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REGULAR ARTICLE

Influence of plant spatial arrangement and water supplementation on soybean productivit

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Abstract

The present study aims to evaluate the influence of plant spatial arrangement and water supplementation on soybean yield for the 2020/21 crop year, in the edaphoclimatic conditions of the central region of Rio Grande do Sul (Brazil). The field experiment was installed in an experimental area of the Rio Grande do Sul State University (UERGS) in the city of Cachoeira do Sul. Supplementary irrigation provided positive increases in soybean yield between 13% (row spacing of 0.75 m) and 35% (row spacing of 0.50 m). The conventional row spacing of 0.50 m can be recommended as a spatial arrangement strategy for both irrigated areas (productivity 5,196.6 kg ha^{-1}) and rainfed areas (productivity 3,360.0 kg ha^{-1}), optimizing costs regarding the mechanization of farming.

Keywords

Soybean productivity; Water Supplementation; Line spacing.

Introduction

In recent years Brazil has become the largest producer of soybeans in the world. According to the eighth survey of the Brazilian National Supply Company (CONAB) from May 2021, in the 2020/21 harvest, the country reached a production of 135.4 million tons, 8.5% higher than the last harvest. The planted area grew by 4.2%, compared to the previous harvest, reaching 38,502.1 million hectares. Yield increased by 4.1% compared to the previous crop, reaching 3,517.0 kg ha^{-1} (Conab, 2021). In the state of Rio Grande do Sul, soybean occupies most of the cultivated area in the summer, where, in the 2020-2021 harvest, 6,075,024 ha were planted with a production of 20.2 million tons and an average productivity of 3,326.0 kg ha^{-1}, according to a survey by Emater/rs-ascar (2020).

In the state of Rio Grande do Sul, the main factor responsible for soybean yield variations is the climate (Matzenauer et al., 2018; Zanon et al., 2018). The amount and distribution of rainfall during January and March may be the main limiting factor for soybean productivity in that region (Berlato; Fontana, 2003; Zanon et al., 2016), with estimates of 93% of soybean yield losses due to water deficit (Berlato; Fontana, 2003).

According to Gajić et al. (2018), irrigation is necessary for soybean cultivation in dry and semi-dry years, when seasonal rainfall is less than 300 mm. In wet years, where there is a favourable amount and distribution of rainfall during the development cycle, yields are similar to those obtained with irrigation. Oliveira et al. (2001), in a study in the central region of Rio Grande do Sul, evaluated the productivity of soybean cultivars in the 2018/19 and 2019/20 harvests. When the accumulated rainfall during the cycle totalled 639 and 312 mm, the authors observed an increase in productivity with irrigation of 7% and 34%, respectively.

Despite the reduction in soybean productivity due to the water deficit, especially in La Niña years, most of the areas cultivated with the crop in this region are rainfed (Sentelhas et al., 2015). Only 2.98% of the total cultivated area is irrigated by about 2617 central pivots, totalling approximately 178,050 hectares (Ribeiro et al., 2018). According to Montoya et al., (2017), the use of supplemental irrigation can significantly increase soybean productivity, stabilizing agricultural production, especially during years of water scarcity.

In addition, other management practices must be thought of to achieve greater crop yields. Among them, there is the adjustment in the spatial arrangement of plants, which can contribute to an increase in productivity, with low costs and little impact on the environment, since more inputs are not necessary for this practice (Balbinot Junior, 2017). The spatial arrangement of plants directly influences the intraspecific competition of plants for environmental resources, such as water, light, and nutrients (Ferreira et al., 2016). And

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consequently, intraspecific competition modifies the physiology of plants (Werner et al., 2016).

Silveira et al. (2021) evaluated the spatial arrangement of plants in the agronomic performance of soybean and found positive increases in productivity close to 20% with the use of the paired arrangement of 0.25 x 0.50 m compared to the conventional spacing of 0.50 m between rows. Carmo et al. (2018), obtained higher soybean productivity when smaller row spacing was used (reduced arrangement of 0.25 m) compared to the traditional arrangement of 0.50 m.

In view of the above, the present study aims to evaluate the influence of the spatial arrangement of plants and water supplementation on soybean productivity for the 2020/21 harvest, in the soil and climate conditions of the central region of Rio Grande do Sul (Brazil).

