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Disponibilidade hídrica para alta produtividade de cultivares de soja

Water availability for high yield of soybean cultivars

Disponibilidad de agua para la alta productividad de los cultivares de soja

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Resumo

A irrigação incrementa a produtividade da soja, porém cada cultivar pode responder com diferentes magnitudes. Assim, considerando a hipótese de que diferentes cultivares de soja apresentam diferentes potenciais produtivos, mesmo em condições ideais de umidade, este estudo objetivou identificar as cultivares de soja mais produtivas sob condições ótimas de manejos de umidades do solo. Dois experimentos foram conduzidos nas safras 2015/16 e 2016/17 em blocos casualizados com quatro repetições. No primeiro experimento, as parcelas foram compostas por seis frequências de aplicação de água (0, 1, 2, 3, 4, e 5 dias); no segundo experimento, o fator primário foi constituído por seis níveis suplementares de irrigação (0, 25, 50, 75, 100, e 125% da Evapotranspiração da Cultura - ETc). Em cada experimento, as subparcelas foram compostas por cinco cultivares de soja. As variáveis avaliadas foram altura de plantas, inserção da primeira vagem, massa de cem grãos e produtividade de grãos. Independentemente do manejo de irrigação utilizado, as cultivares de soja apresentaram desempenho agronômico diferente.

Keywords: *Glycine Max* (L) Merrill; Umidade do solo; Variabilidade genética.

Abstract

Considering the hypothesis that soybean cultivars present different yield potential, even under ideal water conditions, this study aimed to identify highly productive soybean cultivars under optimal conditions of soil moisture management. Two experiments were conducted in the 2015/16 and 2016/17 crop seasons in Chapadão do Sul-MS, in a complete In a split-plot arrangement design with four replications. In the first experiment, the plots was composed of six water application frequencies (0, 1, 2, 3, 4, and 5 days); in the second experiment, the primary factor was constituted by six supplementary irrigation levels (0, 25, 50, 75, 100, and 125% of the Crop Evapotranspiration - ETc). In each experiment, subplots was composed of five soybean cultivars. The following variables were evaluated: plant height, insertion of the first pod, hundred grain weight, and grain yield. Regardless of the irrigation management used, soybean cultivars presented different agronomic performance.

Palavras-chave: *Glycine max.* (L) Merrill; Soil moisture; Genetic variability.

Resumen

El riego aumenta la productividad de la soja, pero cada cultivar puede responder con diferentes magnitudes. Por lo tanto, considerando la hipótesis de que los diferentes cultivares de soya tienen diferentes potenciales de rendimiento, incluso en condiciones ideales de humedad, este estudio tuvo como objetivo identificar los cultivares de soja más productivos en condiciones óptimas de manejo de la humedad del suelo. Se realizaron dos experimentos en las cosechas 2015/16 y 2016/17 en bloques aleatorios con cuatro repeticiones. En el primer experimento, las parcelas estaban compuestas por seis frecuencias de aplicación de agua (0, 1, 2, 3, 4 y 5 días); En el segundo experimento, el factor primario consistió en seis niveles suplementarios de riego (0, 25, 50, 75, 100 y 125% de la evapotranspiración del cultivo - ETc). En cada experimento, las subparcelas estaban compuestas por cinco cultivares de soja. Las variables evaluadas fueron altura de la planta, inserción de la primera vaina, masa de cien granos y rendimiento de grano. Independientemente del manejo de riego utilizado, los cultivares de soya mostraron un rendimiento agronómico diferente.

Palabras clave: *Glycine Max* (L) Merrill; Humedad del suelo; Variabilidad genética.

1. Introduction

Since soybean's domestication (*Glycine max*, (L.) Merrill.), its yield potential has been increasing each year. However, with the need to double global food production by 2050 to meet the demand of the world population, soybean yields must increase at a rate of 2.4% per year (Zhou et al., 2015). Currently, the soybean crop increases at a rate of approximately 1.3% per year (FAO, 2018), confirming the need for new technologies to supply the world demand for this oilseed.

The subtropical region of South America, which includes Brazil, Argentina, and Paraguay, has the world's largest soybean cultivation area, with more than 50 million hectares (FAO, 2018). Brazil stands out with 31% of the total production, characterizing the country as the second largest producer in the world. In 40 years, the Brazilian soybean yield increased by approximately 170%. This value used to be 1250 kg ha^{-1} in 1977 but it reached 3364 kg ha^{-1} in 2017 (CONAB, 2018).

The main factors that contributed to this increase were the development of new cultivars adapted to the Brazilian edaphoclimatic conditions and the opening of new areas in the country. Among these areas, the Center-West region of Brazil stands out for being responsible for 45% of the national production, which is the result of the high technology employed in the area. However, the region undergoes severe climate variations, mainly during the El Niño years (higher rainfall in the south and drought in the north of the country) and the La Niña years (drought in the south and higher rainfall in the north of the country) (INPE, 2018).

In this way, Brazilian soybean yield and production have fluctuated in the last few crop seasons, mainly due to drought periods in the rainy season, coinciding with important stages of soybean cultivation. Gava et al. (2015) reported that the occurrence of drought at the phenological stage of grain filling is already enough to cause yield loss of 62% in relation to areas irrigated with supplementary water depth during these periods of stress. However, FAO (2018) demonstrated that soybean yield, even under irrigation conditions, depends on the genetic traits of the cultivars. It detected large increases for some cultivars and no effect for others.

