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Effect of Water Intervals on Some Agronomic Traits and Yield Components Parameters and Seed Yield of Two Soybean (*Glycine max*. L) Cultivars in Semi-Arid Conditions

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Drought stress, considered the most limiting abiotic factor for plant growth and development, compared to other stress types, has a strong effect on grain yield, limiting crop production in both tropical and subtropical regions. In present studies we evaluated effects of different water interval (7, 14 and 21 days) on growth traits, yield and yield components of two soybean varieties (indeterminate variety and determinate variety) under semi-arid regions. We observed that there were significant differences between water interval, varieties and interaction between water interval and varieties for most of parameters. Moreover, water interval every 21 days significantly decreased plant height, leaf area, weight of plant, number of seeds per plant, weight of seeds per plant and final seed yield by 16.3%, 45.5%, 17.5%, 16.6%, 23.3% and 15.3%, respectively as compared with water interval every 7 days. Water interval every 14 days recorded the highest seed yield by 1908.4 kg/h, while water interval every 21 day recoded the lowest seed yield. Determinate variety recorded the high weight of seed yield compared with that of indeterminate variety under the study conditions with irrigation treatments applied. In conclusion, the soybean cultivars used in this study were very sensitive to water stress during the growth season. Therefore, timely scheduled and proper irrigation management is essential to improve plant growth and yield potential.

Introduction

Grain legume crops are generally grown in semi-arid and arid regions of the world and are considered as important part of human diet, and known to improve soil fertility by symbiotic N_2-fixation (Vanlauwe *et al.,* 2010). Soybean (*Glycine max* (L.) Merrill) is one of the most important crops in the world. It has high nutritional qualities due to its high protein content of 40% by weight, 32% carbohydrate, 20% fat, 5% minerals and 3% fiber, and other trace substances (Singh, 2010; Comlekcioglu and Simsek, 2011). It is richer than cow milk, egg, moderate fatty beef, bean and lentil in terms of nutrients content, phospholipids, vitamins and diet fiber which are used for both human and animal consumption as well as for industrial purposes (Mentreddy *et al.,* 2002; Singh, 2010). According to Mahamood *et al.,* (2009), soybean is a promising pulse crop proposed for the alleviation of the acute shortage of protein and oil worldwide.

World agriculture is facing many challenges and 70% more food is needed to feed a growing population. However, crop productivity is not increasing at the same rate as the demand for food. Lower productivity in most cases is attributed to various abiotic stresses such as drought and salinity stresses (Ali *et al.,* 2019, 2020). The decrease in crop yield as a result of kind of stress has been reported between 54% and 82%. The maximum decrease is of abiotic stresses including drought, salinity, heat, cold, light intensity, inadequate nutrients and soil acidity (Ali *et al.,* 2021). Drought stress is one of the most important limiting factors for growth and yield of crop, which affects 40 to 60 percent of world agricultural lands (Ardestani *et al.,* 2011).

Drought stress impairs plant morpho-physiological attributes related to growth and causes drastic reduction in grain yield (Sehgal *et al.,* 2017). It also, accentuates leaf senescence, induces injury to photosynthetic apparatus (Farooq *et al.,* 2009), decreases carbon fixation and assimilate translocation (Mondal *et al.,* 2011), and reduces sink capacity (Andersen *et al.,* 2002). Drought stress in legumes elevates abscisic acid (ABA) level and causes pollen sterility by impairing the ability of reproductive sinks to use starch and sucrose resulting in ovary abortion and poor pollen grain development (Farooq *et al.,* 2017), leading to fewer grains and reduced grain yield (Farooq *et al.,* 2020a). Drought stress at any stage of soybean development can reduce yield, but the extent and nature of damage, the capacity for recovery, and the impact on yield, timing of a stress episode are varies (Brevedan and Egli, 2003). Drought stress occurring during this period increases the rate of pod abortion (Westgate and Peterson, 1993), leads to a less number of pods per plant (Desclaux *et al.,* 2000), and ultimately decreases seed yield (Kokubun *et al.,* 2001). The yield of soybean is highly affected by drought stress, particularly when the stress is occurs during flowering and early pod expansion. The yield loss is due mainly to an increased rate of pod abortion resulting in a smaller number of seeds per unit area. All the physiological processes of plant are directly or indirectly influenced by water status of plant (Ali *et al.,* 2009). Soybeans respond well to irrigation during later growth stages where water stress may lead to a decrease in yield. Therefore, timely scheduled and proper irrigation management is essential to improve yield potential and water use efficiency. Soybean yield is highly affected by soil water availability (Ali *et al.,* 2009). Similarly, various soybean cultivars show varying sensitivity to drought at their different developmental stages (Liu, 2004). Moisture stress in soybean reduced the number of pods per plant, pod weight, number of seeds per pod and seed weight (Khodambashi *et al.,* 1988). Irrigation increased seed yield, 100 - seed weight and seed weight per plant (Kolařík, 1990).

