THE EFFECT OF DROUGHT STRESS ON THE GROWTH AND YIELD OF SOYBEAN (*GLYCINE MAX* L.)

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Abstract. Drought stress affects the growth and yield of soybean. Stunted growth will have an impact on yield. This study aims to determine the effect of drought stress on the growth characteristics and grain yield of soybean. This research uses a randomized complete block design (RCBD) and three replications. The first factor was soil moisture content consisting of four levels, i.e., 100%, 75%, 50%, and 25% field capacity. The second factor was the growth stage consisting of three kinds, i.e., the vegetative active, flowering, and seed filling stages. The results showed that soil moisture content below 75% field capacity reduced the leaf area index (LAI), leaf area duration (LAD), specific leaf area (SLA), net assimilation rate (NAR), crop growth rate (CGR), the seed weight per 100 seeds, and the weight of the seeds per plant. In seed filling stage is more sensitive to water shortages than the vegetative or flowering stages. At all stages of growth, a higher drought level equals a higher decrease in the soybean growth and yield. For future research, we suggest that soybean planting utilize 100% field capacity.
Keywords: *field capacity, grain, growth analysis, growth phase, soil moisture*

Introduction

Drought stress has significantly reduced agricultural productivity worldwide, including in soybean (*Glycine max* L.) seeds (Buezo et al., 2019). In Indonesia, soybeans are often grown as an intercropping plant after rice and are widely cultivated in times of drought. Soybean production during the dry season is constrained by limited water availability. Therefore, some or all stages of plant development are affected by drought.

Along with the increase in air temperature caused by global warming, drought also harms soybean production, decreasing seed yields (Daryanto et al., 2015). Ahmed et al. (2010) stated that the lack of water increased the canopy's root ratio to increase water utilization. Thu et al. (2014) found that roots were distributed to the topsoil zone if sufficient water was available. If not, roots would grow and develop in deeper soil.

In general, drought stress affected the vegetative and generative phases of plants and resulted in a yield decrease. The reproduction phase is sensitive to drought stress as it directly affects the flowering and pod filling stages (Hatfield et al., 2011). Ghassemi-Golezani et al. (2010) found that drought stress decreased the number of flowers and filled pods in the reproductive phase. The plant can not effectively distribute carbohydrates from leaves to pods, reducing the amount and size of produced seeds.

Alqudah et al. (2011) and Ozalkan et al. (2010) stated that the LAI, NAR, and CGR continued to increase until the pod filling stage. Over its entire vegetation period, chickpeas had a reduced LAD, specifically in their initial pod arrangement while their biomass increases. LAD positively correlated with the biomass and yield of chickpeas in Southern Spain (López-Bellido et al., 2008). In several varieties, Ozalkan et al. (2010) found that CGR was greater at the pod filling stage compared to earlier stages. Furthermore, Ozalkan et al. (2010) stated that the growth process, namely CGR, RGR, and NAR, directly affected economic gains, as seen in greater grain yields. In plants, researchers had identified development parameters such as optimum LAI and CGR during the flowering stage as the main determinants of yield (Baloch et al., 2006). The vegetative and generative growth stages of soybean consisted of emergence, first trifoliate, second trifoliate, third to fifth trifoliate, sixth trifoliate, beginning bloom, full bloom, beginning pod, full pod, beginning seed, full seed, beginning maturity, and full maturity (Nleya and Sexton, 2019).

Maleki et al. (2013) examined soybean plants undergoing drought stress treatment at various stages of growth in several varieties. The results showed that drought stress and variant significantly affected plant height, fertile pods, harvest index, oil, and protein percentages. Under drought stress, the seed filling and flowering stages showed the lowest production with a yield of 2,682 $kg.ha^{-1}$ and 2,918 $kg.ha^{-1}$, respectively. Luo et al. (2016) examined cotton plants in four growth phases given light and moderate water stress. The results showed that the water deficit significantly reduced leaf water potential, net photosynthetic rate, and stomatal conductance in cotton. In this study, there was no clear mention of moisture levels for mild or moderate stress.

