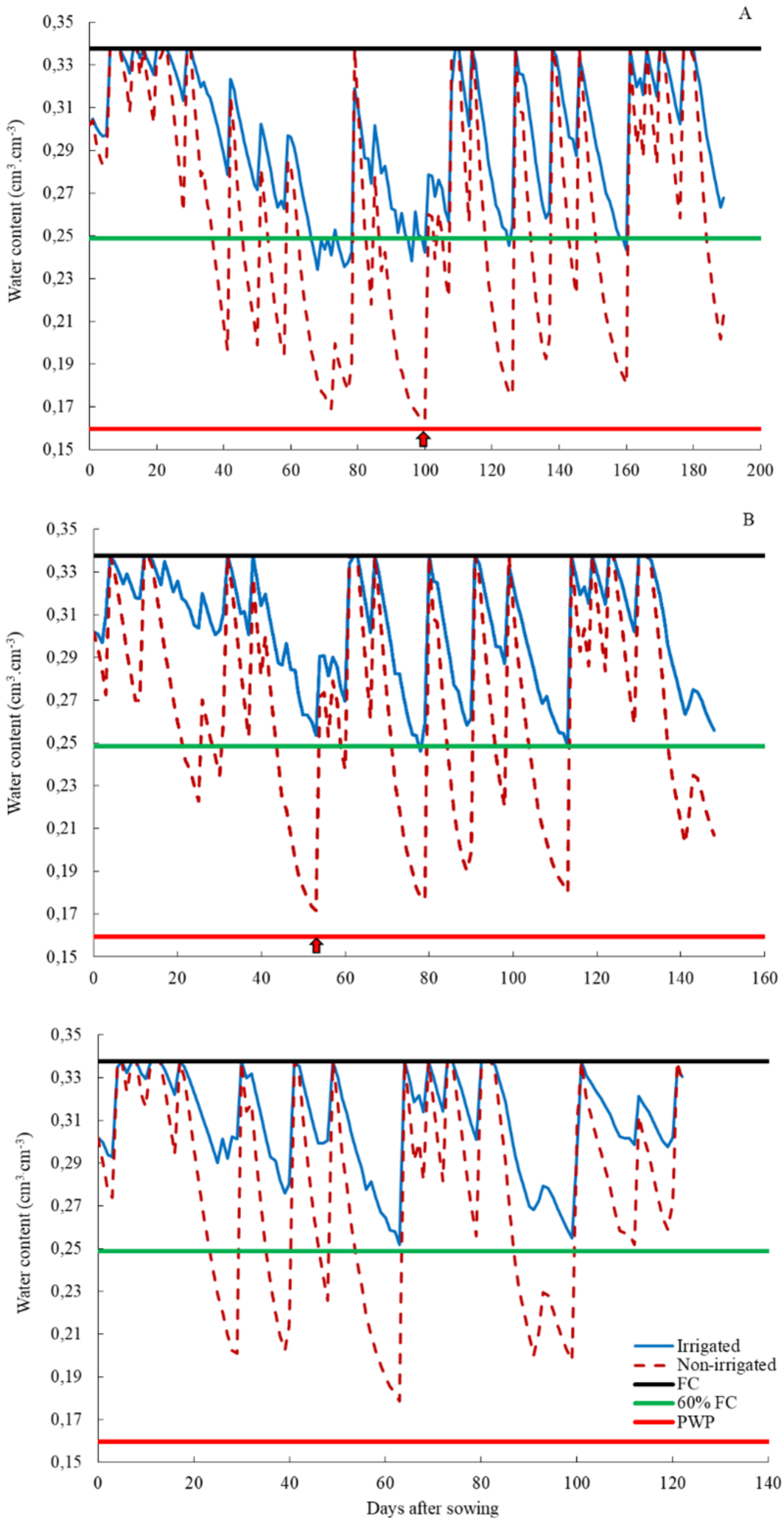

Figure 1: Water content (cm³cm⁻³) throughout the developmental cycle of soybean for the three sowing dates, (A) October, (B) November and (C) January. Solid blue lines are the irrigated area and red dotted line is the non-irrigated area. The solid black line represents the field capacity (FC), the solid green line represents 60% of the field capacity (60% FC) and the solid red line represents the permanent wilting point (PWP).