The water requirements of soybean vary with soil, climatic conditions, growth duration, and yield level of cultivars. Generally, soybean water use is low during the germination and seedling stages; the water use is especially high during the reproductive stages and less than during the maturation stages (Liu, 2004). The best yield and most efficient water use are generally obtained when the available soil water in the root zone is not depleted by more than 50 - 60%. Thus, sufficient water supply, especially during the early reproductive stages is essential for soybean production under water-limited conditions (Liu, 2004).

There are different varieties of soybean growth in the world. Consideration in the choice of varieties depends on yield, habit of growth, colors of seed ability to hold leaves, to shatter seed, length of growing season, disease resistance and oil and protein content. Whether it is grown for seed, forage, and green vegetable or for general purposes. The objective of this research was to study the effect of different irrigation intervals (7, 14 and 21 day) on growth, yield components and seed yield of tow soybean genotype (indeterminate growth genotype and determinate growth genotype).This information will provide growers with new cultivation options which will lead to more stable and higher soybean seeds yields than those obtained using conventional cultivation methods.

Materials and Methods

Experimental site

A field study was carried out on the Experimental Farm of Sudan University of Science and Technology, College of Agricultural Studies (32.35"E, 15.31"N, within the semi-desert region) (Adam, 2002), in the soybean growing seasons of 2010 - 2011 and 2011 - 2012. The soil of the site is described by Abd elhafiz (2001) as loam clay it is characterized by a deep cracking, moderately alkaline clays, low nitrogen content, pH 7.5- 8 and high exchangeable sodium percentage (ESP), in subsoil. The soil contained 12.2 g kg^{-1} organic matter, 1.0 g kg^{-1} total N, 14.1 mg kg^{-1} $Bray^{-1}$ P, and 77.3 mg kg^{-1} soil test K with pH 7.1. The soil was tested containing 12.2 g kg^{-1} organic matter, 1.0 g kg^{-1} total N, 14.1 mg kg^{-1}, 77.3 mg kg^{-1} K with pH 7.1 (1:1 in water), the cation exchange capacity was 12.0 cmolc kg^{-1}, and the electrical conductivity of the saturation extract was 1.2 dSm^{-1}. The climate of this area is semi-arid and with low relative humidity, the annual rainfall is about 151.8 mm (Oliver, 1965).

Experimental Design and Land Preparation

This field experiment was laid out in randomized complete block design (RCBD) with four replications. The main plots were assigned for irrigation treatments and the sub plots for the variety. Each experimental unit was divided to plots (3.5 m long and 3.5 m wide).

Each plot including for 6 ridges, each ridge long 5 meters and 70 cm between ridges. Each variety was planted in hole in ridge, 30 cm between the hole. Before conducting the experiment, land was prepared by applying two dry ploughings. These ploughing operations were followed by clod crushing and leveling to obtain a good quality seedbed.

Seeds varieties and sowing data

Pure quality seeds of two varieties including indeterminate variety (Egyptian) and determinate variety (1448) were obtained from Agricultural Research center in Khartoum (Shambata) was used in this study. Seeds within a variety were selected for uniform size, shape, and color. All seeds were less than 9-mo old and were previously stored in paper bags under laboratory conditions (RH 40-60% at 15-20 °C) to maintain good germination ability. Before planting, seeds were sterilized using sodium hypochlorite solution (1%) for 3 min, washed with distilled water three times, and then air-dried. Seeds rate was four seeds per hole spaced at 30cm between holes. Sowing was carried out on July 21^{th}, 2011 and 2012. Thinning was carried out three weeks after sowing date to raise two plants / hole+. Weeding was done twice using hand hoeing. These seeds were planted carefully by following the methodology generally recommended for the region.