Marchese et al. (2010) examined *Artemisia annua* L. plants with five water deficit treatments, namely irrigated, 14, 38, 62, 86 hours, and without irrigation. The results showed that water deficit limits plant growth but can trigger the accumulation of secondary metabolites. Water deficits of 38 and 62 hours increased leaf artemisinin content. However, only the 38-hour treatment caused a significant increase in leaf and plant artemisinin without negatively affecting plant biomass production. In a greenhouse study, Samarah et al. (2009) compared four wheat varieties with a soil moisture content of 75%, 50%, and 25% field capacity. This research did not attempt to determine the optimal moisture content for growth; it compared variants and their relation with drought and yield. Zulfiqar et al. (2020) studied two varieties of marigolds under the stress of 60% and 40% field capacity. The results showed that leaf thickness decreased at 40% field capacity and the Inca variety was more resistant than the Bonanza variety to water stress.

Sacita et al. (2018) researched two varieties in their vegetative and generative phases, with irrigation intervals of 2.5 and 10 days. The results showed that water stress in the vegetative stage had no significant effect on soybean production. Soybean plants adapt to water stress by reducing the leaf number, leaf area, and stomata openings and responding to a motion by folding the leaves.

Many previous studies examined the effect of drought stress on plant morphological characteristics and only a few examined the effect of drought stress on plant physiological characteristics, especially soybeans, and this physiological observation was only observed at harvest time. Research that has not been carried out is to examine drought stress on physiological characters and soybean yields at various growth stages. There has been no attempt to examine the effects of drought stress at various stages of growth on the growth characteristics and yield of soybean. This research will attempt to

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determine the stage of soybean growth most affected by water stress which can impact soybean yield. Based on the description above, this research aims to determine the effect of drought stress on the growth characteristics and yield of soybean.

Materials and methods

Study area

The team conducted the research in a plastic house in Demangan, Sambi, Boyolali, Central Java, Indonesia, from August to November 2020 with alfisol soil. The Department of Food Crops Agriculture, Grobogan, Central Java, Indonesia provides soybean seeds with a drought-resistant variant of Grobogan. A geographical position was between 110° 22'-110° 50' east longitude and between 7°7'-7°36' south latitude with a height of 184 m above sea level (ASL). The average rainfall and temperature were 139 mm $month^{-1}$ and 26-32°C, respectively.

Experimental design

This research was arranged in a randomized completely block design (RCBD) with two factors and three replications. The first factor was soil moisture content consisting of four levels, i.e., 100%, 75%, 50%, and 25% field capacity. The second factor was the growth stage, which consisting of three kinds, i.e., the active vegetative, flowering, and pod filling stages. In this study, there were 12 treatment combinations. Each treatment combination was three times replications, and each replication consisting of four plant samples. Overall, the study required 144 polybags.

Research procedures

Before the research, the team conducted a chemical analysis of the soil used for the research substrate. The results showed an H_2O pH of 6.38 (slightly sour), C concentration of 3.60% (very high), organic matter concentration of 6.22% (very high), total N concentration of 0.15% (low), available P of 8.10 ppm (very high), available K of 0.79 me/100 g (high) and CEC value of 26.12 me/100 g (high).

The media used was 10 kg of alfisol soil and manure at a ratio of 1:1. After being prepared and mixed, the media filled a 35 × 35 cm polybag as a medium for soybean seeds. NPK Phonska and SP-36 fertilizers at a dose of 100 and 75 kg ha^{-1}, respectively, were applied at planting time and five weeks after planting.

The planting utilized a depth of 3 cm, with each polybag containing three soybean seeds. The selection process took 14 days selected one plant. Thinning was conducted 1 week after planting (WAP), leaving one plant per polybag. During the research, no weeds, pests, or diseases caused significant problems. Therefore, the team did not carry out control measures. According to the treatment, water application must reach a soil moisture content of 100%, 75%, 50%, and 25% field capacity by accounting for the growth stages, namely the active vegetative, flowering, and pod filling stages. Harvesting was conducted 90 days after planting (DAP).

Measurement

The parameters observed were the leaf area index (LAI), leaf area duration (LAD), specific leaf area (SLA), net assimilation rate (NAR), crop growth rate (CGR), and the weight of the seeds per plant. The data observation was conducted in 4, 6, 8, and 10

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WAP. LAI was calculated from the ratio between the total leaf surface area per unit ground area. LAI was determined by the intensity of radiation intercepted divided planting spacing. LAD is the time a leaf could last on the plant. LAD was calculated from leaf area (cm^2) divided by time (week).

