Growth and yield of soybean plants under water deficit and application of foliar fertilizer

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Abstract

The objective of this work was to assess the effects of a commercial foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil) on growth and yield of soybean plants grown under water deficit. The experiment was conducted for 105 days from November 2021 to February 2022 in a greenhouse at the State University of Goiás, in Ipameri, GO, Brazil. A completely randomized design was used, with a 2×5 factorial arrangement and three replications. The first factor consisted of foliar fertilizer rates (0 and 300 mL ha^{-1}), and the second factor consisted of water depths applied to the plants (25%, 50%, 75%, 100%, and 125% of the daily evapotranspiration). Morphological variables and agronomic components of the crop were analyzed at 60 and 90 days after emergence. Water deficit at the R_5 reproduction stage limits the growth and yield of soybean plants. The important results found for vegetative and reproductive growth of plants treated with the foliar fertilizer were due to the greater number of leaves and transpiration of these plants, even under water deficit, denoting a higher photosynthetic potential. The foliar fertilizer did not mitigate water deficit effects on soybean plants grown in pots, but denoted potential for mitigation of damages in the field.

Keywords: Biostimulant; *Glycine max* L; grain crops; H2 Protector; plant stress.
Abbreviations: ETc_crop evapotranspiration; ETo_reference evapotranspiration; IPRO_ confers resistance to glyphosate and caterpillar; kc_crop coefficient; NEO_Neogen; R2_full bloom; R5_Start of grain filling; R9_viable harvest; SPAD_Soil Plant Analysis Development; V4_third leaf trifoliolate.

Introduction

Soybean (*Glycine max* L.) is an economically important oilseed crop in the world. The main producing countries are The United States, Brazil, and Argentina, representing approximately 35%, 33%, and 11% of the world's soybean grain production, respectively (Ritchie and Roser, 2022).
The area grown with soybean in Brazil in the 2020/2021 crop season was 38.53 million hectares, which resulted in a grain production of 135.91 million Mg, with a mean yield of 3,527 kg ha^{-1} (CONAB, 2022). Soybean is among the most important commercial legumes in the world; its grains can provide adequate oil, micronutrient, mineral, and protein contents for animal and human consumption (Malavolta, 2008). In addition, soybean is a raw material for industries of biodiesel, plastic, lubricants, and hydraulic fluids (Dall'Agnol, 2004).
Soybean and maize are used to produce vegetable oil and food and comprise 85% of animal feed and approximately 68% of the biodiesel produced in Brazil (CONAB, 2018; ANP, 2020). Soybean is a versatile grain that is a constituent of several products and has several byproducts; thus, the world interest in this legume has been increasing (Ainsworth et al., 2012).
In the next ten years (2018 to 2028), the demand for grain may increase in approximately 3.2% a year due to the population growth; the Brazilian Institute of Geography and Statistics (IBGE, 2018) estimates that the world population

will reach more than nine billion in 2050. In this context, increasing soybean production is needed for meeting the increasing world demand (Langevin, 2018).
However, increases in soybean grain supply should be connected to increases in yield, as there are environmental barriers for the opening of new areas because it is contrary to rationality in agriculture. Therefore, developing technologies that allow crop productions under stressful condition, such as water deficit, is important.
The state of Paraná, Brazil, underwent intense problems due to low water availability in the 2018/2019 crop season, presenting a yield decrease of approximately 15% (Procedi, 2020). Dry spells are common in the Cerrado biome, which encompasses the largest area of soybean crop production in Brazil (Albuquerque and Silva, 2008; Teixeira et al., 2020).
Annually, many private companies have products approved for use in agriculture, including biostimulants, resistance inductors, bioprotective products, and foliar fertilizers. These products are known for their morphophysiological effect on plants; they usually contain plant regulators, mineral nutrients, amino acids, and/or seaweed. Their action in the plant is usually beneficial by stimulating photosynthetic metabolism and partition of assimilates for grain production. They can be applied single or combined with other products to promote increases in shoot and root growth in soybean plants (Dos Santos et al., 2017). However,

increases in plant development may not occur, depending on the composition. According to Hermes et al. (2015), the application of a biostimulant did not modify the root length of soybean plants as they hypothesized.