Drought stress treatments

The irrigation strategies included: 1. The plants were watered to field capacity every 7 days (WI 1), 2. The plants were watered to field capacity every 14 days (WI 2), and 3. The plants were watered to field capacity every 21 days (WI 3). The crop received equal quantities of water at 7 days' interval for establishment. The watering treatment was introduced four weeks after sowing.

Sampling and data collection

Morphological characters

In order to study the morphological parameters, five plants were selected randomly from each experimental unit and average values were calculated for traits such as

Plant height (cm)

On the 60^{th} and 90^{th} day after sowing date, plant height was determined from a point immediately above the soil surface to the end of the plant, and then the mean of plant height was obtained in cm.

Number of Leaves per Plant

The five selected plants, mentioned above, number of leaves per plant was continuously counted. Then, the average number of leaves per plant was worked out.

Leaf area (cm^2)

Leaf area were obtained using the leaf area measuring instrument (LI-3100C Area Meter, Li-Cor Biosciences) by putting leaves on the instrument. Each leaf was scanned individually by the machine.

Yield components parameters

For assessing the relationship between yield and its components, according to Yoshida *et al.,* (1971), the yield components were recorded at time of harvest. Five plants were selected randomly from each experimental unit and average values were calculated for traits. The traits were investigate including fresh weight of plant, number of pods per plant, number of seeds per plant, weight of seeds per plant and number of seeds per pod. Number of seeds per pod was calculated using the following equation:

$$\text{Number of seeds per pod} = \frac{\text{Number of seeds per plant}}{\text{Number of pods per plant}}$$

Harvest index

It was estimated using the data of grain yield and biological yield as follows:

Seeds yield (kg per ha)

Plants on the one-meter length from middle of each plot of each treatment were harvested, sun-dried, weighed to obtain the biological yield. The pods of the harvested plants were threshed, and seeds were collected. The seed yield per unit area was converted into kg ha^{-1} at 14 % moisture content.

Statistical Analysis

Analysis of variance was performed using MSTAT-C Statistical Package software with season and replication as random and drought stress and varieties as field effects (Abdelgadir *et al.,* 2010). Dependent variables included plant weight, number of pods $plant^{-1}$, weight of pods $plant^{-1}$, number of seeds $plant^{-1}$, weight of seeds $plant^{-1}$, 100 seeds, seeds yield, and harvest index, and were analyzed across the 2 yr. The procedure of analysis of variance and mean separation were followed according to the description of Gomez and Gomez (1984). When F values were significant, each parameter's means were compared by the LSD test ($P \leq 0.05$).

Results and Discussion

Plant height

A significant difference in plant height was observed by water interval, so the highest average of plant height (53.7 cm) were obtained in the WI2, the WI3 treatment caused a slight decrease in plant height by 16.3%, while the WI2 increased plant height by 7.8% as compare with WI1 (Table 1). The interaction between seasons × water interval, seasons × varieties, water interval × varieties and interaction among three experiments factor seasons × water interval × varieties for plant height were also significant affected (Table 1). In the interaction between seasons and water interval, average of plants height were 36.48 cm and 44.98 cm at the first season and second season under WI 3 shorter by 35.6 % and 16.18 % respectively, than WI 3 at the same season (Table 2). The variety 1448 showed the highest plant height by 51.66 cm at the second season, while the lowest plant height was observed for the indeterminate variety by 45.18 cm at the first season (Table 4).

In the interaction between water interval and varieties, determinate variety at WI 2 was increased the plant height by 28.58%, while, deceased by the 40.32% at the WI 3 as compare with variety 1448 at WI 1 (Fig 1a). In the interaction between seasons and varieties and dwater interval, at the first season, 1448 under WI 2 recorded the highest plant height (62.83 cm)(Table 5).

Number of leaves per plant

A significant difference in number of leaves per plant was observed by water interval, so the highest number of leaves per plant (28.13 leaves) were obtained in the WI 2 (Table 1). The interaction between seasons × varieties and water interval × varieties for number of leaves per plant were also significant affected (Table 1).

In the interaction between seasons and varieties, average of number of leaves per plant of the determinate variety were 21.93 and 27.23 leaves at the first and second seasons shorter by 9.21 % and 14.17% respectively of the and indeterminate variety at the first and second season of the experiment (Table 4). In the interaction between water interval and varieties, determinate variety at WI 1 was recorded the high number of leaves, while at the WI 3, the indeterminate variety recorded the high number of leaves per plant (Fig 1b).