Materials and methods

In the 2020/21 harvest, a field experiment was carried out with soybean in an experimental area of the State University of Rio Grande do Sul, located in the Três Vendas district in the city of Cachoeira do Sul (29º53 ' S and 53º 00' W, altitude of 125 m). The climate of the region is classified by Köppen as humid subtropical, Cfa, predominant in the South region. The soil of the experimental area was classified as a typical dystrophic Red Argisol (Embrapa, 2013).

The experiment was carried out in a randomized complete block design with split plots, in a factorial scheme (4 x 2) in four replications. The 'A' factor consisted of four spatial arrangements of plants: row spacing of 0.25 m, 0.50 m, 0.75 m, and 0.50 x 0.25 m (paired). Factor 'B' consists of two water regimes: irrigated and non-irrigated. In the irrigated water regime, irrigations were carried out to supplement the rainfall, keeping the soil water storage close to 60% of the available water capacity (AWC).

The cultivar Brasmax Zeus IPRO was used. Sowing was carried out on November 5^{th}, 2020, with a tractor-seeder set, in the no-tillage system, maintaining the same sowing density in all treatments of 300,000 plant ha^{-1}. The other managements and cultural treatments followed the agronomic recommendations for the soybean crop.

Irrigation was performed using a conventional sprinkler system, in which sprinklers (model Plona Pa 150) were installed at a spacing of 12 x 12 m, with an application rate of 12 mm h^{-1}. The crop was irrigated when soil water depletion represented approximately 40% of the AWC; moisture between field capacity (0.318 cm^3 cm^{-3}), and the permanent wilting point (0.148 cm^3 cm^{-3}), in the soil layer, 0 to 60 cm depth of soil profile.

For the calculation of the water balance, rainfall, and irrigation were the inputs of water in the system. When the rain was greater than the real AWC, the excess value was not considered as effective rain, counting as losses by surface runoff and percolation. Crop evapotranspiration (ETc) was the output of water from the system and its estimate was based on the proposal by Allen et al. (1998). The meteorological data needed to calculate the reference evapotranspiration (ETo) were obtained from an automatic meteorological station located close to the experiment site, managed by Irriga Global, which made these data available. For the adjustment of the Kc curve (simple) the methodology proposed by Allen et al. (1998) was applied, with the canopy cover fraction (Fc). The Fc was estimated using a 0.50 x 0.50 m checkered grid, with a 0.10 x 0.10 cm mesh, in which the canopy coverage was obtained in relation to the maximum it could occupy for that row spacing and between plants. Phenological evaluations were also carried out to monitor the crop development cycle.

The determination of the leaf area of the plants was performed when they were in the phenological stage of R3. For this, two plants were collected per experimental plot, measuring the width and length of the central leaf of each trefoil, manually with the aid of a ruler. Afterwards, the leaf area of each trefoil was calculated using the equation proposed by Richter et. al (2014), and the leaf area of all trifoliate was made to the leaf area of the plant. The leaf area index (LAI) was obtained by the ratio between the total leaf area of the plant and the area of soil occupied by the plant. The plant height (m) was measured from the soil surface to the last node, on the same day as the leaf area.

For the productivity analysis, the plants were manually harvested in the central area of each experimental plot (4.5 m^2 for the spatial arrangement in which the plants were spaced at 0.75 m between rows and 3 m^2 for the other spatial arrangements). The counting of plants, threshing, cleaning, determination of grain moisture, and weighing were subsequently carried out. The weight obtained was corrected for a humidity of 13% and extrapolated to hectare (kg ha^{-1}). For the analysis of the yield components, four plants were randomly selected per plot, which were processed manually considering the number of productive nodes, number of pods plant $^{-1}$, number of grains pod^{-1}, and weight of one thousand grains (WTG) (g). To determine the WTG, the moisture was measured, and the weight obtained was corrected to a moisture content of 13%.

The response variables were subjected to analysis of variance by the F test and complementary analysis by the Tukey test, at a level of 5 % error probability, using the Sisvar software.