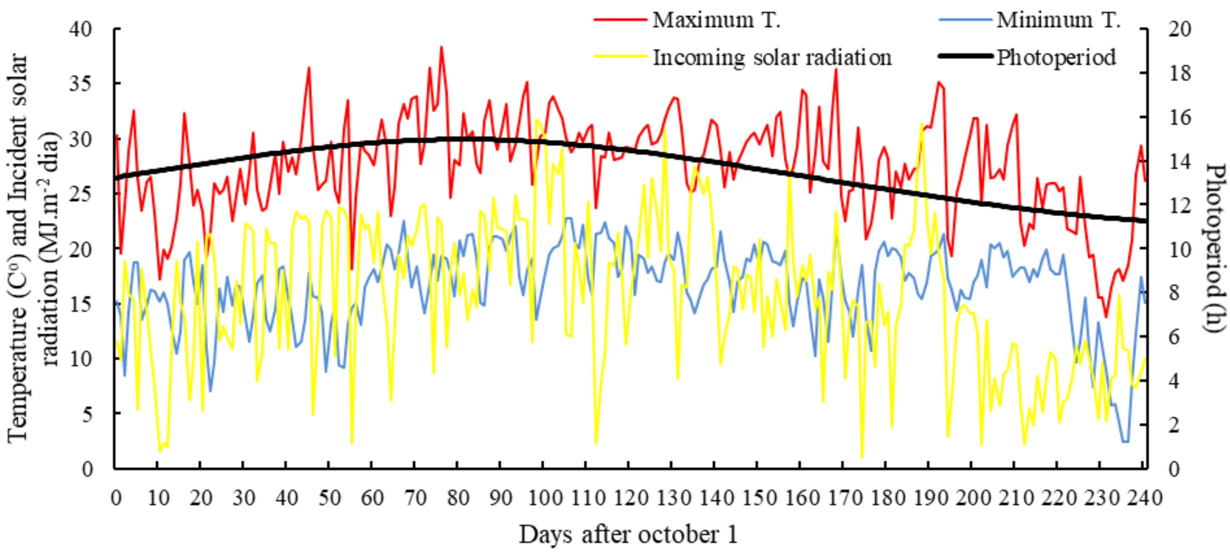

Figure 2: Daily maximum and minimum air temperature, incoming solar radiation, and photoperiod during the experimental period in Santa Maria, RS, Brazil.