NAR is the ability of plants to produce dry materials that assimilate each unit of leaf area at each unit of time, which is stated in *Eq. 1*.

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\ln LA_2 - \ln LA_1}{LA_2 - LA_1}, \text{ (in g.cm}^{-2}\text{.weeks}^{-1}\text{)} \quad \text{(Eq.1)}$$

CGR is the ability of plants to produce dry materials that assimilate each unit of land area at each unit of time, which is stated in *Eq. 2*.

$$CGR = \frac{1}{G} \times \frac{W_2 - W_1}{t_2 - t_1}, \text{ (in g.m}^{-2}\text{.weeks}^{-1}\text{)} \quad \text{(Eq.2)}$$

Description: W_1 = total dry weight per plant at the time of t_1. W_2= Total dry weight per plant at the time of t_2. LA_1= Total leaf area per plant at the beginning. LA_2 = Total leaf area per plant at the time of t_2. G = the area of land overgrown with plants. t_1 = harvest time in the beginning. t_2 = harvest time in the end.

Statistical analysis

Observational data were analyzed using analysis of variance (ANOVA) with the SAS 9.1 program. If the treatment had a significant effect, then to know the difference between treatments was done using Duncan's new multiple range tests (DMRT) at 5% significance level (Gomez and Gomez, 1984).

Results

Analysis of variance

Based on the analysis of variance, there is an interaction between the level of drought and the growth rate on the parameters of LAI, LAD, NAR, SLA, CGR, at 4-6, 6-8, 8-10, and 10-12 WAP, the weight of 100 seeds and seeds per plant at harvest (*Table 1*).

Leaf area index

The ANOVA showed a significant interaction between soil moisture and growth rate on LAI at the ages of 4-6, 6-8, 8-10, and 10-12 WAP. The result of DMRT at 5% significant levels on the average LAI in ages of 4-6, 6-8, 8-10, and 10-12 WAP are shown in *Table 2*.

Leaf area duration

The ANOVA on LAD showed a significant interaction between soil moisture and growth rate at the ages of 4-6, 6-8, 8-10, and 10-12 WAP. The result of DMRT at 5% significant levels on the average LAD in ages of 4-6, 6-8, 8-10, and 10-12 WAP are shown in *Table 3*.

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Table 1. *Analysis of variance of all parameters*

Parameter	Time observation (WAP)	Drought stress level (S)	Growth stage (G)	S x G
Leaf area index (LAI)	4-6	4.94**	0.67 ns	3.31 **
	6-8	9.86**	0.04 ns	3.18 **
	8-10	3.74*	0.30 ns	2.81 *
	10-12	9.33**	0.73 ns	4.89 **
Leaf area duration (LAD)	4-6	6.42 **	1.47 ns	3.90 **
	6-8	9.19 **	0.04 ns	2.46 *
	8-10	3.99 *	0.06 ns	3.05 *
	10-12	13.68 **	5.77 **	13.15 **
Spesific Leaf Area (SLA)	4-6	3.83 *	0.19 ns	3.28 **
	6-8	3.34 *	0.19 ns	2.62 *
	8-10	2.58 ns	0.43 ns	3.08 *
	10-12	8.67 **	1.57 ns	5.48 **
Net assimilation rate (NAR)	4-6	3.02 *	0.14 ns	2.42 *
	6-8	4.27 *	0.13 ns	2.73 *
	8-10	2.77 *	0.08 ns	2.41 *
	10-12	5.46 **	0.22 ns	3.76 **
Crop Growth Rate (CGR)	4-6	5.15 **	0.73 ns	2.80 *
	6-8	4.81 **	0.29 ns	2.25 *
	8-10	5.05 **	0.29 ns	3.40 **
	10-12	2.39 ns	0.20 ns	2.24 *
Weight of 100 seeds	12	15.42 **	33.73 **	49.36 **
Seeds per plant	12	25.09 **	5.71 **	8.95 **

Note: ** = Signinificance at 1% significant levels, * = Signinificance at 5% significant levels, and ns = Non significant at 5%. WAP = week after planting