Results and discussion

The accumulated rainfall during the soybean crop development cycle totalled 426 mm, exceeding the accumulated evapotranspiration of the crop, which was 403 mm. For the irrigated water regime, due to the irregular distribution of rainfall, there was a need for supplementation of 168 mm to maintain soil water storage at desired levels (Figure 1).

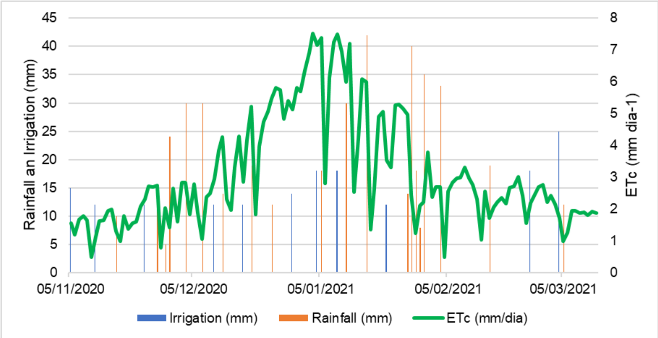

Figure 1. Result of crop evapotranspiration, rainfall, and irrigation (irrigated water regime) throughout the soybean crop development cycle. Cachoeira do Sul, 2021.

The demand for irrigation had already started in the sowing and initial phase of the development cycle (Figure 1), which is one of the critical periods relating to water deficit for the establishment of the culture (Farias et al., 2001). This demand occurred mainly in the reproductive phase, when evapotranspiration reached its maximum, which is to say greater than 7 mm day^{-1}. In the reproductive phase of the soybean crop, it is important that no water deficit occurs, since this is the phase in which the productivity components will be defined (Gajić et al., 2018; Zanon et al., 2018).

Table 1 shows that there was an interaction between the factors for the following response variables: plant height, LAI, WTG, and productivity. On the other hand, the number of pod grains-1, the number of pod plants-1, and the number of productive nodes were influenced only by the water regime factor. The results of these variables are shown, bellow, in Table 2.

Table 1. Summary of analysis of variance for the response variables. Cachoeira do Sul, 2021.

	Calculated F value						
S.V	Plant Hight	LAI	productive nodes	pod plants $^{-1}$	pod grains $^{-1}$	WTG	Productivity
SA	3.66*	5.11*	4.09^{ns}	0.65^{ns}	5.05^{ns}	0.02*	6515.00*
B	560.75*	57.12*	68.29 *	30.65*	14.31*	17.77*	37.99*
A * B	5239.00*	0.80*	0.31^{ns}	3.08^{ns}	14.99^{ns}	1.92*	3.99*
Rep.	1.16^{ns}	1.08^{ns}	0.56^{ns}	0.07^{ns}	4.27^{ns}	5.73^{ns}	0.15^{ns}
CV (%)	3.85	28.22	5.18	11.15	4.15	2.27	12.44

Where: S.V = source of variation; Rep.= repetitions; SA = spatial arrangement; B = water regime factor; LAI = leaf area index; WTG = weight of one thousand grains; CV = coefficient of variation; * Pr>Fc equal to or less than 0,05; ^{ns} = Pr>Fc bigger than 0,05.

Table 2. Results obtained for the response variables in the different spacings between rows that provided different spatial arrangements of plants, as well as the evaluated water regimes (irrigated and rainfed). Cachoeira do Sul, 2021.

Response variables	**Water regime**	**Spatial arrangement (m)**							
		0.25		**0.50**		**0.25 x 0.50**		**0.75**	
Plant hight (m)	Irrigated	1.15	aA	1.10	aA	1.15	aA	1.08	aA
	Rainfed	0.84	bA	0.84	bA	0.75	bB	0.80	bAB
LAI	Irrigated	6.58	aB	8.40	aAB	11.45	aA	9.80	aAB
	Rainfed	3.96	bA	3.99	bA	4.57	bA	4.27	bA
No. pod grains^{-1}	Irrigated	2.55	aA	2.50	aA	2.58	aA	2.53	aA
	Rainfed	2.34	bA	2.32	aA	2.34	bA	2.32	bA
No. productive nodes	Irrigated	17.50	aA	16.75	aA	17.00	aA	16.25	aA
	Rainfed	15.00	bA	14.75	bA	14.75	bA	13.50	bA
No. pod plants $^{-1}$	Irrigated	58.25	aA	59.25	aA	60.50	aA	59.50	aA
	Rainfed	50.75	bA	50.50	bA	48.00	bA	48.50	bA
WTG (Kg)	Irrigated	0.210	aAB	0.214	aA	0.204	aB	0.205	aB
	Rainfed	0.199	bA	0.204	bA	0.198	bA	0.200	bA

Numbers followed by the same capital letters in the columns and by the same lowercase letters in the rows do not differ from each other by the Tukey test at a 5% error probability level.