The use of products containing biostimulants, such as plant regulators, has been promising due to the capacity of hormones to regulate many plant functions; however, the handling of these substances requires caution due to their significant action at low concentrations. The use of plant regulators for establishing soybean crops and decreasing flower and pod abortions has been frequent (Borges et al., 2014; Kutschera and Wang, 2012; Nonokawa et al., 2012; Passos et al., 2011; Pelacani et al., 2016). According to Bertolin et al. (2010), the use of a product containing biostimulants composed of cytokinin, indole-3-butyric acid (auxin), and gibberellic acid increased soybean grain yield in 37%.

According to Matos et al. (2019), a small flaw in the regulator rate applied may result in an opposite effect to that intended for the research or commercial crop, thus resulting in losses; for example, a low concentration of brassinosteroid can stimulate root system growth and absorption of soil solution, while the use of a high concentration has the opposite effect.

The nonexistence of recommendations for the management of agricultural species with the use of biostimulants, bioprotective products, resistance inductors, and foliar fertilizers recently released to the market for soybean plants stimulates researches to develop innovating techniques for their use in agricultural crops. The use of these products is an important tool for increasing soybean crop yield focused on meeting the trends and perspectives of increasing world demand for grains. Thus, the objective of this work was to assess the effects of a commercial foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil) on growth and yield of soybean plants grown under water deficit.

Results and discussion

Vegetative variables
The analysis of variance for root length, plant height, number of leaves, leaf area, SPAD index, leaf dry weight, transpiration rate, relative water content, number of pods per plant, number of grains per plant, grain weight per plant, and 1,000-grain weight are shown in Tables 1, 2, and 3. Root length and number of leaves were, respectively, 16% and 55% lower in soybean plants under water deficit when compared to the irrigated ones (control), denoting that water availability affects positively leaf emergence and that the pots probably limited the root growth under the water deficit conditions evaluated. According to Matos et al. (2019), leaf emergence and development of leaves are dependent on available water for absorption. Despite the higher absolute values found for plants subjected to application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil), the use of this product little affected root length, plant height, and leaf area, but had a strong effect on number of leaves. The results found for root length and number of leaves fitted to regression models.

Physiological variables
The SPAD index, transpiration, and relative water content found were 25.7%, 90.1%, and 38.5% lower in plants under water deficit, respectively, compared to those under adequate water supply conditions. Under low water availability conditions, plants commonly minimize water losses by decreasing transpiration. The maintenance of a stable relative water content in plants under low water availability indicates that the plant protection system through stomatal control is efficient to attenuate dehydration. The low SPAD index found was probably due to decreases in chlorophyll concentrations, as minimizing absorption of light energy to avoid oxidative stress is important under water deficit. Decreases in growth, relative water content, transpiration, and pigments are important responses of cultivated plants to water deficit (Campos et al., 2021; Matos et al., 2019).

Productive variables
The number of grains per plant, grain weight per plant, and 1,000-grain weight found were 19.2%, 58%, and 47.4% lower in plants under water deficit, respectively, compared to those under adequate water supply conditions. Despite the higher values, the foliar fertilizer had no significant effect on the production variables of soybean plants under water deficit. The more vigorous vegetative growth and, consequently, the greater photosynthetic potential of adequately irrigated plants made them more productive than plants under water deficit, as water limitation interferes with plant growth and limits pod production and grain filling. According to Borges et al. (2014), limitations in assimilates increase abortion of pods, decreasing pod formation and grain filling in soybean plants; thus, in the present study, water deficit limited plant growth, photosynthetic potential, and grain production.

The results found for plant height, number of leaves, root length, transpiration, relative water content, grain weight per plant, number of grains per plant, SPAD index, and 1,000-grain weight (Figures 1 and 2) were proportional to the water availability. The foliar fertilizer had significant effect on number of leaves and transpiration. Plant height increased as the water availability was increased, since water is essential for cell expansion and plant growth, as reported by Matos et al. (2019). Plants commonly invest in root system growth under dehydration conditions by water deficit to maximize absorption of soil solution and minimize stress. However, the present study was conducted in pots, which limited the deepening of the root system inside the container, thus, the stress was more severe, limiting the root system growth, resulting in a low root growth in plants under water deficit.