Table 2. *LAI at various levels of drought and growth stages at 4-6, 6-8, 8-10, and 10-12 WAP*

Soil moisture (% field capacity)	Growth stage	LAI			
		4-6 WAP	6-8 WAP	8-10 WAP	10-12 WAP
100	Active vegetative	0.75 ab	1.05 ac	1.20. b	0.88 ab
	Flowering	0.85 a	1.21 ab	1.24 ab	0.90 ab
	Seed filling	0.69 ab	1.34 a	1.34. a	0.95 a
75	Active vegetative	0.73 ab	1.04 a-c	1.26 ab	0.87 ab
	Flowering	0.70 ab	0.99 b-d	1.22 ab	0.86 ab
	Seed filling	0.70 ab	1.02 a-c	1.26 ab	0.90 ab
50	Active vegetative	0.59 b	0.87 b-d	1.22 ab	0.86 ab
	Flowering	0.61 b	0.86 b-d	1.20 b	0.83 bc
	Seed filling	0.72 ab	0.83 cd	1.15 bc	0.72 d
25	Active vegetative	0.63 ab	0.84 cd	1.23 ab	0.81 b-d
	Flowering	0.34 c	0.82 cd	1.15 bc	0.74 cd
	Seed filling	0.63 ab	0.67 d	1.06 c	0.71 d
Interaction treatments		(+)	(+)	(+)	(+)

Note: The numbers followed by the same characters in the same column indicate no significant difference based on DMRT at 5% significant levels. LAI = leaf area index WAP = week after planting

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Table 3. *LAD at various levels of drought and growth stages at 4-6, 6-8, 8-10, and 10-12 WAP*

Soil moisture (% field capacity)	Growth stage	LAD (cm^2 week^{-1})			
		4-6 WAP	**6-8 WAP**	**8-10 WAP**	**10-12 WAP**
100	Active vegetative	959 ab	1318 a-c	1258 b-d	1220 ab
	Flowering	1021 a	1505 ab	1271 a-d	1140 bc
	Seed filling	926 ab	1596 a	1362 a	1268 a
75	Active vegetative	944 ab	1303 a-c	1317 ab	1118 b-d
	Flowering	895 ab	1249 a-c	1260 b-d	1239 ab
	Seed filling	913 ab	1281 a-c	1305 ab	934 ef
50	Active vegetative	833 ab	1079 bc	1256 b-d	1129 b-d
	Flowering	794 b	1013 c	1286 a-c	1037 c-e
	Seed filling	824 ab	1032 c	1190 cd	915 ef
25	Active vegetative	814 ab	1005 c	1221 b-d	1008 de
	Flowering	533 c	1007 c	1244 b-d	929 ef
	Seed filling	865 ab	898 c	1171 d	845 f
Interaction treatments		(+)	(+)	(+)	(+)

Note: The numbers followed by the same characters in the same column indicate no significant difference based on DMRT at 5% significant levels. LAD = leaf area duration, and WAP = week after planting

Table 3 shows that LAD had the same pattern as LAI. The highest value occurred at a soil moisture content of 100% field capacity during the seed filling stage, while the lowest occurred at a soil moisture content of 25% field capacity during the seed filling stage at 6-8, 8-10, and 10-12 WAP.

Specific leaf area

The ANOVA on SLA showed a significant interaction between soil moisture and growth rate at the ages of 4-6, 6-8, 8-10, and 10-12 WAP. The result of DMRT at 5% significant levels on the average SLA in ages of 4-6, 6-8, 8-10, and 10-12 WAP are shown in *Table 4*.

Table 4 shows that the highest specific leaf area during 4-6, 6-8, 8-10, and 10-12 WAP were at a soil moisture content of 100% field capacity during the seed filling stage. Meanwhile, the lowest SLA occurred at a soil moisture content of 25% field capacity during the seed filling the stage at 6-8, 8-10, and 10-12 WAP. Drought stress is most detrimental to soybean plants during generative growth, especially during the seed filling stage.

