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Response of Physiological Parameters and Water Use Efficiency to Water Stress and Plant Population in Soybean (*Glycine max* L)

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Abstract: This study had the objective of evaluating the effect of water deficit on the Physiological Parameters and Water Use Efficiency on soybean plants under different planting densities. It was conducted during winter and summer seasons of 2014-2015. The different plant densities designated as D1, D2 and D3 (5, 10 and 15 cm between plants) under three watering regimes (W1,W2 and W3) irrigation every 7,14 and 21 days. The experimental design was a complete randomized blocks design in split trail with three replications. All physiological parameters (LAD, RGR,CGR, NAR) and relative water content of soybean plants tended to decrease with prolonged watering interval (W3) or in high planting density (D1).Water use efficiency for dry mater (WUEdm) was higher in moderate watering interval (W2) as compared to frequent and pronged watering regimes (W1 ,W3). An interaction treatment (W1D3) increased RGR,CGR, NAR while the highest WUEdm was recorded in (W2D3).the result revealed that, the improvement in water availability with low planting density stimulated plant growth and caused increase in dry matter accumulation and longer leaf area might explain the higher CGR, NAR. In conclusion, sowing soybean in wider spacing under frequent irrigation can increase most of the physiological characters measured in this investigation.

Keywords: Soybean, Water stress, plant population, Water use Efficiency and Physiological Parameters.

INTRODUCTION

Soybean *Glycine max* L Merrill is a legume that grows in tropical, subtropical and temperate climate. Soybean is a crop which can provide complete protein, containing eight amino acids essential for human.

That means it can play a major role in elevating nutritional standers of foods in developing countries, where human beings are facing protein deficiencies [1]. The effect of water stress and plant population on soybean plant height was reported by many workers [2, 3]. They concluded that, the higher seeding rates have generally resulted in an increase in plant height but water stress significantly decreased the soybean plant. Also [4] concluded that leaf water potential and stomatal conductance, as well as the rate of leaf area expansion, in soybeans are closely related to changes in soil water potential, and therefore, could be used to explain soybean water stress effects in the field. However [5], attributed the reduction in shoot biomass per plant under water stress to the reduction in leaf area and hastened leaf senescence. On the other hand, [6] reported that, individual soybean plants compensated increased as dry matter as spacing increased. Relative water content is one of the physiological characters that are related to water status of plants and have a great deal of importance in growth and development during water stress conditions [7]. For all crops, high plant populations also increase competition for water, may reduce relative leaf water content so relative water content (RWC) is an important indicator for plant water deficit tolerance. In this respect [5, 9], concluded that, water use efficiency increased under dry compared to wet conditions although total crop production is severely restricted. Increasing moisture stress resulted in progressively less Net assimilation rate and lower values of relative growth rates [10]. Also, according to [11] the low plant densities gave higher values of leaf area duration, net assimilation rates, greater relative growth rates and crop growth rates than higher plant density.

To optimize yield and soybean crop for any given production system it is necessary first to understand the crop responses to environmental and management factors. As water for agriculture become scarcer, the cost of water will increase, adding further pressure on irrigated agricultural. This basically implies that yield per area of land needs to be increased, while less water is used. Consequently adequate levels of irrigation and proper plant population are needed. Researches in the future should be directed to the proper water management and water use efficiency. These factors interrelate providing an important insight to the study the effects of water stress and plant population on physiological attributes and water use of soybean.

MATERIALS AND METHODS

To evaluate the impact of Plant density on stressed soybean, growth and yield of soybean *Glycine max* (L.) Merill a field experiment was carried out during summer and winter seasons of (2014/2015) and (2015), on the faculty of Agriculture and natural Resources Farm, Kassala University, Halfa Elgadida, Sudan (latitude 15° 19' N.) Longitude 35° 36' E and Altitude 45 m asL). A soybean cutivar; Willim study and the seeds for two seasons were obtained from Agriculture Research Station in Wad Madani. The experiment was designed to study the effect of three watering intervals and three levels of plant densities on the performance of soybean plants during two successive seasons. The watering intervals in this study are designed as W_1, W_2 and W_3 where plants were irrigated every 7, 14 and 21 days, respectively. The three plant population levels were designated as D_1, D_2 and D_3, corresponding to spacing between plants of 5, 10 and 15 cm, respectively. The experiment was arranged in 3×3 split Plot trail of RCBD design with three replications in both season. Main plots were allotted for watering treatments and the sub plots for population treatments.

Characters studied

Ten plants were randomly selected and tagged in each subplot to determine the following growth parameters. Leaf area index (LAI) was determined the following formula-

$$LAI: \frac{\text{leaf area} \times \text{number of leaves per plants} \times \text{number of plant}}{\text{Ground area}}$$

Shoot dry weight (g plant^{-1})

Physiological attributes

The following physiological parameters will be computed from the predetermined dry weight and leaf area data.