Leaf area and fresh weight of plant

Leaf area (cm^2) and fresh weight of plant (g $plant^{-1}$) of both soybean varieties (indeterminate variety and determinate variety), grown under the three-water interval treatments are presented in Table 1 and 2. Leaf area and fresh weight of plant were significantly affected by seasons, water interval and varieties (Table 1). For both seasons, the highest leaf area and fresh weight of plant were obtained at the first season by 66.1 cm^2 and 77.4 g $plant^{-1}$(Table 2).

It is clear that, water interval every 14 and 21 days decreased leaf area and fresh weight of plant, WI 2 and WI 3 decreased leaf area by the 18.11% and 45.28% respectively as compared with WI 1 (Table 1). However, WI3 decreased the fresh weight of plant by the 17.54%, while WI 2 increased the fresh weight of plant by the 50.49% as compared with WI 1 (Table 1). The indeterminate variety showed the highest leaf area, while the determinate variety was observed the highest value for fresh weight per plant (Table 2).

Number and weight of pod plant^{-1}

The results in Table 2 indicated that, the number and weight of pods per plant had a significant change during the seasons of study and the highest number and weight of pods per plant was observed in the first season (104.7 pods and 29 g of pods per plant). Determinate variety with the average of 123.2 pods per plant and 29.3 g of pods per plant was identically superior to indeterminate variety with the average of 84.2 pods per plant and 25.8 g of pods per plant (Table 2).

The mean comparison of the water interval and variety interaction revealed that the 1448 variety had the highest number of pods per plant and weight of pods per plant at the water interval every 14 days by 152.13 pods per plant (Fig 2a) and 40.65 g per pods per plant (Fig 2b). The both varieties were recorded the highest number of pods per plant and weight of pods per plant at the water interval every 14 days (Fig 2 a and b). The mean comparison of the number of pods per plant and weight of pods per plant affected by the water interval showed that, by increasing the day of water interval, the number of pods per plant and weight of pods per plant was increased.

Therefore, as a result of the water interval intensity, it increased the number of pods per plant from 86.9 pods per plant to 120.5 and 103.6 pods per plant at the water interval every 14 days and 21 days respectively. In addition, the weight of pods per plant increased from 20.9 g per plant to 36.6 g and 25.1 g per plant at the water interval every 14 days and 21 days respectively (Table 1).

Number and weight of seeds plant^{-1}

In this study, the effect of season on the number of seeds per plant and weight of seeds per plant was a significant affected (Table 1). The number of seeds per plant and weight of seeds per plant were change during the seasons of study and the highest number of seeds per plant observed in the first season (187.7 seed). While, the highest weight of seed per plant was recorded in the second season (29.2 g per plant) (Table 2). In this study, there was a significant difference between two tested varieties in terms of the studied traits. Therefore, the determinate variety with the mean value of 182.1 seed per plant and 27.7 g weight of seeds per plant proved its superiority over indeterminate variety with the mean value of 149.3 seed and 22.6 g per plant for number of seeds per plant and weight of seeds per plant (Table 2).

The interaction between the season and variety represented that the highest number of seeds per plant and weight of seeds per plant were related to determinate variety in both seasons and the lowest one was seen in indeterminate variety (Table 4). The number of seeds per plant and weight of seeds per plant was remarkably affected by the water interval. Hence, at the water interval every 21 days, the number of seeds per plant and weight of seeds per plant were decreased by 16.58% and 23.33% respectively, as compared with water interval every 7 days (Table 1). The mean comparison of the number of weight of seeds per plant affected by the interaction between seasons and water interval showed that, at the both seasons, at the water interval every 21 days, the weight of seeds per plant was decreased. Therefore, at the first and second seasons water interval every 21 days were decreased the weight of seeds per plant by 13.92% and 29.33% respectively as compared with water interval every 7 days (Table 3).

Harvest Index

Effect of interaction between seasons and varieties was not significant, while, other factor and there interaction were significant difference in harvest index (Table 1). In the interaction between season and water interval, found that at the both seasons water interval increased harvest index, WI 2 and WI 3 were increased harvest index by the 24.62% and 10.28% respectively for first season and increased by 40.94% and 23.64% respectively for the second season ae compared with WI 1 (Table 3). In the interaction between water interval and varieties, indeterminate variety recoded the highest value of harvest index flowing by determinate variety at the water interval every 14 days. Whereas, the determinate variety recoded the lowest harvest index at the WI1 (Fig 3a). Data in Table (3) shows that there was insignificant interaction effect between seasons, water interval and varieties on harvest index. However, as can be seen in Table (3), the highest harvest index (49.82) was obtained in the treatment 2012 × Egyptian variety × WI 2, and lowest harvest index (25.85) was recorded at the treatment 2011 × determinate variety × WI 1.