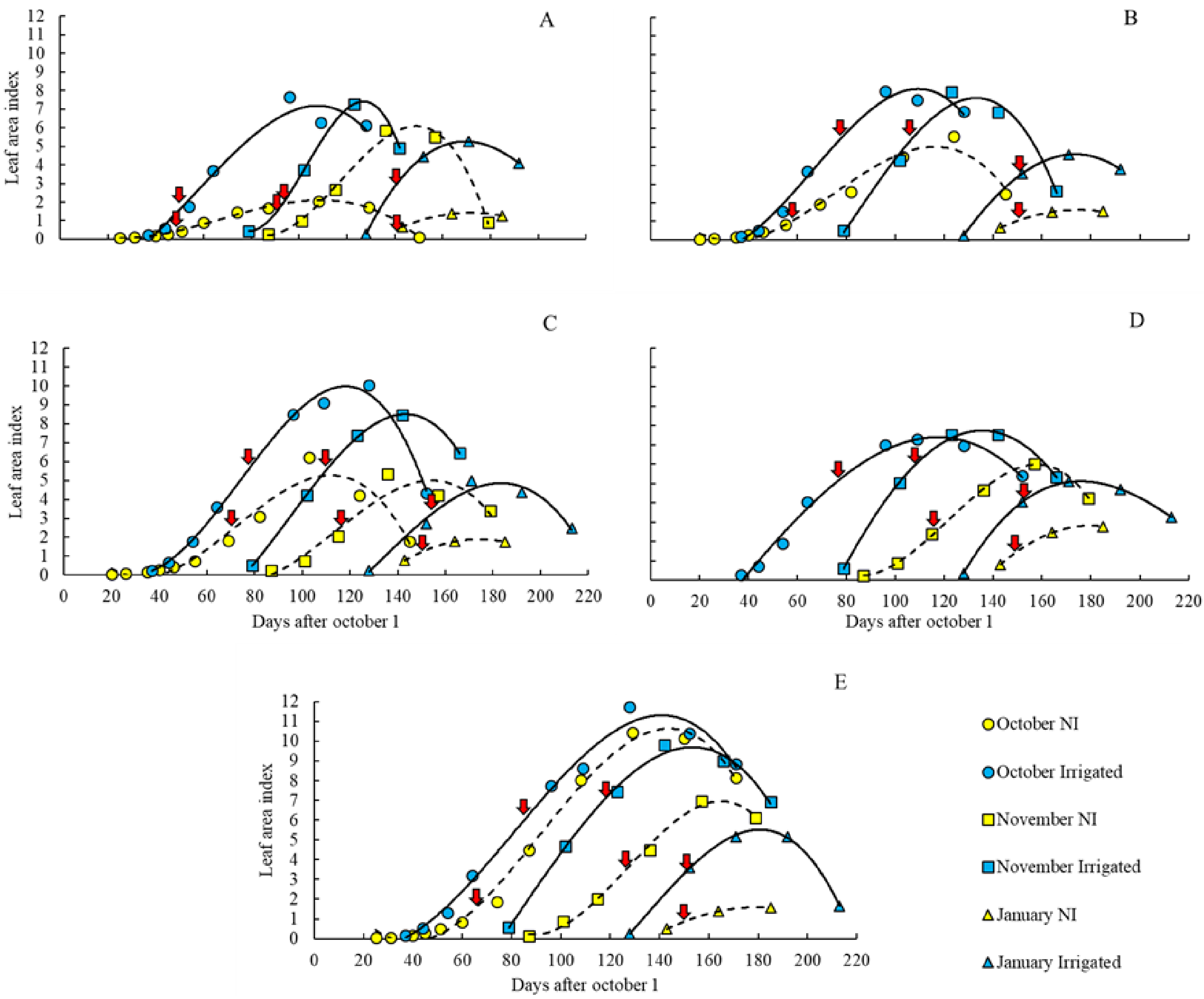

Figure 3: Relationship between leaf area index (LAI) in soybeans and days after October 1, in irrigated and non-irrigated (NI) treatments for cultivars of MG 4.8 (A) MG 5.5 (B), MG 6.2 (C), MG 6.8 (D) and MG 78 (E). Red arrows indicate flowering date (R1).