Significant decreases in transpiration by stomatal closure minimized decreases in relative water content, decreasing the dehydration of soybean plants; thus, this plant is classified as isohydric, with a hydraulic mechanism for protection against water deficit. However, these results are not consistent with those predicted for short-cycle species with high genetic improvement levels but are similar to those reported for perennial plants with low genetic improvement levels, such as *J. curcas* L., which also present isohydric mechanism (Campos et al. 2021).

Table 1. Analysis of variance, regression analysis, and mean test for root length (RL), plant height (PH), number of leaves (NL), and leaf area (LA) of soybean plants as a function of daily evapotranspiration water volumes and application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil).

Source of Variation	DF	RL	PH	NL	LA
			Mean squares		
Water volume (A)	4	37.450*	6.6167 ns	1324.1**	279.99 ns
Foliar fertilizer (B)	1	10.800 ns	3.3333 ns	1044.3**	8.9217 ns
Interaction A×B	4	17.050 ns	40.917*	248.05 ns	170.23 ns
Residue	20	9.2000	13.767	96.633	434.54
CV (%)	-	18.72	5.64	17.69	31.91
Components of model			P-value		
Linear	1	4.07*	0.78 ns	32.64**	0.21 ns
Quadratic	1	1.17 ns	5.04 ns	17.32**	0.01 ns
Water volume			Means		
Control		17.83 a	64.67 a	64.17 a	65.89 a
Water deficit		15.00 b	65.83 a	29.17 b	66.98 a
Foliar fertilizer rate			Means		
300 mL ha^{-1}		16.80 a	66.13 a	61.47 a	64.78 a
0 mL ha^{-1}		15.60 a	65.47 a	49.67 b	65.87 a

DF = degrees of freedom; CV = coefficient of variation; * = significant at 5% probability; ** = significant at 1% probability; ns = not significant by the F test. Means followed by the same letter in the columns are not different from each other by the Tukey's test at 5% significance level.
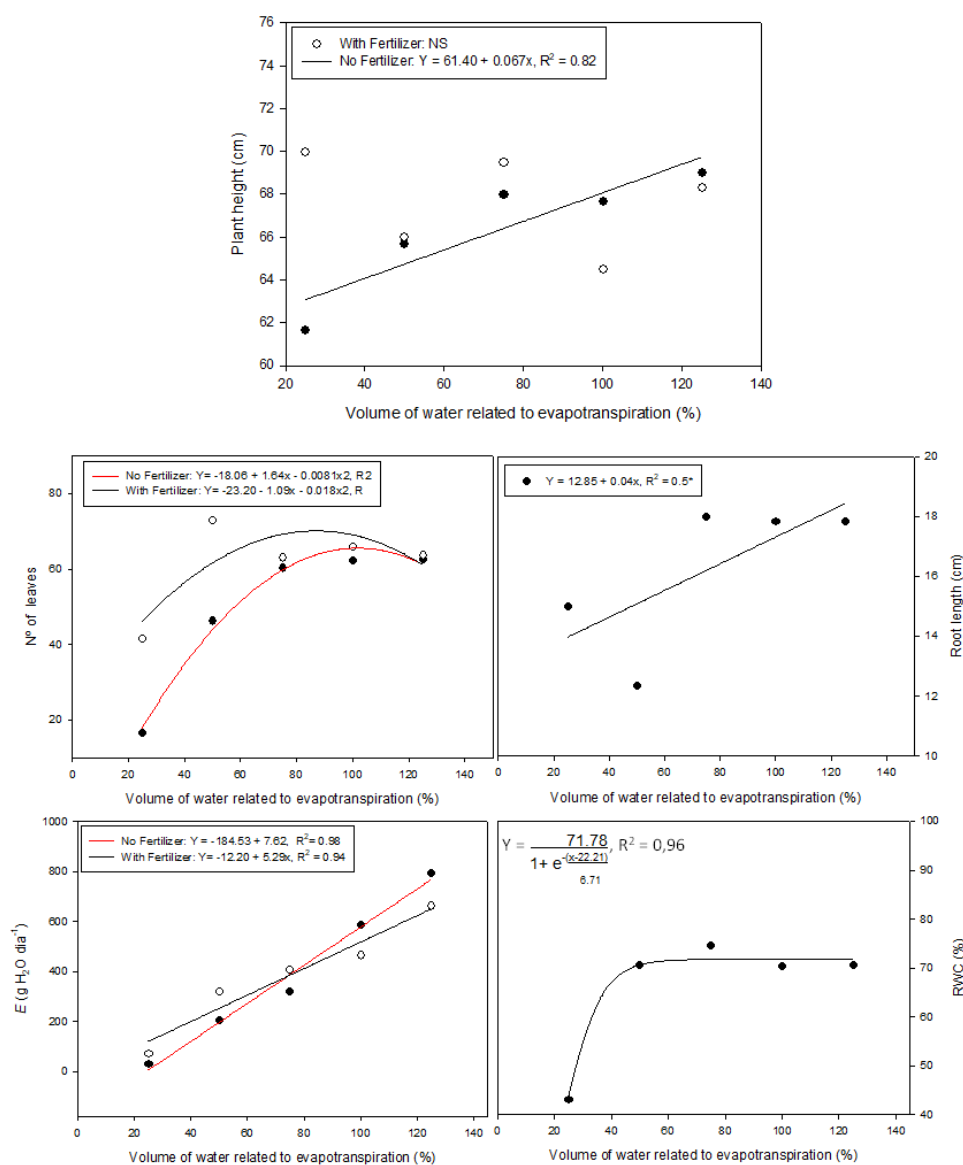