Wate ruse efficiency (dm gm -2)

Wateruse efficiency (WUE) was determined using the equation described by [12] as follows: WUE = (total dry meter yield ha-1) / Etc. Crop evapotranspiration (ETc) was calculated using the following formula:

$$ETc = ETo \times Kc$$

The reference crop evapotranspiration (ETo) was calculated using metrological data obtained from New Halfa Station, using Penn man- Monteth equation.

Relative water content (%)

Samples for RWC were taken from the upper leaves from the plant top and it was calculated according to the following formula:

$$RWc\ (\%) = \frac{(\text{Actual fresh mass} - \text{Dry mass})}{(\text{Full turgor mass} - \text{Dry mass})} \times 100$$

Leaf area duration (dm2 days)

(LAD) was worked out according to the formula of [13].as follows:

$$LAD = (A_2 - A_1)\,(t_2 - t_1) / (\text{In } A_2 - \text{In}A_1)$$

Where:
A_1: leaf area at sampling time t_1.
A_2: leaf area at sampling time t_2.
t_2, t_1 L time intervals in days between two stages

Net assimilation rate (gm^{-2} day^{-1})

NAR was determined by using the equation described by [13].

$$NAR = \frac{(W_2 - W_1)\ (\text{In}A_2 - \text{In } A_1)}{(A_2 - A_1)\ t_2 - t_1)}$$

Where:
W_1, W_2 are dry weights at t_1 and t_2
A_1, A_2: total leaf area at t_1 and t_2.

Crop growth rate (mgm^{-2} day^{-1})

Crop growth rate (CGR) determined by using the equation described by as follows:

$$CGR = (W_2 - W_1) / (t_2 - t_1)$$

Where, W_1, W_2 are dry weights at t_1 and t_2

Relative growth rate (gg^{-1} weak):

Relative growth rate (RGR) was determined using the equation described by [13] as follows:

$$RGR: (\text{In}W2 - \text{In } W_1) / (t2 - t_1)$$

STATISTICAL ANALYSIS

Data was statistically analyzed according to the analysis of variance (ANOVA) for split plot design using computer software package. Mean comparisons was worked out by Duncan's Multiple Range Test (DMRT) at 5% level for probability.

RESULTS AND DISCUSSIONS

Growth parameters (shoot dry weight and LAI), physiological parameter (LAD, RGR,CGR, NAR) and relative water content of soybean plants tended to decrease with increase of watering interval in both season,(Tables 1,2). This reduction was more pronounced at the higher watering interval (W_3) as compared with frequent watering regime (W_1). Water use efficiency for dry mater (WUEdm) was higher in moderate watering interval (W_2) as compared to frequent and pronged watering regimes (W_2 ,W_3) In both seasons (Tables 1,2). The aforementioned characters were significantly increased as plant density decreased the highest values of LA, dry weight; RGR, CGR, NAR, RWC and WUE were recorded in D_3 treatment (tables 1, 2). The increase of these characters due to low density (D3) was clearer under frequent watering intervals.

The highest average values of physiological parameters (LAD, NAR, CGR) were (93.4, 0,07, 0.39) recorded in W_1D_3 interaction treatment (Tables 1, 2). The increase in RWC% WUEdm were more pronounced as plant density decreased under prolonged water interval (W_2) in both seasons (Tables 1, 2).

Under limited soil moisture conditions water stress is more yield limited factor than plant population for soybean particularly under hot dry environments. In this regard, the increase in growth characters (dry weight and LAI) measured in this study with frequent watering interval might be due to positive effect of water in cell enlargement and cell division. The results also support the few of [10] who concluded that water stress significantly decreased shoot biomass per plants as a resulted in reduced leaf area and hastened leaf senesce. Although, prolonged watering interval reduced shoot biomass, but WUE increased in these treatments compared to frequent watering, this could be attributed to the lower number of irrigations applied due to the short season of growth. On the other hand, maintenance of leaf RWC under water stress conditions further explain the high WUE observed under prolonged watering intervals. In this study water stress at all density levels had greater effects on shoot dry weight, physiological traits as a consequence and yield contributing characters were also decreased severely. The longer leaf area duration under frequent water interval might explain the higher CGR. NAR and dry matter accumulation.

The increase in growth and physiological characters due to low plant population might be attributed to the fact that in the wider space the individual plants could not compete on water and nutrients supply. The over all enhancement of growth under low density possibly might explain the increases in LAD, CGR and NAR observed in the study.

The positive effects on low density on LAD, Nar and CGR was exacerbating under frequent watering intervals. These results are in accord with results reported by [3] that started that, improvement in water availability stimulated plant growth and caused increase in dry matter accumulation. LAD and NAR. Also, due to the fact that, legumes differed in their ability to maintain leaf area index, LAD at high levels of water stress. On the other hand, In low plant densities there were accumulated more dry matter than higher plant density which contributed to the greater relative growth rates (RGR's) and crop growth rates (CGR's) in low plant densities [11]. According to these results, the scheduling of irrigation water can be used without significant depression in physiological parameters in W_2.