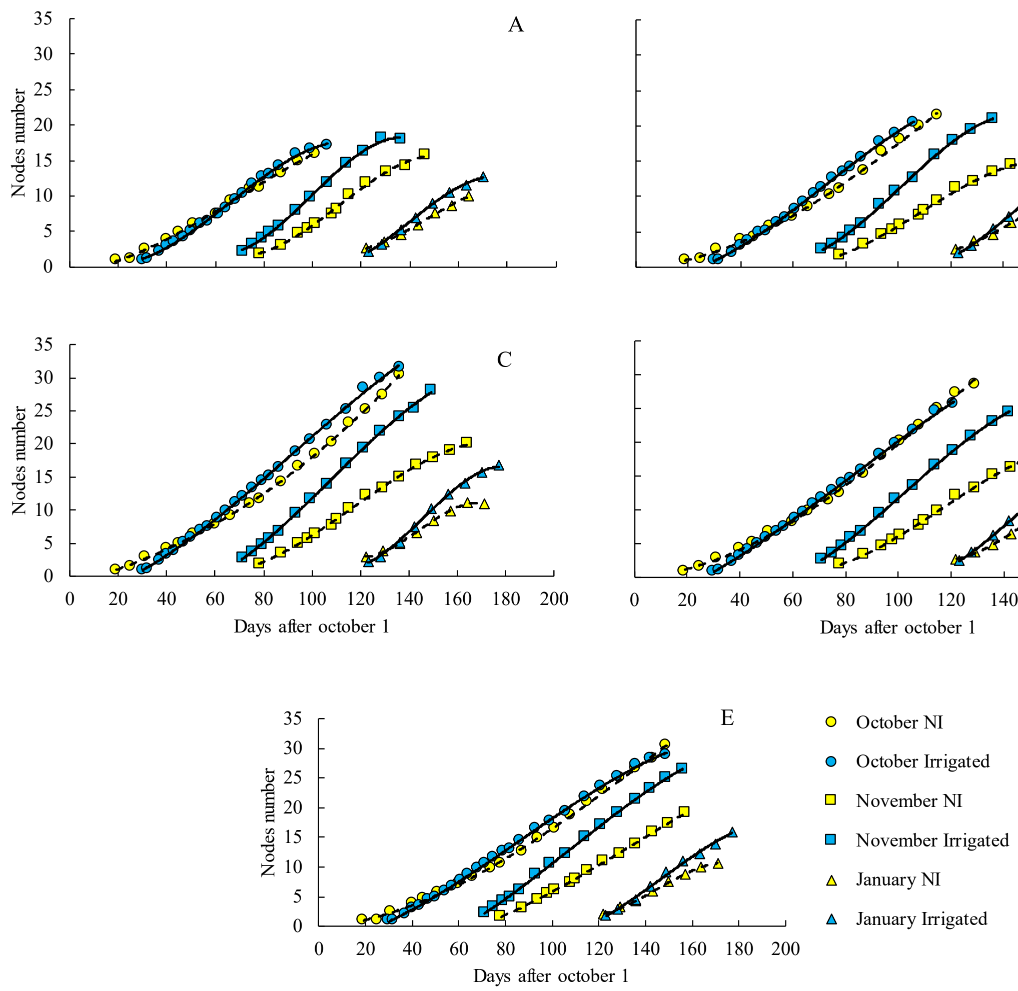

Figure 4: Relationship between nodes number (NN) in soybeans and days after October 1, 2017 in irrigated and non-irrigated (NI) treatments for cultivars MG 48 (A) MG = 55 (B), MG 62 (C), MG = 68 (D) and MG = 78 (D).

In January sowing, the FNN was lower than in the other sowing dates for the two experiments (Figure 4), since soybean is a short-day plant, being induced to flowering when there is exposure to the short photoperiod. Thus, the late sowing causes the shortening of the cycle, the period of emission and the final node number (Setiyono *et al.*, 2007; Martins *et al.*, 2011; Zanon *et al.*, 2015b; Marques da Rocha *et al.*, 2018). The final height in non-irrigated and irrigated cultivars were 0.95 and 1.40m in October, 0.73 and 1.38m in November and 0.37 and 0.81m in January, respectively (Figure 5). The non-irrigated cultivars showed a lower final height than the irrigated ones whatever of the sowing date (Figure 5B), because there is a reduction in the growth and the development of plants with water deficit (Figure 3). There was no variation in the development of the cultivars in the non-irrigated environment, in relation to the irrigated environment.

There was a decrease in the number of pods m-² with the delay of the sowing date in both water regimes and MG, except for MG 4.8 and 5.5, which had a higher number of pods.m^{-2} when irrigated and sown in November (Figure 5C). This matches with the results obtained by Zanon *et al.* (2018), in which it is described that the best sowing date for MG < 5.5 is between the period from October 20 to November 20. The number of pods.m^{-2} in general was higher during the October sowing (2168 pods.m^{-2}), not statistically different between irrigated and non-irrigated, since the water deficit was not severe (Table 2). In addition, the number of pods.m^{-2} for the October sowing date did not differ statistically from the irrigated experiment of the sowing date of November (1920 pods.m^{-2}) (Table 2). The irrigated experiment in January (1353 pods.m^{-2}) (Table 2) showed a higher average of more than 600 pods.m^{-2} when compared to the same period conducted without irrigation, which is justified since it was the period of the year with the highest water deficiency (MAPA, 2017). According to Zanon *et al.* (2018), the optimum number to achieve high yields is 1,950 pods.m^{-2}, a value that was only reached in October (irrigated and non-irrigated) and in November (irrigated) (Table 2).