The height of irrigated plants in the R3 stage was on average 1.12 m, regardless of the spatial arrangement used (Table 2). The rainfed plants had a lower height, which was 0.84 m for plants in the spatial arrangement with row spacing of 0.25 and 0.50, and 0.80 and 0.75 m for plants in the spatial arrangement of 0. 75 m between the rows and 0.25 x 0.50 m paired, respectively. According to Farias et al. (2020), the stress caused by water deficiency determines the presence of poorly developed plants, of small stature, with small leaves and short internodes.

The LAI was higher for irrigated soybean, reaching a maximum value of 11.4 for plants in the paired spatial arrangement of 0.25 x 0.50 m, and a minimum of 6.6 for plants in the spatial arrangement of 0.25 m row spacing. For the spatial arrangements of 0.50 and 0.75 m between rows, the irrigated plants showed an intermediate LAI of 8.4 and 9.8, respectively. According to Zanon et al. (2018), for soybeans to reach high yields, a LAI greater than 6.3 is required. The rainfed plants had an average LAI of 4.20, regardless of the spatial arrangement adopted (Table 2). According to Taiz and Zeige (2013), one of the first responses to water stress is the reduction in growth, explaining the lower values of LAI and plant height for the rainfed specimens.

The number of pod grains^{-1} was around 9% higher in irrigated soybean, not being influenced by the spatial arrangement of plants (Table 2). According to Board (2000), the management practice such as spacing between rows normally does not affect the number of grains per pod, as it is an intrinsic characteristic of the plant. Mundstock and Thomas (2005) also emphasize that the number of pod grains^{-1}, among other direct components, is the one with the least variation.

The number of productive nodes and the number of plant pods^{-1} were increased by 14 and 17%, respectively, with the use of supplementary irrigation. However, they were also not influenced by the spatial arrangement of plants, showing average values of 16.8 and 14.5 productive nodes, as well as 59.4 and 49.4 pods plant^{-1} for the irrigated and rainfed water regime, respectively (Table 2).

The lower water availability at the end of December (Figure 1) contributed to the reduction in the number of plant pods $^{-1}$ and productive nodes in the rainfed area. Deficits during flowering and grain filling cause physiological changes in the plant, such as stomatal closure and leaf wilting. As a consequence, there is an increase of premature flower drop and pod abortion (Streck, 2004; Taiz and Zaiger, 2013).

The highest WTG was 0.214 kg for irrigated soybeans in the 0.5 m spatial arrangement, followed by 0.210 kg for plants in the 0.25 m spatial arrangement (Table 2). On the other hand, for rainfed soybeans, there were no statistical differences between the spatial arrangements for the WTG, with an average value of 0.19 kg. Regarding this, Correa et al. (2019) observed that sprinkler irrigation promoted an increase in WTG in the average of the cultivars under study, in the order of 20 g in relation to the treatment without irrigation.

The highest soybean yield was under irrigation (Figure 2), given the positive increments in growth parameters and in all evaluated yield components (Table 2). The increase in productivity with irrigation was 35, 24, 23, and 13% for the spatial arrangements of 50, 0.25 x 50, 0.25, and 0.75 m, respectively. Oliveira et al. (2020), under conditions which were similar to the study with soybean in conventional spacing (0.5 m), observed that the yield of irrigated soybean was 39% higher than that of rainfed soybean. Supplementary irrigation of soybeans in Rio Grande do Sul is an essential practice for consistency and the pursuit of high levels of productivity (Battisti et al., 2018).