Net assimilation rate

The ANOVA on NAR showed a significant interaction between soil moisture and growth rate at the ages of 4-6, 6-8, 8-10, and 10-12 WAP. The result of DMRT at 5% significant levels on the average NAR in ages of 4-6, 6-8, 8-10, and 10-12 WAP are shown in *Table 5*.

Table 5 shows that during 4-6 WAP, the NAR value was highest at a soil moisture content of 100% field capacity during the flowering stage, while the lowest was at a soil moisture content of 25% field capacity during the flowering stage. Conditions during 6-8 and 8-10 WAP had the same pattern as previous observations. Conditions during

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10-12 WAP contradict previous results, as the NAR value was highest at a soil moisture content of 25% field capacity during the seed filling stage, while the lowest was at a soil moisture content of 100% field capacity during the seed filling stage.

Table 4. *SLA at various levels of drought and growth stages at 4-6, 6-8, 8-10, and 10 -12 WAP*

Soil moisture (% field capacity)	Growth stage	SLA ($cm^2.g^{-1}$)			
		4-6 WAP	6-8 WAP	8-10 WAP	10-12 WAP
100	Active vegetative	287.33 ab	230.00 ab	246.67 ab	225 a-d
	Flowering	321.67 a	237.00 ab	241.67 b	254 ab
	Seed filling	298.33 ab	270.00 a	313.67 a	278 a
75	Active vegetative	275.00 ab	232.33 ab	272.00 ab	245 a-c
	Flowering	291.67 ab	225.67 ab	241.33 b	169 d
	Seed filling	283.33 ab	230.67 ab	272.33 ab	220 a-d
50	Active vegetative	282.33 ab	236.00 ab	268.00 ab	224 a-d
	Flowering	288.67 ab	219.67 b	231.33 b	192 b-d
	Seed filling	280.33 ab	225.67 ab	249.67 ab	162 de
25	Active vegetative	287.67 ab	224.33 ab	241.00 b	184 cd
	Flowering	199.00 c	221.67 b	246.67 ab	167 d
	Seed filling	264.33 b	169.00 c	156.33 c	102 e
Interaction treatments		(+)	(+)	(+)	(+)

Note: The numbers followed by the same characters in the same column indicate no significant difference based on DMRT at 5% significant levels. SLA = specific leaf area, WAP = week after planting

Table 5. *NAR at various levels of drought and growth stages at 4-6, 6-8, 8-10, and 10-12 WAP*

Soil moisture (% field capacity)	Growth stage	NAR (x 10-5 $g.cm^{-2}.week^{-1}$)			
		4-6 WAP	6-8 WAP	8-10 WAP	10-12 WAP
100	Active vegetative	332.33 bc	306.67 ab	168.33 ab	24.47 c-e
	Flowering	560.99 a	243.67 a-d	151.00 a-c	317.26 a-d
	Seed filling	502.00 ab	372.00 a	208.33 a	219.47 e
75	Active vegetative	451.43 ab	277.00 a-c	144.67 bc	277.15 b-e
	Flowering	464.67 ab	283.67 a-c	192.33 ab	228.48 de
	Seed filling	480.43 ab	304.00 ab	160.33 a-c	229.36 de
50	Active vegetative	402.33 ab	254.67 a-d	164.33 ab	286.29 b-e
	Flowering	445.67 ab	261.33 a-d	135.00 bc	298.46 b-e
	Seed filling	384.67 a-c	373.33 cd	141.33 bc	351.27 ab
25	Active vegetative	417.67 ab	189.00 b-d	139.67 bc	320.32 a-c
	Flowering	194.33 c	259.67 a-d	155.00 a-c	301.68 b-e
	Seed filling	340.00 bc	137.67 d	101.00 c	387.76 a
Interaction treatments		(+)	(+)	(+)	(+)

Note: The numbers followed by the same characters in the same column indicate no significant difference based on DMRT at 5% significant levels. NAR = net assimilation rate, WAP = week after planting

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Crop growth rate

The ANOVA on CGR showed a significant interaction between soil moisture and growth rate at the ages of 4-6, 6-8, 8-10, and 10-12 WAP. The result of DMRT at 5% significant levels on the average CGR in ages of 4-6, 6-8, 8-10, and 10-12 WAP are shown in *Table 6*.