Thus, considering the hypothesis that soybean cultivars present different yield potential, even under ideal water conditions, this work aimed to identify highly productive soybean cultivars under optimal conditions of soil moisture.

2. Material and Methods

Two experiments were conducted in the 2015/16 and 2016/17 crop seasons in center pivot irrigation system of the Fundação de Apoio à Pesquisa Agropecuária de Chapadão, in the city of Chapadão do Sul - MS (lat. 18°46'49"S; long. 52°38'5"W; alt. 810 m asl.). The climate of the region is defined as tropical humid (Aw), according to the Köppen’s classification (Peel, et al. 2007), with rainy summer and dry winter, presenting average annual temperature of 25 °C and average annual rainfall of 1800 mm. The soil was classified as a Dystrophic Oxisol, and its Soil physical-hidrical properties are presented in Table 1.

Table 1. Soil Physical-hydrological analysis. Chapadão do Sul-MS, 2018.

Camada	**CC**	**PMP**	**CAD**	**Ds**	**Dp***	**PT**	**Frações Granulométricas**			**Classe Textural**
(cm)	**(cm^3 cm^{-3})**		**(mm cm^{-1})**	**(g cm^{-3})**		**(%)**	**Areia**	**Silte**	**Argila**	
							(%)			
0 – 15	0,413	0,282	1,76	1,34	2,65	53,6	39,24	6,68	54,08	Argiloso
15 – 30	0,383	0,262	1,74	1,44	2,65	48,4	36,76	4,56	58,68	

FC - Moisture in the field capacity at the matric potential (Ψ_m) of 0.3 atm; PWP - Permanent wilting point in Ψ_m of 15 atm; WCA – water capacity available; ρ - Soil bulk density; TP - total soil porosity; Pd– Soil particle density. Fonte: Authors.

Observe that the soil in the experimental area has almost 60% clay, which favors water retention (Table 1).

In the first experiment, the plots was composed of six water application frequencies (0, 1, 2, 3, 4, and 5 days); in the second experiment, the plots was constituted by six supplementary irrigation levels (0, 25, 50, 75, 100, and 125% of the Crop Evapotranspiration - ETc). In each experiment, the secondary factor was formed by five soybean cultivars (NA 5909 RR, Desafio RR, Power IPRO, P98Y30 RR, and M7739 IPRO) (Table 2).

Table 2. Plant population and cycle of soybean cultivars.

Cultivar	Holder	Commercial name	Cycle / days	Population recommended (seeds m^{-1})/(one thousand plants ha^{1})
C1	Nidera	NA 5909 RR	Early / 100	23 / 511.111
C2	Brasmax	Desafio RR	Intermediate / 115	24 / 533.333
C3	Brasmax	Power IPRO	Intermediate / 118	18 / 400.000
C4	Pioneer	P98Y30 RR	Late / 125	25 / 555.550
C5	Monsoy	M7739 IPRO	Late / 125	12 / 266.664

† seeds m^{-1} - number of seeds per linear meter, using 0.45 meters between rows. Fonte: Authors.

It is important to observe that each soybean cultivar have a different crop cycle and then can respond differently (Table 2).

Seeds were treated with fungicide and insecticide of the chemical group pyraclostrobin and Fipronil, at a dosage of 200 mL for each 100 kg of seeds. Sowing occurred on October 15, 2015 (2015-16 crop season) and October 19, 2016 (2016-17 crop season), under a no-tillage system, with a spacing of 0.45 m between rows. Plots consisted of five sowing rows, and the three internal rows were considered as the useful plot.

The fertilization was carried out by applying 150 kg ha-1 of NPK (11-52-00) to the sowing row and 150 kg ha-1 of KCl as topdressing. The water application frequencies consisted of 0, 1, 2, 3, 4, and 5 days, where the volume applied accounted for the Crop Evapotranspiration (ETc) accumulated in the interval between irrigations.

However, the second experiment, the supplementary water depths 0, 25, 50, 75, 100, and 125% of ETc were applied only when the crop reached the lower limit of the Readily Available Water (Allen et al., 1998). These treatments were applied using a center pivot of 4 hectares, suitable for experiments.

Irrigation management was performed via meteorological data, where the ETc was obtained by the product of the Reference Evapotranspiration (ETo) and the Crop Coefficient

(Kc). The estimates of ETo were obtained by the Penman-Monteith-FAO method, according to (Allen et al., 1998), using data from an automatic weather station and with constant measurements of the actual soil moisture by the HidroFarm equipment to adjust the calculations. The crop coefficients and the root system depth of each subperiod were defined based on Doorenbos et al. (1994).

The following response variables were analyzed: plant height (PH), by measuring the vertical distance from the soil to the end of the main stem; insertion of the first pod (IFP), by measuring the vertical distance from the soil to the first pod; hundred grain weight (100GW), by weighing one hundred grains; and grain yield (GY), by harvesting the plot's central rows, totaling an experimental unit of 3.6 square meters. The 100GW and GY were corrected to 13% of moisture, determined by an electronic sampler at the time of the evaluation.