The results presented in Figure 2 demonstrate the importance of supplementary irrigation as a strategy to increase soybean productivity, overlapping the spatial arrangement, as the yields were similar between them, with the exception of the 0.75 m line spacing in the irrigated water regime.

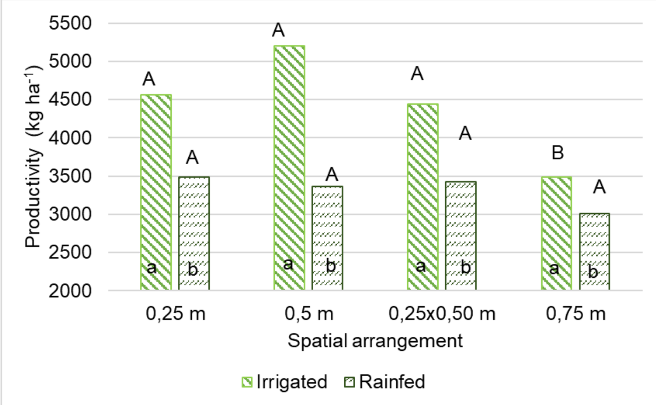

Figure 2. Results of soybean productivity in the different adopted spatial arrangements, as well as irrigated and rainfed water regimes. The capital letters compare the different spatial arrangements for the same water regime and the small letters compare water regimes for the same spatial arrangement, using the Tukey test at a 5% error probability level. Cachoeira do Sul, 2021.

The row spacing of 0.75 m stood out as a negative strategy for the spatial arrangement of the soybean cultivar evaluated in this study under irrigation (Figure 2). It presented a productivity of 3,480.6 kg ha^{-1}, which is 26% lower than the average productivity of 4,731.2 kg ha^{-1} obtained for the spatial arrangements of 0.25 and 0.50 m between rows, and 0.25 x 0.50 m (paired). In the rainfed water regime, the average soybean yield was 3351.0 kg ha^{-1}, not being influenced by the spatial arrangement of the plants (Figure 2).

In this case (Figure 2), the productivity results demonstrate that the conventional spacing between rows of 0.50 m can be used both for the irrigated area and for the rainfed area, optimizing the mechanization costs of the crop. Therefore, the reduction or increase of spacing between rows requires adaptations in the seeder, making the sowing operation more expensive.

Silveira et al. (2021), evaluating the cultivar CA 7442 in a rainfed area in Paraná, obtained a productivity of: 4,732.0 kg ha^{-1} for the 0.25 x 0.50 m (paired); of 3,817.0 kg ha^{-1} for 0.50 m spacing, and of 3,628.0 kg ha-1 for 0.25 m spacing. Carmo et al. (2018), using the BMX Desafio variety, found a better performance when using smaller row spacing (reduced arrangement of 0.25 m), with a superiority of 356 kg ha^{-1} in relation to the traditional arrangement of 0.5 m.

The divergence of results is in agreement with what Balbinot et al. (2015) affirms: many studies have shown that the soybean crop present little response to changes in the spatial arrangement, as the crop adapts to environmental and management conditions, changing its morphology, plant structure and yield components (Pires et al., 2000). This demonstrates the need for further studies evaluating the specifics of each cultivar in each producing region, since Walker et al. (2010) report that changes in grain yield due to reduced spacing are cultivar dependent.

Conclusions

Under the conditions in which this work was carried out, for the evaluated cultivar (Brasmax Zeus IPRO), the conventional row spacing of 0.50 m can be recommended as a spatial arrangement strategy both for irrigated areas (productivity 5,196.6 kg ha^{-1}) as well as for rainfed areas (productivity 3,360.0 kg ha^{-1}), optimizing the costs related to the mechanization of the crop. Supplementary irrigation provided positive increases in soybean yield between 13% (row spacing of 0.75 m) and 35% (row spacing of 0.50 m).

References

Allen, R. G.; Pereira, L.S.; Raes, D.; Smith, M. (1998). *Crop vapotranspiration - Guidelines for computing crop water requirements***.** Roma: FAO, 300p. (Irrigation and Drainage Paper, 56).

Balbinot Junior, A. A.; Fleck, N. G. (2005). Manejo de plantas daninhas na cultura do milho em função do arranjo espacial de plantas e características dos genótipos. ***Ciência Rural***, 35 (1), 245-252.