Table 6. *CGR at various levels of drought and growth stages at 4-6, 6-8, 8-10, and 10-12 WAP*

Soil moisture (% field capacity)	Growth stage	CGR (x 10^{-5} mg.cm^{-2}.week^{-1})			
		4-6 WAP	**6-8 WAP**	**8-10 WAP**	**10-12 WAP**
100	Active vegetative	272.33 ab	271.00 bc	193.67 a-c	330.85 bc
	Flowering	318.00 a	300.00 a-c	185.67 a-d	252.36bc
	Seed filling	267.67 ab	418.00 a	234.67 a	188.62 c
75	Active vegetative	274.33 ab	321.67 ab	186.00 a-d	233.82 bc
	Flowering	246.33 a-c	303.67 a-c	227.33 ab	251.48 bc
	Seed filling	252.33 a-c	311.67 a-c	186.33 a-d	232.69 bc
50	Active vegetative	240.33 bc	239.67 bc	200.00 a-c	270.26 ab
	Flowering	189.33 c	238.67 bc	182.67 b-d	246.47 bc
	Seed filling	276.33 ab	242.00 bc	154.00 cd	272.62 ab
25	Active vegetative	220.67 bc	255.00 bc	168.00 cd	256.38 bc
	Flowering	187.67 c	224.33 bc	154.67 cd	236.78 bc
	Seed filling	223.00 bc	182.00 c	141.00 d	334.32 a
Interaction treatments		(+)	(+)	(+)	(+)

Note: The numbers followed by the same characters in the same column indicate no significant difference based on DMRT at 5% significant levels. CGR = Crop Growth Rate and WAP = week after planting

Table 6 shows that 4-6, 6-8, and 8-10 WAP showed the same pattern, namely having the highest Crop Growth Rate (CGR) at 100% soil moisture content during the seed filling stage while having the lowest at a soil moisture content of 25% during the seed filling stage. However, conditions during 10-12 WAP had the opposite pattern to previous observations. The CGR value was highest at a soil moisture content of 25% field capacity during the seed filling stage, while the lowest was at a soil moisture content of 100% field capacity during the seed filling stage. NAR showed the same pattern, meaning that CGR related to NAR.

Seeds weight

The ANOVA on seed weight per 100 seeds and per plant showed a significant interaction between soil moisture and growth rate at the ages of 4-6, 6-8, 8-10, and 10-12 WAP. The result of DMRT at 5% significant levels on the average seed weight per 100 seeds and plants is shown in *Table 7*.

Table 7 shows that the highest seed weight per plant occurred at a soil moisture content of 100% field capacity in the active vegetative stage, while the lowest was at a soil moisture content of 25% field capacity in the seed filling stage. This pattern was identical to the pattern of the weight of 100 seeds.

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Table 7. *Weight of 100 seeds (g) and weight of seeds per plant (g) at various levels of drought and growth stages*

Soil moisture (% field capacity)	Growth stage	Seed weight	
		g 100 seeds^{-1}	g plant^{-1}
100	Active vegetative	14.013 a	4.285 a
	Flowering	13.580 a	3.594 ab
	Seed filling	13.187 a	3.837 ab
75	Active vegetative	13.183 a	3.315 b
	Flowering	13.793 a	3.565 ab
	Seed filling	10.353 c	2.994 bc
50	Active vegetative	11.787 b	3.303 b
	Flowering	13.607 a	2.941 bc
	Seed filling	7.293 d	2.231 cd
25	Active vegetative	11.477 bc	2.174 cd
	Flowering	11.890 b	2.332 c
	Seed filling	5.307 c	1.441 d
Interaction treatments		(+)	(+)

Note: The numbers followed by the same characters in the same column indicate no significant difference based on DMRT at 5% significant levels

Discussion

Regardless of drought stress, the LAI value increased from 4-6 to 6-8 and from 6-8 to 8-10 WAP. However, from 8-10 to 10-12 WAP, the LAI value decreased. This decrease was due to the harvest age, in which the leaves begin to experience senescence. In this research, 8-10 WAP showed the highest LAI value. However, Özalkan et al. (2010) found the highest LAI and LAD values during the linear vegetative growth stage.