Figure 1. Regression analysis for plant height, number of leaves, root length, transpiration, and relative water content (RWC) of soybean plants subjected to water deficit and application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil).

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Table 2. Analysis of variance, regression analysis, and mean test for chlorophyll contents (SPAD), leaf dry weight (LDW), transpiration rate (TR), and relative water content (RWC) of soybean plants as a function of daily evapotranspiration water volumes and application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil).

Source of Variation			Mean squares		
	DF	SPAD	LDW	TR	RWC
Water volume (A)	4	116.44**	0.0099 ns	395494.2**	976.96*
Foliar fertilizer (B)	1	5.4613 ns	0.0120 ns	26.1333 ns	86.896 ns
Interaction A×B	4	1.8422 ns	0.0032 ns	20329.8*	50.178 ns
Residue	20	24.627	0.0058	2715.46	95.626
CV (%)	-	15.20	30.25	13.49	14.85
Components of model			P-value		
Linear	1	15.66**	0.01 ns	193.86**	18.54**
Quadratic	1	1.54 ns	2.00 ns	1.23 ns	17.50**
Water volume			Means		
Control		34.18 a	0.2833 a	526.33 a	70.30 a
Water deficit		25.40 b	0.2967 a	52.00 b	43.25 b
Foliar fertilizer rate			Means		
300 mL ha^{-1}		33.08 a	0.2727 a	385.20 a	64.14 a
0 mL ha^{-1}		32.23 a	0.2327 a	387.07 a	67.55 a