Balbinot, A. A.; Procópio, S. O.; Debiasi, H.; Franchini, J. C. (2015). *Densidade de plantas na cultura da soja*, Londrina: Embrapa Soja, 36 p, ISSN 2176-2937.

Balbinot Junior, A. A.; Procópio, S. O.; Debiasi, H.; Franchini, J. C. (2014). *Redução do espaçamento entre linhas na cultura da soja*. Londrina: Embrapa Soja. 8 p. (Embrapa Soja. Circular técnica, 106).

Battisti, R.; Sentelhas, P. C.; P.P. S.; Nendel, C.; C. Gil M. De S.; Farias, J. R. B.; Basso, C.J. (2018). Assessment of crop-management strategies to improve soybean resilience to climate change in Southern Brazil**.** *Crop & Pasture Science* 69(2), 154-162.

Berlato, M.A.; Fontana, D.C. (2003). El *Niño e La Niña: impactos no clima, na vegetação e na agricultura do Rio Grande do Sul; aplicações de previsões climáticas na agricultura*. Porto Alegre: UFRGS, 110p.

Carmo, E.L.; Braz, G. B. P.; Simon, G.A.; Silva, A.G.; Rocha, A.G.C. (2017). Desempenho agronômico da soja cultivada em diferentes épocas e distribuição de plantas. *Revista Ciência Agroveterinária*, Lages, SC, Brasil. https://doi.org/10.5965/223811711712018061

Conab. *Boletim de Monitoramento Agrícola* N. 8 - V. 8, 2021. Disponível in: https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos. Acesso em: 06 set. 2021.

Corrêa, M.F.; Navroski, R.; Schuch, L.O.B.; Vernetti Junior, F.J.; Almeida, T.L.; Rodrigues, H.C.S.; Nadal, A. P.; Gadotti, G. I. (2019). Efeito da irrigação por aspersão no rendimento e potencial fisiológico das sementes de soja. *Revista de Ciências Agroveterinárias*, Lages, 18 (4), 482-488. DOI: https://doi.org/10.5965/223811711832019482

Emater/RS-ascar. Safra de verão 2020-2021. *Estimativas iniciais de área, produtividade e produção***.** Setembro, 2020. Disponível em: http://www.emater.tche.br/site/arquivos_pdf/safra/safraTabela_10092020.pdf Acess in: 15 de maio, 2021.

Empresa Brasileira De Pesquisa Agropecuária – EMBRAPA (2013). *Sistema brasileiro de classificação de solos*. Brasília, Editora :Embrapa, 3ed., p.353.

Farias, J. R. B.; Assad, E.D.; Almeida, I.R.; Evangelista, B.A.; Lazzarotto, C.; Neumair, N.; Nepomuceno, A.L. (2001). Caracterização de Risco de Déficit Hídrico nas Regiões Produtoras de Soja no Brasil. *Revista Brasileira de Agrometeorologia*, 9 (3), 415-421.

Farias, J. R. B.; Neumaier, N.; Nepomuceno, A. L. *Árvore do conhecimento soja*. EMBRAPA.

Ferreira, A. S.; Balbinot Junior, A. A.; Werner, F.; Zucareli, C.; Franchini, J. C.; Debiasi, H. (2016). Plant density and mineral nitrogen fertilization influencing yield, yield components and concentration of oil and protein in soybean grains. *Bragantia*, 75 (3),362-370.

Gajić, B.; Kresovic, B.; Tapanarova, A.; Zivotic, L.; Todorovic, M. (2018). Effect of irrigation regime on yield, harvest index and water productivity of soybean grown under different precipitation conditions in a temperate environment. *Agricultural Water Management*, Elsevier, 210, 224-23.

Mattioni, F.; Corrêa, L. A. V.; Gomes, J. C. C.; Wünch, J. (2008). Arranjos espaciais, plantas concorrentes e características agronômicas da soja (*Glycine max* (L.) merril) em cultivo orgânico. *Revista Brasileira de Agrociência*, 143 (4), 21-32.

Matzenauer, R.; Radin, B.; C, A. (2018). Rendimento de grãos de soja e de milho, no Rio Grande do Sul, não difere entre eventos El Niño Oscilação Sul. *Revista Agrometeoros*, 26 (1), 123-129.