The four observation periods showed that rather than the growth stage, drought stress determines the value of LAI. Drought stress was inversely proportional to the LAI value. One of the functions of water was to support the photosynthetic process. With decreased photosynthesis, the size of the leaves will also decrease. The disruption in cell division and enlargement in drought stress conditions was due to loss of turgor and decreased photosynthesis and energy supply caused a decrease in leaf area (Talbi et al., 2020).

Hatfield et al. (2011), stated that drought stress affected the growth of the vegetative and generative stages of plants, decreasing crop yields. However, the reproductive stage was highly sensitive to drought stress as it directly affected the flowering and pod filling stages. The linear vegetative growth stage showed the highest LAI and LAD values (Özalkan et al., 2010). The NAR represents the ability of plants to produce dry matter (Li et al., 2012). The NAR value showed a positive correlation with RGR (Li et al., 2016). Therefore, NAR can act as the main determinant of the RGR value. In general, SLA increases from initial growth to 10 WAP, after which it decreased as leaves begin to experience senescence. Plants with severe drought did not experience an increase in SLA, especially in the vegetative or seed filling stages. One of the functions of water is to accommodate photosynthesis. With low photosynthesis activity, leaf size will not increase at its usual rate.

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Regardless of drought stress, the CGR value increased from 4-6 WAP to 6-8 WAP and decreased from 6-8 to 8-10 WAP. The plants have entered the seed filling stage from 6-8 to 8-10 WAP, decreasing dry weight. According to Anjum et al. (2014), CGR will be continued to increase until the middle growth stage and decrease towards maturity.

During rice plant growth, NAR and RGR generally show an increase (height) at the beginning of the growth phase, then decrease rapidly with plant age (Sridevi and Chellamuthu, 2015). At 40-50 days after planting, NAR had a weak positive correlation with grain yield. The flowering stage showed the highest NAR and CGR scores (Ozalkan et al., 2010). Ozalkan et al. (2010) stated that there was a significant correlation among most of the growth parameters during all growth stages.

One of the functions of water is to translocate the assimilation from the leaf (source organ) to the seed (sink organ). A lack of water will hamper the seed filling process. Drought stress affects seed production and quality (Alqudah et al., 2011). Ghassemi-Golezani et al. (2010) stated that drought stress experienced during the reproductive phase decreases flowers and filled pods. This stress inhibited the distribution of carbohydrates from the leaf to the pod, resulting in a decrease in the number and size of seeds (Alqudah et al., 2011).

A considerable lack of water will reduce the quality and quantity of soybean production. Hatfield et al. (2011) stated that drought stress affected the growth of plants during the vegetative and generative stages, which ultimately resulted in a decrease in crop yields. The occurrence of water shortages and high temperatures at the beginning of the flowering to the ripening stage accelerated the pod filling period and reduced yield weight (Kobraei et al., 2011).

Plant morpho-physiological characteristics, such as leaf thickness and plant growth rates affected productivity, considering that these characteristics affected photosynthesis speed. For long periods, a high seed filling rate will produce a high seed weight as long as the seed as a sink can accommodate a high assimilation rate. Conversely, a large enough sink with a low assimilation rate can result in a seed void. Source limitations often occur during the seed filling stage but sink limitations can occur even in non-stress conditions (Egli, 1999). Production had a significant positive correlation with the net photosynthetic rate (NAR) (Li et al., 2012). Drought stress reduced the yield of soybean. A soil moisture content of 80 and 60% field capacity reduced the yield of soybean genotypes by 15.7% and 23.4%, respectively (Patriyawaty and Anggara, 2020). Daryanto et al. (2015) stated that yield reduction was generally higher in legumes experiencing drought during their reproductive stage than during their vegetative stage. Sridevi and Chellamuthu (2015) found that higher grain yields reflected satisfactory dry matter production, LAI, LAD, CGR, NAR, and RGR values.

Conclusion

In conclusion, our study found that soil moisture content at below 75% field capacity reduced the LAI, LAD, SLA, NAR, CGR, the seed weight per 100 seeds, and seed weight per plant. In seed filling stage is more sensitive to water shortages than the vegetative or flowering stages. At all stages of growth, a higher drought level equals a higher decrease in soybean growth and yield. For future research, we suggest that soybean planting utilize 100% field capacity.

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