DF = degrees of freedom; CV = coefficient of variation; * = significant at 5% probability; ** = significant at 1% probability; ns = not significant by the F test. Means followed by the same letter in the columns are not different from each other by the Tukey's test at 5% significance level.
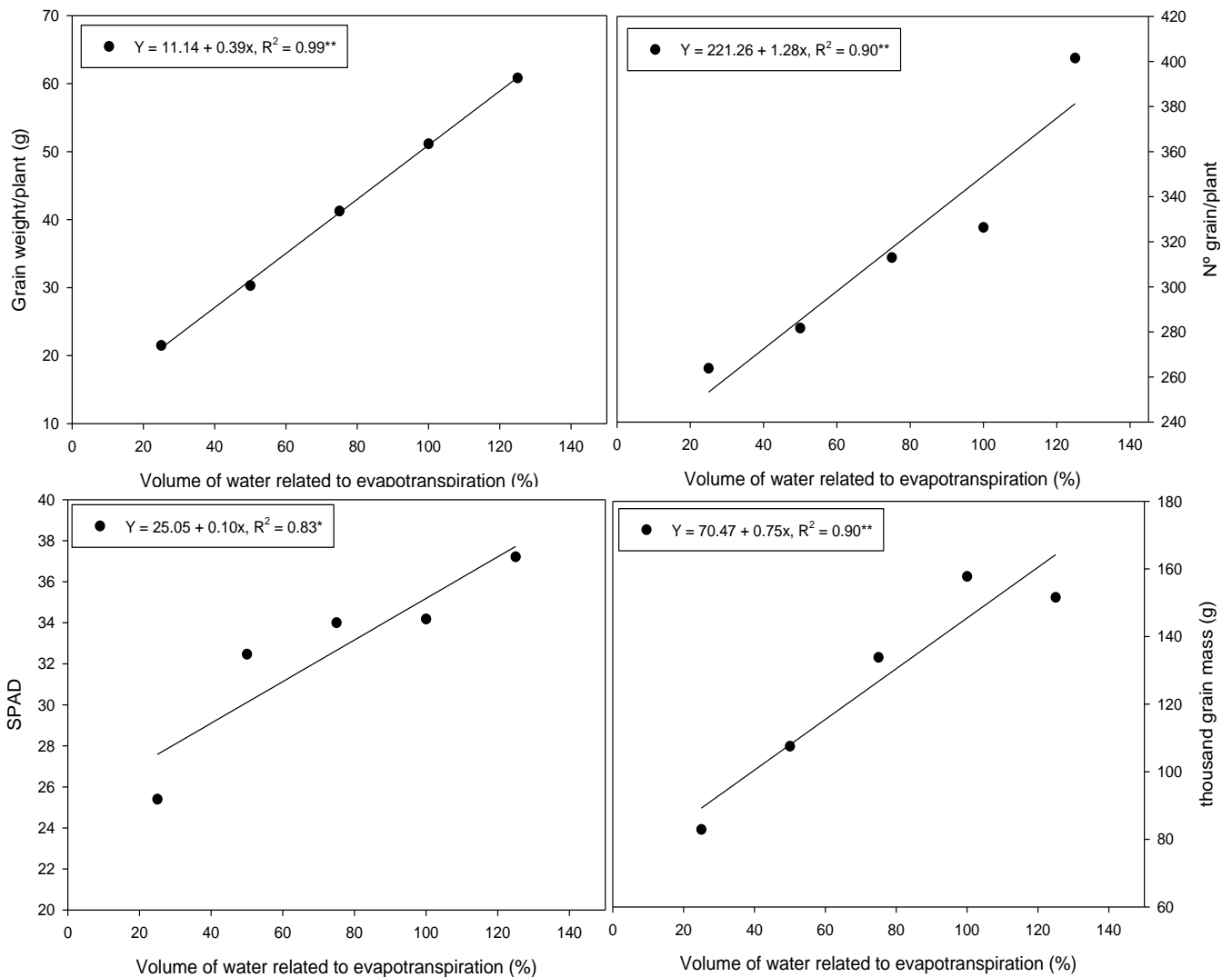

Figure 2. Grain weight, number of grains per plant, SPAD index, and 1,000-grain weight of soybean plants subjected to the water deficit and application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil).

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Table 3. Analysis of variance, regression analysis, and mean test for number of pods per plant (NPP), number of grains per plant (NGP), grain weight per plant (GWP), and 1,000-grain weight (1000GW) of soybean plants as a function of daily evapotranspiration water volumes and application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil).

Source of Variation		Mean squares			
	DF	NPP	NGP	GWP	1000GW
Water volume (A)	4	170.88 [ns]	16977.2 [**]	1487.1 [**]	5874.9 [**]
Foliar fertilizer (B)	1	800.83 [ns]	3898.8 [ns]	142.61 [ns]	6.3497 [ns]
Interaction A×B	4	604.75 [ns]	2138.8 [ns]	58.613 [ns]	459.80 [ns]
Residue	20	582.70	2962.1	76.251	427.33
CV (%)	-	14.49	17.15	21.29	16.31
Components of model		P-value			
Linear	1	0.44 [ns]	20.74 [**]	77.94 [**]	49.35 [**]
Quadratic	1	0.08 [ns]	1.35 [ns]	0.00 [ns]	4.11 [ns]
Water volume		Means			
Control		174.17 a	326.33 a	51.14 a	157.76 a
Water deficit		165.33 a	263.83 b	21.49 b	82.92 b
Foliar fertilizer rate		Means			
300 mL ha^{-1}		171.73 a	328.67 a	43.18 a	127.18 a
0 mL ha^{-1}		161.40 a	305.87 a	38.82 a	126.26 a