In each experiment, the data were subject to joint analysis of variance, according to the splitplot model:

$$Y_{ijkl}=\mu+B/Y_{kl}+Y_l+C_i+\alpha_{ikl}+I_j+C\times Y_{il}+I\times Y_{jl}+C\times I_{ij}+C\times I\times Y_{ijl}+\varepsilon_{ijkl} \quad (1)$$

where μ is the overall mean; B/Y_{kl} is the random effect of the l-th block within the k-th year; Y_l is the random effect of the 1-th year; C_i is the fixed effect of the i-th cultivar; α_{ikl} is the experimental error associated with the primary factor over the years; I_j is the fixed effect of the i-th irrigation management; $C\times Y_{ij}$ is the random effect of the cultivars x years interaction; $I\times Y_{jl}$ is the random effect of irrigation managements x years interaction; $C\times I_{ij}$ is the fixed effect of the cultivars x irrigation management interaction; $C\times I\times Y_{ijl}$ is the random effect of the cultivars x irrigation management x years interaction; ε_{ijkl} is the experimental error associated with the secondary factor over the years.

For the fixed factors of the first experiment, the application frequencies and the soybean cultivars were clustered by the Scott-Knott’s test. For the fixed factors of the second experiment, the soybean cultivars were clustered by the Scott-Knott’s test, while the supplementary water depths were subject to polynomial regression analysis, using the Sisvar software (Ferreira, 2011). Afterward, for the joint analysis of all the factors studied, the means of each treatment were subject to the principal component analysis to verify the interrelationship between the variables and their association with the treatments, using the Rbio software (Bhering, 2017).

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3. Results and Discussion

Water balance over the two crop seasons

The irrigation management was applied to each experiment to maintain soil moisture under optimum conditions, whenever rainfall did not occur. Table 3 shows the number of applications, total water depths applied by irrigation management, and the ETc accumulated in the two crop seasons.

Table 3. Management of soil moisture, with different water application frequencies and supplementary water depths.

Crop season	Irrigation Management	Number of applications	Total water depth applied mm	Accumulate ETc mm
	Application frequencies (days)			
2015/16	1 day	19	116	379
	2 days	8	67	
	3 days	6	62	
	4 days	2	15	
	5 days	1	10	
2016/17	1 day	36	176	370
	2 days	13	123	
	3 days	8	103	
	4 days	7	91	
	5 days	4	65	
	Supplementary water depth (% ETc)			
2015/16	25%	3	7	379
	50%	3	14	
	75%	3	21	
	100%	3	28	
	125%	3	34	
2016/17	25%	5	25	370
	50%	5	46	
	75%	5	66	
	100%	5	86	
	125%	5	106	

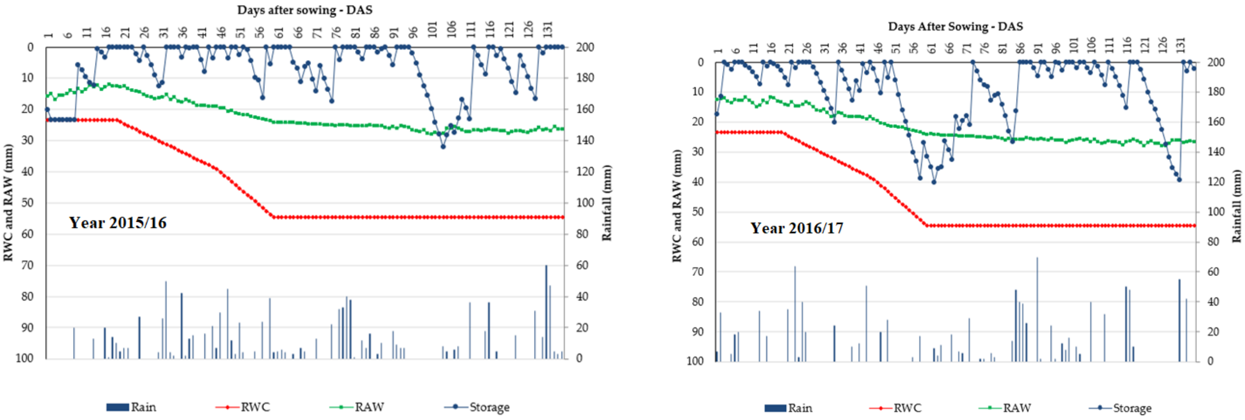
Source: Authors.

Observe in the Table 3 that treatments with application frequencies that involved larger intervals did not occur in all irrigation cycles due to the occurrence of rainfall in that interval. For instance, in the 2015/16 crop season, the treatment with water application frequency every five days occurred only once, because of the weather conditions, which makes it similar to another treatments.

To obtain a uniform plant stand in all the experiment, 100% of the ETc was replaced from the initial stage to the phenological stage V2. Thus, in the 2015/16 crop season, three equal irrigation applications were performed in all treatments, totaling 47 mm. Conversely, no irrigation for establishment was necessary for the 2016/17 crop season.

The water balance shows that the periods without rain occurred at different stages of the soybean cycle in each crop season (Figure 1).