In conclusion

Sowing soybean in wider spacing under frequent irrigation can increase most of the physiological characters measured in this investigation.

Table-1: Responses of Physiological, Yield Parameters and Water Use Efficiency to Water Stress and Plant Population in Soybean (*Glycine max.L.*) during 2014/2015 season

Treatments		DryWeight(g)	LAI	LAD	RGR	CGR	NAR	RWC	WUEdm
	W_1	4.08	3.47	88.112	0.054	0.319	0.073	51.66	0.92
	W_2	3.55	5.53	57.63	0.033	0.219	0.053	47.35	1.25
	W_3	2.68	2.76	50.63	0.033	0.170	0.028	47.95	0.99
	$LSD_{0.05}$	0.53	0.82	16.48	0.003	0.078	0.0177	10.04	0.12
	D_1	2.65	3.94	68.58	0.036	0.172	0.043	48.84	0.98
	D_2	3.62	3.22	61.52	0.043	0.207	0.049	49.32	1.04
	D_3	4.03	3.02	66.26	0.042	0.329	0.062	48.80	1.14
	$LSD_{0.05}$	0.47	0.25	3.50	0.005	0.034	8.93	4.33	0.12
W_1	D_1	3.01	4.54	84.96	0.039	0.192	0.047	51.09	0.80
	D_2	4.15	3.00	85.12	0.057	0.282	0.067	47.85	0.88
	D_3	5.07	2.87	94.24	0.068	0.484	0.105	56.04	1.09
W_2	D_1	2.84	3.58	66.01	0.033	0.174	0.056	52.72	1.06
	D_2	3.74	3.58	52.17	0.034	0.185	0.055	44.05	1.29
	D_3	4.08	3.43	54.70	0.027	0.300	0.049	45.29	1.38
W_3	D_1	2.12	3.71	54.76	0.037	0.151	0.025	42.27	1.08
	D_2	2.98	3.08	47.27	0.039	0.155	0.025	56.07	0.94
	D_3	2.93	2.76	49.84	0.027	0.204	0.033	45.06	0.95
	$LSD_{0.05}$	0.58	0.89	17.16	0.008	0.091	0.021	7.33	0.21

LAI: leaf area index ; LAD (days) : leaf area duration ; RGR(gg^{-1} week) : relative growth rate; CGR(mg $m^{-2}day^{-1}$) : Crop growth rate; NAR($gm^{-2}day^{-1}$): net assimilation rate; RWC% : relative water content and WUE dm(kg m^{-3}): water use efficiency for dry matter.

Table-3: Responses of Physiological, Yield Parameters and Water Use Efficiency to Water Stress and Plant Population in Soybean (*Glycine max* L.) during 2015/2016 season

Treatments		DryWeight(g)	LAI	LAD	RGR	CGR	NAR	RWC	WUEdm
	W_1	55.60	3.08	84.53	0.05	0.31	0.06	28.73	0.87
	W_2	48.53	2.40	54.93	0.03	0.19	0.04	27.64	1.19
	W_3	38.50	2.37	48.67	0.03	0.18	0.02	23.01	1.02
	$LSD_{0.05}$	8.94	0.33	2.83	0.01	0.06	0.01	5.28	0.18
	D_1	41.37	2.94	62.85	0.03	0.18	0.04	26.27	0.96
	D_2	49.32	2.60	60.10	0.03	0.20	0.04	26.83	1.02
	D_3	51.94	2.31	65.16	0.04	0.30	0.02	26.29	1.10
	$LSD_{0.05}$	4.13	0.10	1.86	6.44	0.04	6.51	5.32	0.11
W_1	D_1	48.75	3.67	77.86	0.04	0.17	0.04	27.90	0.72
	D_2	57.46	3.26	82.88	0.04	0.26	0.05	30.09	0.82
	D_3	60.61	2.32	92.84	0.07	0.51	0.08	28.19	1.09
W_2	D_1	39.72	2.60	61.10	0.03	0.21	0.05	26.49	1.09
	D_2	51.30	2.33	49.72	0.03	0.17	0.05	25.38	1.23
	D_3	54.95	2.28	53.96	0.03	0.18	0.04	31.05	1.25
W_3	D_1	35.65	2.56	49.61	0.03	0.16	0.03	24.42	1.08
	D_2	39.22	2.22	47.71	0.03	0.17	0.03	25.00	1.01
	D_3	40.62	2.35	48.69	0.02	0.20	0.02	19.62	0.97
	$LSD_{0.05}$	10.71	0.36	3.84	0.01	0.09	0.01	13.56	0.24

Symbols and abbreviations as in table 1.

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