Montoya, F. C.; Pintos, F.; Otero, A. (2017). Effects of irrigation regime on the growth and yield of irrigated soybean in temperate humid climatic conditions. *Agricultural Water Management*, Elsevier, 193, 30–45.

Mundstock, C.M.; Thomas, A.L. (2005). *Soja: fatores que afetam o crescimento e rendimento de grãos*. Porto Alegre: Universidade Federal do Rio Grande do Sul, 31p.

Oliveira, Z. B.; Knies, A. E.; Bottega, E. L.; Silva, C. M.; Gomes, J. I. T. (2021). Influência da irrigação suplementar na produtividade de cultivares de soja para a safra e safrinha 2018-19 e 2019-20 na região central do RS. *Brazilian Journal of Development*, 7,15580-15595.

Oliveira, Z.; Knies, A. E.; Gomes, J. I. T. (2020). Produtividade de cultivares de soja com e sem irrigação suplementar para a safra e safrinha de 2019/20 na região central do RS. *Brazilian Journal of Development*, 6, 81268-81284.

Pires, J.L.F.; Costa, J.A.; Thomas, A.L.; Maehler, A.R. (2000). Efeito de populações e espaçamentos sobre o potencial de rendimento da soja durante a ontogenia. *Pesquisa Agropecuária Brasileira*, Brasília, 35 (8), 1541-1547.

Rambo, L.; Costa, J. A.; Pires, J. L. F.; Parcianello, G.; Ferreira, F. G. (2004). Estimativa do potencial de rendimento por estrato do dossel da soja, em diferentes arranjos de plantas. *Ciência Rural,* 34 (1), 33-40.

Richter, G.L.; Zanon, A.; Streck, N.A.; Guedes, J.V.C.; Kräulich, B.; Rocha, T.S.M.; Winck, J.E.M.; Cera, J.C. (2014). Estimativa da área de folhas de cultivares antigas e modernas de soja por método não destrutivo. *Bragantia***,** Campinas, 73 (4), 416-425.

Ribeiro, L. M.; Ceccon, G.; Mechi, I. A.; Santos, A. L. F.; FachinellI, R.; Makino, P. A (2018). Produtividade da soja em sucessão a cultivos de outono-inverno. *Revista Agrarian,* Dourados, 11 (40),120-131.

Sentelhas, P. C; Battisti, R.; Câmara, G.M.S; Farias, J.R.B.; Hampf, A.C.; Nendel, C. (2015). The Soybean Yield Gap in Brazil - Magnitude, Causes and Possible Solutions for a Sustainable Production. *Journal of Agriculture Science***,** Cambridge, 153,1394-1411.

Silveira, D.A.; Silveira, B.B.; Prete, C. E.C.; Bahry, C.A.; Nardino, M. (2021). Agronomic performance of soybean with indeterminate growth habit in different plant arrangements. *Communications in Plant Sciences*.11, 9-2.

Solano, L.; Yamashita, O. M. (2011). cultivo de soja em diferentes espaçamentos entre linhas. *Varia Scientia Agrárias*, 02, 35-47.

Streck, N.A. (2004). Do we know how plants sense a drying soil?. *Ciência Rural*. Santa Maria,v. 34, p.581-584.

Taiz, L.; Zeiger, E. (2013). *Fisiologia vegetal***.** 5.ed. Porto Alegre: Artemed, p. 954.

Walker, E. R.; Mengistu, A.; Bellaloui, N.; Koger, C.H.; Roberts, R.K.; Larson, J. A. (2010). Plant population and row-spacing effects on maturity group III soybean. *Agronomy Journal*, 102 (3), 821-826.

Zanon, A. J.; Silva, M. R., Tagliapietra, E.L.; Cera, J.C. (2018). *Ecofisiologia da soja- Visando altas produtividades***.** 1° ed. Santa Maria: [n.s.], 2018. ISBN: 978-85-54856-14-4. 136p.

Zanon, A. J.; Streck, N.A.; Grassini, P. (2016). Climate and management factors influence soybean yield potential in a subtropical environment. *Agronomy Journal*, 108,1447-1454.