Figure 1. Daily Water Balance of the 2015/16 and 2016/17 crop seasons, by Rainfall, Residual Water Content (RWC), Readily Available Water (RAW) and Soil Water Storage



Source: Authors

In Figure 1, the blue line determines the change in soil water storage, which, when crossing below the green line Readily Available Water (RAW), indicates the water stress, going from moderate to severe, until reaching the red line, demonstrating the lower limit of water capacity available (WCA). RAW was established by the Depletion Fraction of 0.50 (Allen, et al. 1998).

Periods with lower rainfall resulted in a lower soil water content due to the water inflows and outflows balance. The rainfall and the water deficit occur in different periods of the phenological cycle within each crop season. However, in both crop seasons, water deficit did not cause significant differences between the two years of observations. Therefore, the factor 'year' was considered as a random effect in the statistical model used.

The moisture level was below the ideal in both crop seasons. Nevertheless, in the 2015/16 crop season (Fig 1a) this phenomenon occurred at the beginning of the crop season (germination and emergence stage) and during grain filling (at 104 days after sowing). In the 2016/17 crop season, the moisture level was below the ideal at the flowering phenological stage (Fig 1b), remaining at that level for about 14 days (from 55 to 69 DAS).

Gava et al. (2015) reported that the occurrence of water deficit only at the grain filling stage causes losses similar to those caused by water deficit in the total cycle. The adaptation conditions of the cultivar can explain this fact. When a cultivar grows under water conditions below the ideal level throughout the cycle, the plant will have its productive potential and agronomic performance reduced. Conversely, if this cultivar develops under favorable conditions throughout the cycle, but undergoes water deficit at the grain filling stage, the abiotic stress can cause considerable yield reductions. According to the same authors, approximately 22% of grain abortion is expected, regardless of moisture deficit or excess; therefore, this phenomenon does not affect yield.

Agronomic performance of soybean cultivars under different irrigation frequencies

The summary of the analysis of variance for plant height (PH), insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars grown under application frequencies in the 2015/16 and 2016/17 crop seasons (Table 4).

Table 4. Summary of the analysis of variance for plant height (PH), insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars grown under application frequencies in the 2015/16 and 2016/17 crop seasons.

Sources of Variation	Degrees of freedom	Mean Square			
		PH	IFP	100GW	GY
Block/Year	6	4.85E+1^{ns}	6.97E+0**	1.58E-1^{ns}	4.75E+5^{ns}
Year (Y)	1	3.32E+3**	3.52E+1**	1.66E+2**	3.12E+6^{ns}
Frequency (F)	5	1.73E+2*	2.69E+0^{ns}	6.65E+0**	8.10E+5^{ns}
Cultivar (C)	4	4.18E+3**	1.10E+2**	1.00E+0**	6.56E+6**
F * Y	5	4.28E+1^{ns}	1.36E+0^{ns}	2.27E+0^{ns}	4.43E+5^{ns}
C * Y	4	3.19E+2**	4.71E+1**	5.93E+0**	8.17E+5^{ns}
F * C	20	4.88E+1^{ns}	4.73E+0*	5.54E-1^{ns}	8.87E+5^{ns}
F * C * Y	20	3.36E+1^{ns}	1.48E+0^{ns}	1.47E+0*	5.92E+5^{ns}
Error plot	15	4.86E+1	1.58E+0	6.24E-1	7.04E+5
Error splitplot	159	3.13E+1	4.34E+0	5.65E-1	4.58E+5
CV (%) plot		10.22	9.79	4.42	14.64
CV (%) splitplot		8.20	16.23	4.21	11.81

^{ns}, * and **: not significant, significant at 5 and 1% probability by the F test, respectively; CV: coefficient of variation. Source: Authors.

Note in the Table 4 that the effect of years was significant only for the agronomic variables, which indicates that the climatic changes that occurred from one crop season to another were not enough to affect soybean yield. Application frequencies influenced only the variables plant height (PH) and hundred grain weight (100GW). Cultivars presented differences for all variables evaluated. Frequencies x years interaction was not significant for all variables. Similar to the isolated effect of years, the cultivars x years interaction was significant only for the agronomic variables. This effect can be attributed mainly to the climatic effects and timing that occurred from one crop season to another.

Frequencies x cultivars interaction was significant only for insertion of the first pod (IFP). The FxCxY between the factors tested was not significant for all variables, only 100GW. The factors tested did not affect grain yield (GY), which had a significant effect only on cultivars. This result may have occurred due to the high phenotypic plasticity of Brazilian soybean cultivars (Santos et al., 2018), which, associated with small deficits in the two years, did not provide significant water depths x cultivars interaction.

It is important to emphasize that when plants that produce heavier grains, this can be an indicator of lower productivity. We observed in our results that when the plant has less grains, it can have a better quality grain filling (Gava et al., 2015).

The mean values of plant height (PH), insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars in function of application frequencies, it is presented in the Table 5.

High-frequency applications negatively affected PH which might have been an effect of soil moisture excess since it is a clayey soil.

Therefore, stresses due to soil moisture excess or deficit affected this variable, and the best application frequencies were between two, three, and four days.