DF = degrees of freedom; CV = coefficient of variation; * = significant at 5% probability; ** = significant at 1% probability; ns = not significant by the F test. Means followed by the same letter in the columns are not different from each other by the Tukey's test at 5% significance level.
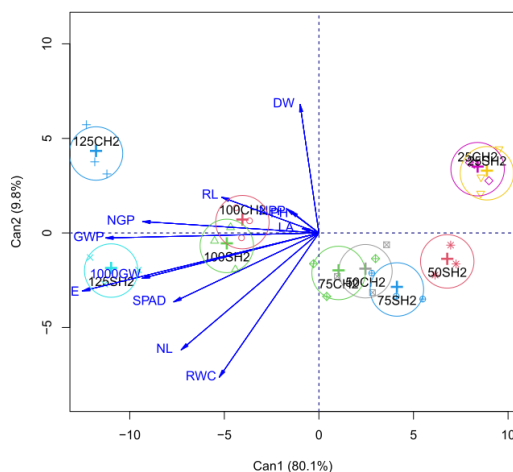

Figure 3. Analysis of canonical variables for sorting the data for root length (RL), plant height (PH), number of leaves (NL), leaf area (LA), chlorophyll contents (SPAD), dry weight (DW), transpiration rate (TR), relative water content (RWC), number of pods per plant (NPP), number of grains per plant (NGP), grain weight per plant (GWP), and 1,000-grain weight (1000GW) of soybean plants subjected to the water deficit, with (CH2) and without (SH2) application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil).

Table 4. Multiple regression analysis for evaluating the importance of the variables for 1,000-grain weight (1000GW) of soybean plants treated with application of foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil).

1000GW	$R^2 = 0.98$		$F_{(11, 18)} = 111.07$		$p < 0.00005$	
	Beta	Standard error (Beta)	B	Standard error (B)	t (18)	p-level
Intercept			156.114	23.648	6.602	0.000
SPAD	-0.042	0.057	-0.251	0.338	-0.741	0.468
Plant height	-0.028	0.032	-0.234	0.272	-0.860	0.401
Number of leaves	0.020	0.046	0.038	0.088	0.431	0.672
Leaf area	-0.018	0.048	-0.033	0.086	-0.381	0.708
Leaf dry weight	-0.006	0.056	-2.789	24.109	-0.116	0.909
Transpiration	0.175	0.063	0.025	0.009	2.782	0.012
Relative water content	0.059	0.064	0.139	0.151	0.917	0.371
Number of pods per plant	-0.065	0.034	-0.095	0.050	-1.906	0.073
Grain weight per plant	1.323	0.078	2.750	0.161	17.063	0.000
Number of grains per plant	-0.848	0.055	-0.418	0.027	-15.475	0.000
Root length	0.082	0.034	0.741	0.308	2.409	0.027

Under low water availability, plants treated with the foliar fertilizer presented higher number of leaves and transpiration. Leaf emergence is dependent on water, temperature, and hormonal signs, such as increase in production of auxins (Taiz et al., 2017). Thus, despite the foliar fertilizer had no significant effect on vegetative and production variables, the higher number of leaves in these plants explains the higher results found for plants treated with the foliar fertilizer, as these characteristics are important for the vegetative development of this plant species by increasing the photosynthetic capacity.

Thus, plants treated with the foliar fertilizer presented higher leaf emergence and transpiration rates despite growing in pots with a limited volume for root growth and under low water availability, denoting that the foliar fertilizer had a positive effect on the soybean plants, protecting them against water deficit; this protection is probably connected to stomatal control and signaling, which are important for overcome water stress and trigger responses, such as leaf emergence, as reported by Matos et al. (2019). The decrease in SPAD index of plants under water deficit is connected to the plant protection system for minimizing stresses, as the decrease in absorption of light energy due to a low stomatal conductance minimizes the oxidative stress.