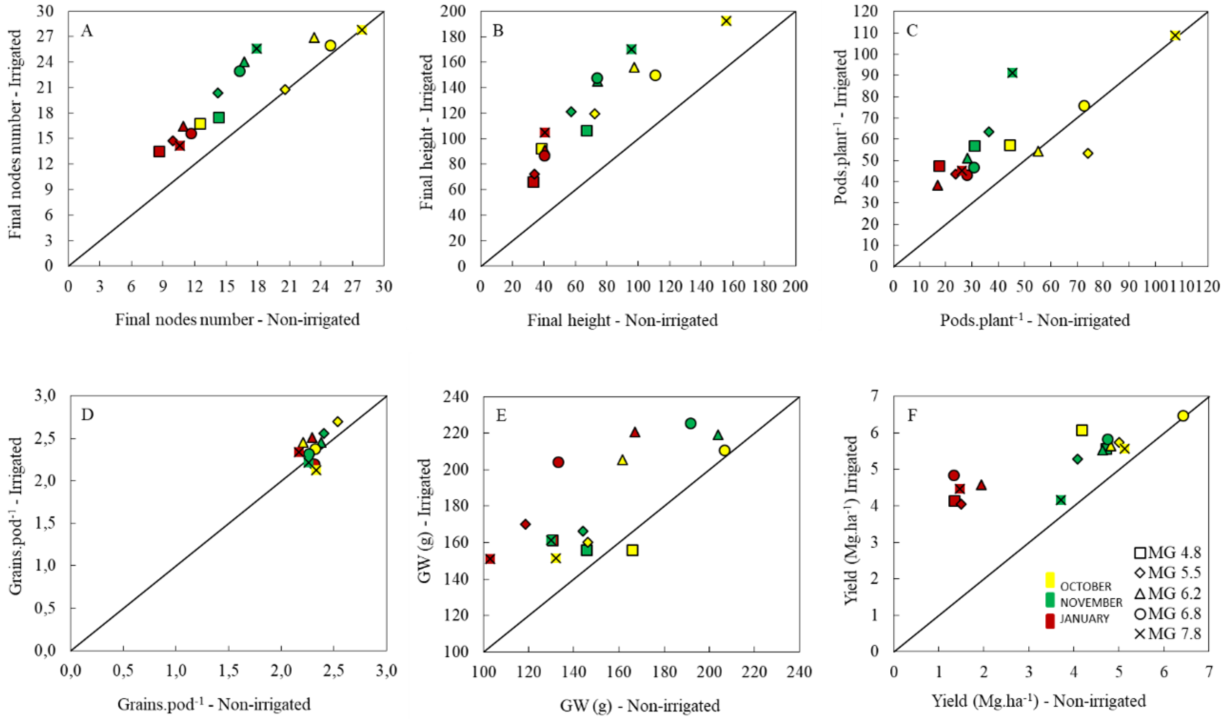

Figure 5: Relationship between the secondary yield components final nodes number (FNN) (A), final height (B) and the primary components pods per plant (C), grains per pod (D) and 1000-grains weight (GW) (E), and the final yield (F) of five maturation groups of soybean in three sowing dates (yellow = October, green = November and red = December) and two water regimes (axis X = non-irrigated and axis Y = irrigated).