The highest PH was verified for cultivar POWER IPRO, demonstrating superiority in relation to the early cultivar NA 5909 RR. This data suggests that, for this cultivar, ideal water conditions over the crop cycle can act as a stimulus to plant height. Conversely, Nunes et al. 2016 verified that treatments with severe and moderate water deficit did not differ, assuming, therefore, the premise that plants under stress from the beginning of the cycle changed their morphology, reducing plant height.

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Table 5. Mean values of plant height (PH), insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars in function of application frequencies.

Variable	Variety	Application frequencies (Days)						Mean
		0	1	2	3	4	5	
PH (cm)	NA 5909 RR	55.4	59.2	58.4	56.3	57.7	52.0	56,5 d
	DESAFIO RR	65.1	70.8	73.1	69.8	68.9	68.9	69,4 b
	POWER IPRO	82.0	76.1	83.7	84.5	80.8	81.9	81,5 a
	P98Y30 RR	63.9	71.6	72.6	74.8	72.1	69.2	70,7 b
	M7739 IPRO	59.1	59.8	63.9	66.1	66.3	62.7	63,0 c
Mean		65.1 B	67.5 B	70.4 A	70.3 A	69.2 A	66.9 B	
IFP (cm)	NA 5909 RR	11.8 aB	11.8 aB	13.8 aA	12.9 aB	12.6 aC	12.5 aB	12,6
	DESAFIO RR	11.7 aB	11.0 aB	11.9 aB	11.3 aC	11.2 aC	10.3 aC	11,2
	POWER IPRO	12.4 aB	10.7 bB	10.7 bB	11.8 aC	12.4 aC	11.6 aB	11,6
	P98Y30 RR	13.3 bA	14.1 bA	14.8 aA	15.1 aA	13.6 bB	14.8 aA	14,3
	M7739 IPRO	14.5 aA	15.3 aA	13.6 bA	15.0 aA	15.2 aA	13.7 bA	14,5
Mean		12.8	12.6	13.0	13.2	13.0	12.6	
100GW (g)	NA 5909 RR	18.1	18.7	19.0	18.9	19.0	19.0	18.8 b
	DESAFIO RR	18.0	19.2	19.0	18.5	18.7	19.3	18.8 b
	POWER IPRO	16.5	16.8	17.2	17.2	16.9	16.9	16.9 c
	P98Y30 RR	14.9	15.9	16.1	16.2	15.9	15.9	15.8 d
	M7739 IPRO	17.8	19.5	19.3	19.5	19.6	19.3	19.2 a
Mean		17.1 B	18.0 A	18.1 A	18.0 A	18.0 A	18.0 A	
GY (kg ha^{-1})	NA 5909 RR	4953.9	5271.1	5249.4	5078.3	5070.5	5535.5	5192.9 b
	DESAFIO RR	5698.3	6679.4	5949.1	5684.5	5723.3	5961.1	5949.3 a
	POWER IPRO	5681.1	6909.9	6523.3	6129.2	5842.2	5789.2	6145.8 a
	P98Y30 RR	5729.3	5353.1	5625.8	5420.0	5336.2	5865.1	5554.9 b
	M7739 IPRO	5698.8	5310.5	5817.9	6039.9	6042.9	5967.4	5812.9 a
Mean		5552.1	5904.8	5833.1	5670.4	5603.0	5823.6	

Means followed by uppercase and lowercase letters in the lines and columns, respectively, differ from each other by the Scott-Knott's test ($p < 0.05$). Source: Authors.

As we can see in the Table 5 that ror IFP, cultivars POWER IPRO, P98Y30 RR, and M7739 IPRO, despite having been affected by the irrigation frequencies, they presented completely different performances (Table 5). In general, late-cycle cultivars have higher IFP values than early-cycle cultivars. IFP is an important agronomic trait for the mechanical harvesting operation of the grains (Sediyama et al., 2016). According to these authors, the mean IFP should be at least 13 cm to reduce losses during the crop season. Thus, the early-cycle cultivars (NA 5909 RR, DESAFIO RR, and POWER IPRO IPRO) did not reach the recommended minimum height under any of the soil moisture conditions.

Water application influenced 100GW even in crops without water deficits since the ideal moisture conditions were maintained. The treatment without irrigation showed lower 100GW in relation to the other frequencies applied (Table 5). The late-cycle cultivars M 7739 IPRO and P98Y30 RR showed the highest and lowest 100GW values, respectively, indicating that the cycle does not affect the variable, unlike the genotypic traits inherent to each cultivar. Cultivar M 7739 IPRO reached the highest 100GW, while cultivar P98Y30 RR presented the lowest values for this variable. 100GW can directly affect GY; however, it depends on a number of factors, although 100GW was affected by the application frequencies, it did not affect yield.

GY was higher for the late-cycle cultivar M 7739 IPRO and 11% lower for the early-cycle cultivar NA 5909 RR. Carvalho et al. (2002) and Nogueira et al. (2012) found a positive direct effect of the number of days to maturation on grain yield of Brazilian soybean cultivars. The authors also observed a negative genetic correlation between earliness and GY. However, earliness is an adaptation mechanism of soybean to tolerate low water availability. The need for water increases during the development of the crop, reaching the maximum development at the flowering/grain filling stage. In this period, the plant needs 7 to 8 mm day-1; this amount decreases soon after this stage. Therefore, the management conditions used in this work favored the late-cycle cultivars, which have a longer cycle to accumulate photoassimilates, consequently leading to higher GY.