Seed yield (kg per ha)

Seed yield of both soybean varieties (determinate variety and indeterminate variety) grown under the three irrigation treatments are presented in Table (2). For both varieties, determinate variety recorded the highest seed yield (1745.1 kg / ha), but yields were not statistically different for both seasons, but yield were higher in the second season than the first season (Table 2). The water interval every 21 days was significantly decreased grain yield. At irrigated every 14 days seed yield was increased by 11.51% and 31.67% as compared with irrigated every 21 days and 7 days, respectively (Table 2). However, in the interaction between seasons and drought, at the first season, in comparison to interaction between 2011 × WI 1, applying the 2011 × WI 2 treatment significantly increased the seed yield with proportions of 21.92%. in addition, applying the 2012 ×WI 2 treatment significantly increased the seed yield with proportions of 2.82% as compared with and 2012 x WI 1 (Table 3). The results also indicated that interactions of water interval and the varieties significant effect on grain yield, determinate variety recorded the higher seed yield at the irrigated every 14 days by 2072.12kg / ha, while, irrigated every 21 days treatment, the seed yield was reduced by the 1472.46kg / ha and 1426.27 kg / ha at the1448 and indeterminate variety respectively (Fig 3b).

Among abiotic factors, water availability is probably the most limiting for crop quality and productivity, comprising economical output and human food supply. Water deficit is a multidimensional stress affecting plants at various levels of their organization. Thus, the effects of drought stress are often manifested at morpho-physiological, biochemical and molecular level, such as inhibition of growth, accumulation of compatible organic solutes, changes in phytohormones endogenous contents (Aimar *et al.,* 2011). Water deficit causes alternations in physiology, growth and plant metabolism by disturbing plant water relations, enzyme activities, photosynthesis, membrane integrity and enhanced oxidative stress (Farooq *et al.,* 2020b).

Growth is accomplished through cell division, cell enlargement and differentiation, and involves genetic, physiological, ecological and morphological events and their complex interactions. The quality and quantity of plant growth depend on these events, which are affected by water deficit. In this study, plants height was affected by limited irrigation and interaction treatments were significantly different and a slight decreased in plant height was observed by increasing drought stress. The reduction in plants height could be explained by decrease in the formation of nodes on the main stem due to water stress throughout the growth period. Cell growth is one of the most drought-sensitive physiological processes due to the reduction in turgor pressure (Farooq *et al.,* 2009). Under severe water deficiency, cell elongation of higher plants can be inhibited by interruption of water flow from the xylem to the surrounding elongating cells (Farooq *et al.,* 2009). Comlekcioglu and Simsek (2011) reported that irrigation treatments significantly increased the plant height. Results showed no significant effect on plant height between the two genotypes. Meanwhile, indeterminate growth genotype (1448) grew taller than the determinate growth genotype. In contrast Comlekcioglu and Simsek (2011) found significant variations.

The most conspicuous effect of drought stress at the whole plant level is decreased growth or development, plants exposed to water stress had less branches, leaf area and vegetative growth (Teixeira *et al.,* 2020). Reduction in leaf area results due to decrease in leaf size. Water deficiency stress causes inhibition of cell division and limits leaf enlargement. Water deficit stress adversely affected leaf area of both the varieties of sunflower. The reduction in leaf area under water stress resulted in decreased photosynthesis, reduced transpiration and cell expansion, and consequently reduced total top dry weight and yield components (Sarwar, 2002). In this study, there were significant differences among the three levels of irrigation intervals and genotypes. Statistically, similar results were shown by the soybean when irrigation was applied at the beginning of seed formation (Jaidee *et al.,* 2012).

In addition, in this study, water deficits have been shown to decreased leaf area and increased the number of leaves per plant. These results are in accordance with the findings of Teixeira *et al.,* (2020) who reported that the well-watered plants were higher and produced more leaves than drought-stressed plants. The number of pods per plant is an important variable for determining yield performance in leguminous crop plants. In this study, the number of pods per plant, decreased with drought stress increase, but under medium water stress the number of pods per plant increased. The reduction in number of pods per plant is the result of water deficiency which has adverse effect on the development of reproductive parts of plants.