Water deficit at the R_5 reproduction stage compromised the yield of soybean plants. Decreases in stomatal opening minimize water loss and CO_2 influx and reduces photosynthesis and production of assimilates, consequently, affecting the production variables, as shown in Figure 2. Stomata link transpiration to production of assimilates; photosynthesis and production of assimilates increase as the plant opens stomata for CO_2 influx. Thus, the results show that the decreases in production variables were consistent with the decreases in transpiration. The analysis of canonical variables represented 89.9% of the variation of the data and confirmed the high effect of water deficit on growth and yield of soybean plants. In addition, hydrological variables (transpiration and relative water content) presented strong correlation with production variables arranged in the same quadrant, confirming the strong correlation between transpiration and grain yield.

The multiple regression analysis (Table 4) showed that root length, transpiration, and grain weight per plant were the most important variables for increasing 1,000-grain weight. This result confirms the correlation and importance of transpiration for yield of soybean plants and that longer roots increase absorption and balance transpiration. The number of grains per plant contributed negatively for 1,000-grain weight due to the competition between weight and number of grains, as grain weight is limited when a greater amount of assimilates is intended for an increasing number of grains.The water deficit in the pots under the evaluated conditions was more severe on plants than that found in the field due to limitation of space for root system development. In these conditions, the action of the foliar fertilizer was limited, as the root system is usually the factor for overcoming water deficit, through a higher growth, reaching the available water in the soil; in the present study, this response was not possible and, thus, further field studies under natural conditions are recommended.

Materials and methods

The experiment was conducted from November 2021 to January 2022 in a greenhouse with 50% interception of solar radiation, at the State University of Goiás, in Ipameri, GO, Brazil (17°42'59.12''S, 48°08'40.49''W, and altitude of 773 m). The region has an Aw, tropical climate with a dry winter and wet summer, according to the Köppen classification, with a mean temperature of 20 °C (Alvares et al., 2013).

Soybean seeds of the cultivar NEO 680 IPRO were sown using three seeds per pot. This is a super-early-maturation cultivar of indeterminate growth habit that was released in the 2019/2020 crop season. Plants of this cultivar present medium size and little branching, mean 1,000-grain weight of 163 g, and resistance to lodging and diseases (stem canker and bacterial pustule).

The pots (experimental plots) were filled with 15 kg of a substrate composed of soil (Typic Hapludox), sand, and manure, at the proportion of 3:1:1, respectively. The chemical analysis of the mixture showed the following results: pH ($CaCl_2$) 5.4; 16 g dm^{-3} of organic matter; 68 mg dm^{-3} of P; 6.81 mmolc dm^{-3} of K (Mehlich^{-1}); 22 mmolc dm^{-3} (SMP) of H + Al; 31 mmolc dm^{-3} of Ca; 15 mmolc dm^{-3} of Mg; 53 mmolc dm^{-3} of sum of bases; 75 mmolc dm^{-3} of CEC; and 71% base saturation. Soil fertilizers were applied after the soil analysis, following technical recommendations for the crop (Prochnow et al., 2010). The seeds were subjected to a treatment with pyraclostrobin, thiophanate-methyl, and fipronil (Standak Top; BASF, Ludwigshafen, Germany), polymer, and drying powder. The seeds were inoculated with a *Bradyrhizobium japonicum* inoculant before sowing. A thinning was carried out at 15 days after the emergence of seedlings, leaving one plant per pot.

A completely randomized design was used, with a 2×5 factorial arrangement and three replications. The first factor consisted of foliar fertilizer rates (0 and 300 mL ha^{-1}), and the second factor consisted of water depths applied to the plants (25%, 50%, 75%, 100%, and 125% of the daily evapotranspiration). The seedlings were irrigated daily, using a water volume of 100% of the evapotranspiration, until the soybean $R_{5.4}$ stage; the water deficit treatments started from the $R_{5.5}$ stage onwards. A crop coefficient (kc) was still not determined for the region of Ipameri, thus, a kc of 1.00 was used, following the estimate reported in the FAO 56 (Allen et al., 1998) for a group of crops at initial growth stage.

The water volume applied was estimated by determining the reference evapotranspiration and the crop coefficient, according to equation:

ETc = ETo × kc

where: ETc = crop evapotranspiration; kc = crop coefficient; ETo = reference evapotranspiration.