Agronomic performance of soybean cultivars under different irrigation water depths

The summary of the analysis of variance for plant height (PH), insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars grown under supplementary water depths in the 2015/16 and 2016/17 crop seasons is reported in Table 6.

The effect of years was significant for all variables, indicating that the climatic changes that occurred from one crop season to another affected the yield components and the soybean GY.

Table 6. Summary of the analysis of variance for plant height (PH), insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars grown under supplementary water depths in the 2015/16 and 2016/17 crop seasons.

Sources of Variation	Degrees of freedom	Mean Square			
		PH	IFP	100GW	GY
Block/Year	6	4.20E+2**	5.45E+0**	1.40E+0**	9.91E+5*
Year (Y)	1	1.53E+3**	4.97E+1**	1.86E+2**	4.84E+6**
Water depth (B)	5	2.58E+2**	1.85E+0^{ns}	3.29E+0**	5.50E+5^{ns}
Cultivar (C)	4	4.35E+3**	1.28E+2**	7.17E+1**	3.15E+6**
B * Y	5	3.17E+2**	1.76E+1**	2.75E+0**	2.45E+5^{ns}
C * Y	4	4.41E+2**	4.30E+1**	5.37E+0**	7.21E+5^{ns}
B * C	20	4.32E+1*	3.28E+0^{ns}	5.16E-1^{ns}	1.38E+5^{ns}
B * C * Y	20	3.30E+1^{ns}	2.39E+0^{ns}	1.88E+0**	5.67E+5^{ns}
Error plot	15	2.09E+1	1.93E+0	3.71E-1	3.84E+5
Error splitplot	159	3.30E+1	3.72E+0	5.68E-1	3.62E+5
CV (%) plot		6.64	10.65	3.46	10.80
CV (%) splitplot		8.34	14.81	4.28	10.49

^{ns}, * and **: not significant, significant at 5 and 1% probability by the F test, respectively; CV: coefficient of variation. Source: Authors.

It is possible to observe in the Table 6 that the supplementary water depths influenced only the variables plant height (PH) and hundred grain weight (100GW). Cultivars presented differences for all variables evaluated. The water depths x years and cultivars x years interaction were significant only for the agronomic variables. This effect can be attributed mainly to the climatic effects that occurred from one crop season to another. The water depths x cultivars interaction was significant only for PH. Thus, as in the first experiment, the interaction between the three factors tested was not significant for all variables evaluated.

The mean values for plant height (PH) of soybean cultivars in function of the supplementary water depths and PH adjustment (R^2) is reported in the Table 7. Look that three cultivars showed PH adjustment in function of the supplementary water depths (Table 7). Cultivars P98Y30 RR, DESAFIO RR, and M 7739 IPRO had a linear behavior in relation to the value of the supplementary water depth. Cultivar POWER IPRO had the highest PH means, while NA 5909 RR presented the lowest means, regardless of the supplementary water depth. This variable (PH) is one of the main factors affecting soybean mechanized harvesting. Sediyama et al. 2016 stated that soybean plants should present between 60 and 120 cm for adequate mechanized harvesting, without risks of lodging. Therefore, only NA 5909 RR presented means below the recommended value, regardless of the water depth.

Table 7. Mean values for plant height (PH) of soybean cultivars in function of the supplementary water depths and PH adjustment (R^2).

	PH (cm)							
	Supplementary water depths (% ETc)							
Cultivars	0	25%	50%	75%	100%	125%	Equation	R^2
NA 5909 RR	55.4 c	54.3 d	56.1 d	55.3 c	58.3 c	57.1 d	Without adjustment	-
DESAFIO RR	65.1 b	69.6 b	66.6 c	70.8 b	69.7 b	73.4 b	0.05L+65.9	68.0
POWER IPRO	82.0 a	80.3 a	82.8 a	82.4 a	78.5 a	87.0 a	Without adjustment	-
P98Y30 RR	63.9 b	71.2 b	70.6 b	71.8 b	76.3 a	77.2 b	0.10L+65.9	86.6
M7739 IPRO	59.1 c	65.3 c	63.8 c	67.3 b	66.2 b	69.3 c	0.07L+61.1	76.0

Means followed by different lower-case letters in the columns differ from each other by the Scott-Knott's test ($p < 0.05$) and R^2. Source: Authors.

Observe in the Table 7 that corroborates Gava et al. 2016 tested the stress levels of water deficit and excess by applying 30, 50, 100, and 150% of ETc, at different phenological stages of the crop. Their results revealed that the total plant height was lower for water deficit at the vegetative growth stage. The total number of pods reduced when the water deficit occurred at the flowering stage, and hundred grain weight decreased considerably when the water deficit occurred at the grain filling stage. The water excess resulted in higher yields; however, it is worth mentioning that the experiment was carried out in sandy soil in and under greenhouse with all conditions controlled.

The means of insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars under different supplementary water depths. Cultivar M 7739 IPRO showed the best performance for all variables (Table 8).

Table 8. Means of insertion of the first pod (IFP), hundred grain weight (100GW), and grain yield (GY) of soybean cultivars under different supplementary water depths.