Table.1 Summary of the analysis of variance [ANOVA] of egyption and 1448 for the season [Y], water interval [WI], variety [V], and their possible interactions on plant weight, number of pods plant^{-1}, weight of pods plant^{-1}, number of seeds plant^{-1}, weight of seeds plant^{-1}, 100 seeds, harvest Index, and seeds yield traits in 2011 and 2012 growing seasons.

Source	F value									
	Plant Height	Number of leaf	Leaf Area	Weight of plant	Number of podsplant^{-1}	Weight of Pods plant^{-1}	Number of seeds plant^{-1}	Weight of seedsplant^{-1}	Harvest index	Final seeds yield
Seasons [Y]	1.20^{ns}	0.34^{ns}	3.25*	57.05***	12.12^{*ns}	22.85^{*ns}	10.59**	143.02**	30.45**	1.79^{ns}
Water interval [WI]	33.11**	54.52***	30.96**	14.76**	9.68*	28.08**	6.42*	168.00***	7.27**	3.75*
Y ×WI	16.39**	1.98^{ns}	1.09^{ns}	0.26^{ns}	0.42^{ns}	0.11^{ns}	0.12^{ns}	9.88**	2.86*	3.37*
Varieties [V]	0.01^{ns}	1.29^{ns}	21.64**	12.13**	41.92**	22.30***	7.93*	20.56**	5.01*	4.32*
Y × V	13.94**	3.91*	0.24^{ns}	1.68^{ns}	0.59^{ns}	0.17^{ns}	3.12*	11.07**	0.01^{ns}	0.52^{ns}
WI× V	15.81**	24.13**	0.43^{ns}	2.50^{ns}	5.04*	21.39***	0.68^{ns}	1.40^{ns}	11.89**	4.39*
Y ×WI× V	3.19*	0.68^{ns}	0.52^{ns}	0.01^{ns}	0.48^{ns}	0.06^{ns}	0.52^{ns}	2.80*	4.02*	1.68^{ns}
Water Interval										
WI 1	49.8 ± 6.5 b	15.1 ± 3.0 c	79.5 ± 14.7 a	51.3 ± 30.3 b	86.9 ± 22.5 c	20.9 ± 5.7 c	164.1 ± 47.0 b	24.0 ± 7.0 b	30.8 ± 7.1 bc	1711.4 ± 337.6 b
WI 2	53.7 ± 8.8 a	28.13 ± 3.9 a	65.1 ± 13.7 b	77.2 ± 28.8 a	120.5 ± 37.0 a	36.6 ± 5.5 a	196.1 ± 55.2 a	33.2 ± 7.2 a	39.1 ± 10.1 a	1908.4 ± 364.3 a
WI 3	41.7 ± 6.1 c	20.7 ± 4.0 b	43.5 ± 11.3 c	42.3 ±19.2 c	103.6 ± 32.7 b	25.1 ± 5.9 b	136.9 ± 62.5 c	18.4 ± 4.7 c	33.3 ± 7.8 b	1449.4 ± 306.8 c
CV [%]	9.48	9.66	16.28	20.24	20.10	9.41	24.40	15.49	12.90	10.90

Notes: ns: No significant effects. * Significant effect at P < 0.05 level, ** Significant effect at P < 0.01 level, and *** Significant effect at P < 0.001 level.WI 1the plants were watered to field capacity every 7 days, WI 2 = the plants were watered to field capacity every 14 days, and WI 3 = the plants were watered to field capacity every 21 days

Table.2 The average of seasons and varieties for leaf area, weight of plant, number of pods plant^{-1}, weight of pods plant^{-1}, number of seeds plant^{-1} and final seed yield [kg per ha] of two varieties of soybean in 2010-2011 and 2011-2012 growing seasons as influenced by different water interval traits