The daily ETo was calculated by the Penman-Monteith method recommended by the FAO (Smith et al., 1991), using daily data of maximum and minimum air temperatures, relative air humidity, insolation, and wind speed obtained from a meteorological station of the Brazilian National Institute of Meteorology (INMET) installed in Ipameri.

The foliar fertilizer used (H2 Protector; H2 Agrosciences, Orizona, Brazil) is a commercial product that contains a salicylic complex that induces the production of phytoalexin, according to the manufacturer. The product also contains 2% sulfur, 4% copper, 0.2% zinc, 1% manganese, and 0.002% 5-sulfosalicylic acid ions, 0.020% ethylenediaminetetraacetic acid, and 0.002% salicylaldehyde salt. The product was applied at the concentration of 300 mL ha^{-1} in a solution volume of 150 L ha^{-1} with addition of 100 mL of mineral oil (H2 Citrus; H2 Agrosciences, Orizona, Brazil). The foliar fertilizer was applied at the soybean V_4 and R_2 stages.

Morphological variables and agronomic components were analyzed at 60 and 90 days after emergence (39 and 78 days after the first and second foliar fertilizer application, respectively).

Morphophysiological and growth variables

Morphological analyses were carried out at the soybean R_5 developmental stage, evaluating one plant per plot. Root length and plant height were determined by measurements from the stem base to the root end and to the shoot top, respectively, using a ruler. The number of leaves was determined by counting all viable leaves of the plant, and the leaf area was determined with the aid of a portable leaf area meter.

Chlorophyll contents (SPAD) were determined by indirect readings in a SPAD-502 device. The SPAD indexes were determined in the morning period (8:00 to 10:00 a.m.), the device was shaded to avoid the effect of solar light. The readings were carried out in the third trifoliate leaf of the middle third of the plant, with three readings per leaflet of each trifoliate leaf. Trifoliate leaves of the middle third of the plants were sampled, placed in paper bags, identified according to the treatments, and dried in a forced air circulation oven at 60 °C for 72 hours to determine the leaf dry weight.

The total daily transpiration rate of plants was measured by the difference in weight of the pots. Each pot was placed in a plastic bag fixed with rubber in the plant stem, keeping only the shoot (leaves and stem) outside the bag; the pots with plants in plastic bags were then weighed at 6:00 p.m. (weight 01) and, after 24 hours, they were weighed (weight 02). The total transpiration was estimated by the difference between weight 01 and weight 02.

Five leaf discs measuring 1.2 cm in diameter were taken from fully expanded leaves, weighed, and saturated for four hours in Petri dishes with distilled water to assess the relative water content. Then, the leaf discs were again weighed, dried at temperature of 70 °C for 72 hours, and the dry weight (g) was obtained.

Production components

Plants of all experimental plots were harvested when they reached the R_9 maturation stage to determine the number of pods per plant, number of grains per plant, grain weight per plant, and 1,000-grain weight.

Statistical procedures

The data were subjected to analysis of variance and regression. The coefficient of determination (R^2) of linear or quadratic regression analysis was obtained by dividing the sum of squares of the regression by the sum of squares of the treatment, using the software SigmaPlot 10.0 (Systat Software, 2006). Multivariate analysis was carried through multiple regression, using the selection criterion of the Forward Stepwise model (Sokal and Rolf, 1995). The analysis of canonical variables was carried out using the candisc package of the software R 4.0.1 (R Core Team, 2020) and RBIO (Bhering, 2017).

Conclusions

The results found for vegetative and reproductive growth of soybean plants treated with the foliar fertilizer (H2 Protector; H2 Agrosciences, Orizona, Brazil) were higher, but not significant, when compared to those found for plants grown with no application of the product. This difference was due to the higher number of leaves and transpiration of treated plants, which presented a higher photosynthetic potential despite the water deficit.

Water deficit at the R_5 reproduction stage of soybean plants limits plant growth and grain yield. Soybean plants present an isohydric mechanism of response to water deficit, with a pronounced decrease in transpiration and delay in dehydration. Decreases in transpiration to minimize water losses limit the growth and yield of soybean plants.

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