Cultivar	**IFP**	**100GW**	**GY**
	cm	g	kg ha^{-1}
NA 5909 RR	12.28 c	18.31 a	5318.5 b
DESAFIO RR	11.30 d	18.37 a	5911.0 a
POWER IPRO	12.07 c	17.01 b	5767.3 a
P98Y30 RR	14.43 b	15.70 c	5711.7 a
M7739 IPRO	15.08 a	18.56 a	5971.8 a

Means followed by different lower-case letters in the columns differ from each other by the Scott-Knott's test ($p < 0.05$). Source: Authors.

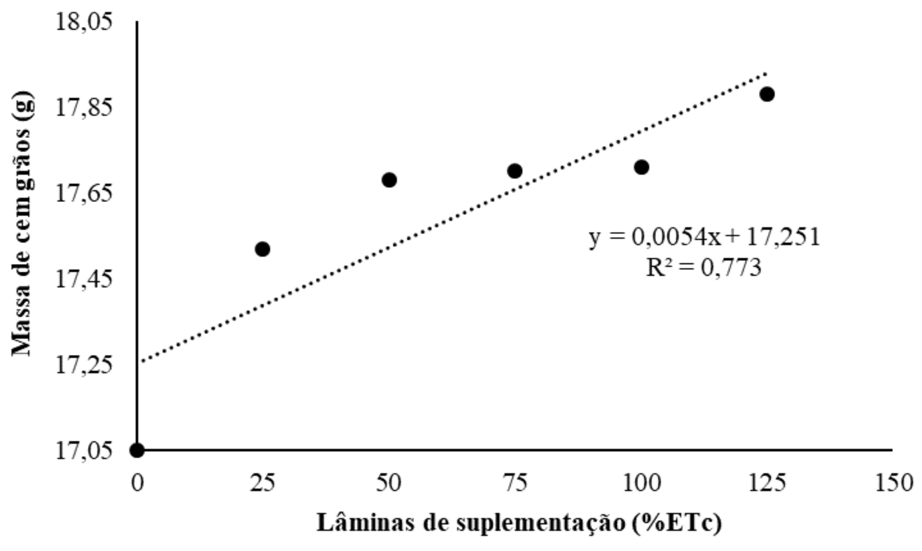
When evaluating IFP in the Table 8 look that cultivar POWER IPRO presented the lowest performance, and its mean was lower than the ideal (12 cm) for mechanized harvesting (Sediyama et al.,2016). Cultivars NA 5909 RR, DESAFIO RR, and M7739 IPRO showed the highest means for 100GW (Table 8). However, only NA 5909 RR was allocated in the group of cultivars with a low mean for GY.

Supplementary water application may increase yield to up to 60% in years when water deficit occurs at the grain filling stage (Gava et al., 2017). However, no water deficit was observed at the grain filling stage in neither crop season. This fact explains the absence of the effect of irrigation management on soybean yield.

An than we have to consider the variances in the weather of each agricultural year, in order to conclude whether or not irrigation has effects on soybean crops. In our work we have carried out two harvests in different years exactly to show the behavior of the cultivars in different weather situations.

Although no significant water deficits occurred, 100GW responded positively to good soil moisture conditions (Figure 2).

Figure 2. Linear regression for hundred grain weight (100GW) in function of supplementary water depths.



Source: Authors.

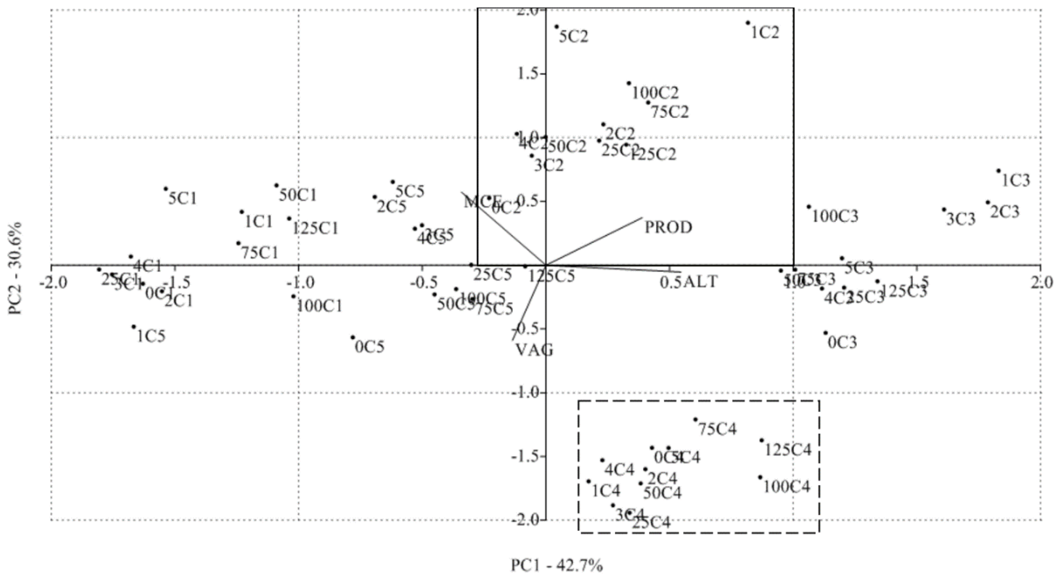
A linear behavior was observed in the Figure 2 in relation to the supplementary water depths, reaching a 5% increase in relation to the treatment without supplementary irrigation. According to (Jha et al., 2018), plants subject to water stress at the flowering and vegetative growth stages have significant reductions in yield, and supplementary irrigation contributes to increasing this variable. These authors also stated that a 20% reduction in rainfall over any 15-day period does not significantly affect soybean yield. However, drought periods with 50% or more of rainfall reductions lead to reduced yields.