Table 2: Yield (Mgha^{-1}) and yield components (pods m^{-2}, Grains.pods^{-1} and 1000-grains weight (g) in three sowing dates (October, November and January) and two water regimes (Irrigated and Non–irrigated)

Sowing date	Irrigation	Pod.m^{-2}	Grain.pod^{-1}	1000-grains weight (g)	Yield (Mg.ha^{-1})
October	Irrigated	2169.22 a	2.44 a	176.64 ab	5.89 a
	Non-irrigated	1986.13 a	2.34 ab	162.63 b	5.11 b
November	Irrigated	1920.33 a	2.44 a	185.52 a	5.26 b
	Non-irrigated	964.75 c	2.37 a	163.08 b	4.38 c
January	Irrigated	1352.56 b	2.35 ab	181.35 ab	4.40 c
	Non-irrigated	630.62 c	2.24 b	130.48 c	1.52 d
VC (%)		35,97	8,13	18,67	19,36

Means followed by the same letter in columns (paired values) do not differ statistically from each other by the test t (p < 0,05).

The highest values of the photothermal coefficient are found in January and February in southern Brazil (Zanon *et al.*, 2016), so, the maximization of yield components, such as the number of pods per area and the weight of grains occur during the sowing in October, since it coincides with the critical phase of pod formation (R3) until the filling of the grains (R7), determining then the highest yield potential for sowing in October (Zanon *et al.*, 2016). Thomas & Costa (2010) observed that the number of grains per pod is the yield component with the lowest variation, being determined mainly by genetics. In this context, the values found (2.36 grains per pod) are sufficient to achieve high yields and higher than those found by Zanon *et al.* (2018), who determined the value of 2 grains per pod to achieve high yields.

The difference in dry mass of one grain between irrigated and non-irrigated increased with the delay in sowing, being 8% in October, 12% in November and 28% in January. This variation caused by the water deficit and associated with the other components of the yield, contributed to the height difference in yield between the irrigated and non-irrigated cultivars sown in November (Table 2) and mainly in January (Figure 5F). The dry mass of one grain for the irrigated experiments was 181g, about 19% higher than the average for the non-irrigated experiments (152g). Consequently, the mean of the irrigated experiment approached the value found by Zanon *et al.* (2018) of 190g as the desired to achieve high yield. This demonstrates that dry mass of one grain is one of the yield components which was the most affected by the low water storage capacity in lowland soils. Regardless of the sowing date, the cultivars obtained higher yields in the irrigated experiment, reaching the highest yields when sown in October (Figure 5F). On the other hand, in the experiment without irrigation, the highest yields were also obtained when sowing in October, except for the MG 4.8, which showed the highest yield when sown in November (Figure 5F). Nevertheless, the highest yield was achieved by a cultivar with MG 6.8 in both experiments (irrigated and non-irrigated), producing 6.50 $Mg.ha^{-1}$ in the irrigated experiment and 6.40 $Mg.ha^{-1}$ in the experiment without irrigation, in October, demonstrating the soybean potential yield crops in the lowlands of southern Brazil (Mundstock *et al.*, 2016). According to Zanon *et al.* (2016) the soybean yield potential is maximized in sowing until November 4, with a loss of yield of 26 kg ha^{-1} for each day of sowing delay. This reduction has been observed in the experiment (Table 2) and was more accentuated in sowing without irrigation. Irrigation maximized the expression of the primary yield components of the soybean (Table 2), enhanced by the occurrence of delays in sowing. Due to that, there were average losses of 780, 880 and 2880 kg ha^{-1} during the sowing dates of October, November and January, respectively, compared to the irrigated experiment. So, the interaction between the yield components can be maximized by the combination of supplemental irrigation, the anticipation of the sowing date and the choice to cultivate with MG from 6.2 to 6.8 for lowland environments. These results can be used as a support tool to make a decision for sowing date and maturity group of soybeans in the lowlands.

CONCLUSIONS

There is a reduction in leaf area index, yield components and grain yield with delayed sowing date for most soybean cultivars, being intensified in an environment without irrigation.

Growing soybeans in lowlands shows a high yield potential, requiring management practices in an integrated way, such as the anticipation of the sowing period (October), sowing of cultivars with MG from 6.2 to 6.8 and whenever possible, irrigated.

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