The principal component analysis applied joining both experiments

The joint analysis of all sources of variation by the principal components analysis revealed that the first two principal components (PC) accumulated 74% of the total variability observed in the two experiments. The number of each treatment is showed in the Appendix A. This value is higher than that recommended by (Mingoti, 2005) for a reliable analysis. The use of this technique allows identifying similar treatments and the variables that contributed to this similarity.

The treatments that most correlated with yield were the cultivar DESAFIO RR subject to different irrigation managements (highlighted by the rectangle with a continuous line). This result indicates this is the main cultivar to be used by producers of the Central-West region of Brazil, regardless of the irrigation management (Figure 3).

Figure 3. Principal components analysis applied to different soil moisture management in soybean cultivars grown in the 2015/16 and 2016/17 crop seasons.



Source: Authors

Observe in the Figure 3 that the five cultivars in the treatment without irrigation are followed by the number zero. Under no water application conditions, cultivars presented completely different performances, corroborating the results of Gava et al. 2018. When evaluating six soybean cultivars, at four levels of supplementary irrigation, the authors verified completely different responses among cultivars. Some cultivars responded considerably well when subject to favorable moisture conditions and others not. These results are related to the genotypic traits of each cultivar since the expression of the genes in soybean is induced by several abiotic stresses, such as cold, drought, salinity, and heat, influencing its different agronomic performance (Kidokoro et al., 2015).

The clustering formed by the treatments within the dashed-line rectangle refers to cultivar P98Y30 RR. This result demonstrates the homogeneity of the agronomic performance of this cultivar, regardless of the moisture management. This phenomenon may be related to its determined growth habit, unlike the other cultivars tested in this work. According to Tagliapietra et al. 2018, the leaf area index (LAI), which is positively related to yield, varies among cultivars of different growth habits. The authors found an optimum LAI at the growth stage (R1) to reach the yield potential of 3.4 (undetermined) and 4.5 (determined) for yields higher than 4500 kg ha^{-1}. These results suggest that soybean management practices involving LAI and high yield potential should be adjusted according to the maturity, growth habit, and sowing date in a subtropical environment.

4. Conclusions

Soybean cultivars differ between each other for their agronomic variables due to their genetic traits, even under optimal potential conditions of soil moisture.

As research like this should continue to be developed year by year as cultivars are always under development and new releases.

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Appendix A. Coding of treatments for principal components analysis

Treatments	Irrigation	Cultivar
1	Rainfed	Na 5909 RR
2	Rainfed	Desafio RR
3	Rainfed	Power IPRO
4	Rainfed	P 98Y30 RR
5	Rainfed	M 7739 IPRO

Irrigation frequency			Supplementary Water depths		
Treatments	Irrigation	Cultivar	Treatments	Irrigation	Cultivar
6	1 day	Na 5909 RR	31	25%	Na 5909 RR
7	1 day	Desafio RR	32	25%	Desafio RR
8	1 day	Power IPRO	33	25%	Power IPRO
9	1 day	P 98Y30 RR	34	25%	P 98Y30 RR
10	1 day	M 7739 IPRO	35	25%	M 7739 IPRO
11	2 days	Na 5909 RR	36	50%	Na 5909 RR
12	2 days	Desafio RR	37	50%	Desafio RR
13	2 days	Power IPRO	38	50%	Power IPRO
14	2 days	P 98Y30 RR	39	50%	P 98Y30 RR
15	2 days	M 7739 IPRO	40	50%	M 7739 IPRO
16	3 days	Na 5909 RR	41	75%	Na 5909 RR
17	3 days	Desafio RR	42	75%	Desafio RR
18	3 days	Power IPRO	43	75%	Power IPRO
19	3 days	P 98Y30 RR	44	75%	P 98Y30 RR
20	3 days	M 7739 IPRO	45	75%	M 7739 IPRO
21	4 days	Na 5909 RR	46	100%	Na 5909 RR
22	4 days	Desafio RR	47	100%	Desafio RR
23	4 days	Power IPRO	48	100%	Power IPRO
24	4 days	P 98Y30 RR	49	100%	P 98Y30 RR
25	4 days	M 7739 IPRO	50	100%	M 7739 IPRO
26	5 days	Na 5909 RR	51	125%	Na 5909 RR
27	5 days	Desafio RR	52	125%	Desafio RR
28	5 days	Power IPRO	53	125%	Power IPRO
29	5 days	P 98Y30 RR	54	125%	P 98Y30 RR
30	5 days	M 7739 IPRO	55	125%	M 7739 IPRO

Source: Authors

In the Appendix A is presented the coding of treatments for principal components analysis for better understand the information in the Figure 3.

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