Source		*F* value				
	Leaf Area	Weight of plant	Number of podsplant^{-1}	Weight of Pods plant^{-1}	Number of seeds plant^{-1}	Final seeds yield
Seasons						
2010 – 2011	66.1 ± 21.0 a	77.4 ± 21.2 a	104.7 ± 37.3 a	29.0 ± 8.8 a	187.7 ± 71.5 a	1598.0 ± 440.5 b
2011 - 2012	59.3 ± 18.4 b	35.3 ± 14.8 b	102.6 ± 30.4 ab	26.0 ± 8.5 ab	143.7 ± 32.9 b	1781.7 ± 290.6 a
Varieties						
Determinate variety	55.8 ± 19.0 b	62.6 ± 34.5 a	123.2 ± 32.5 a	29.3 ± 9.9 a	182.1 ± 69.1 a	1745.1 ± 423.2 a
Indeterminate variety	69.5 ± 18.6 a	51.1 ± 24.1 b	84.2 ± 21.6 b	25.8 ± 7.1 ab	149.3 ± 43.1 b	1634.5 ± 332.6 b
Mean	62.7	56.3	103.7	27.5	165.7	1689.9

Notes: Different letters at the same line and column show significant differences at 0.05 level

Table.3 Interaction of seasons ×water interval for plant height, weight of seed per plant, harvest index and final seed yield [kg per ha] of two varieties of soybean in 2010-2011 and 2011-2012 growing seasons as influenced by different water interval traits

Seasons	Water Interval	Parameters			
		Plant Height	Weight of seedsplant^{-1}	Harvest index	Final seeds yield
2011	WI 1	53.05 ± 4.86 ab	19.18 ± 6.89 cd	26.62 ± 2.35 d	1553.1 ± 358.5 c
	WI 2	56.66 ± 11.14 a	27.94 ± 5.80 b	32.65 ± 6.58 c	1893.5 ± 413.5 ab
	WI 3	36.48 ± 2.82 d	16.51 ± 6.04 d	28.89 ± 8.36 cd	1347.3 ± 405.0 d
2012	WI 1	48.56 ± 6.54 bc	28.74 ± 2.55 b	32.27 ± 5.40 c	1870.4 ± 241.2 b
	WI 2	53.66 ± 6.42 a	38.42 ± 3.94 a	45.48 ± 9.42 a	1923.2 ± 336.1 a
	WI 3	44.98 ± 3.12 c	20.31 ± 1.24 c	39.90 ± 4.92 b	1551.4 ± 117.4 c

Notes: Different letters at the same line and column show significant differences at 0.05 level, WI 1the plants were watered to field capacity every 7 days, WI 2 = the plants were watered to field capacity every 14 days, and WI 3 = the plants were watered to field capacity every 21 days

Table.4 Interaction of seasons × varities for plant height, number of leaf per plant, number of seeds plant^{-1} and weight of two varieties of soybean in 2010-2011 and 2011-2012 growing seasons as influenced by different water interval traits

Seasons	Varities	Parameters			
		Plant Height	Number of leaf per plant	Number of seeds plant^{-1}	Weight of seeds plant^{-1}
2010 - 2011	Determinate variety	50.28 ± 10.38 ab	20.08 ± 7.12 d	214.42 ± 78.68 a	25.64 ± 7.00 c
	Indeterminate variety	45.18 ± 10.74 c	21.93 ± 3.35 c	160.92 ± 54.14 b	16.78 ± 5.93 b
2011 - 2012	Determinate variety	51.47 ± 4.22 a	23.85 ± 9.70 b	149.83 ± 39.03 c	29.84 ± 9.23 a
	Indeterminate variety	46.67 ± 7.24 bc	27.35 ± 6.99 a	137.58 ± 25.55 d	28.48 ± 6.94 ab

Notes: Different letters at the same line and column show significant differences at 0.05 level

Table.5 Interaction of seasons × water interval × varieties for plant height, weight of seeds plant^{-1}, harvest index and final seed yield [kg per ha] of two varieties of soybean in 2010-2011 and 2011-2012 growing seasons as influenced by different water interval traits

Seasons	Drought Stress	Varitiy	Parameters		
			Plant Height	Weight of seedsplant^{-1}	Harvest index
2011	WI 1	Determinate variety	49.03 ± 2.3 cd	24.49 ± 4.33 de	29.70 ± 9.80 de
		Indeterminate variety	57.08 ± 2.49 ab	13.87 ± 4.10 fg	25.85 ± 2.19 f
	WI 2	Determinate variety	62.85 ± 2.33 a	32.31 ± 4.47 bc	26.75 ± 1.04 ef
		Indeterminate variety	44.48 ± 7.69 de	23.58 ± 2.60 de	38.55 ± 2.67 bc
	WI 3	Determinate variety	38.95 ± 0.64 ef	20.11 ± 6.17 e	27.38 ± 2.56 ef
		Indeterminate variety	34.00 ± 1.35 f	12.91 ± 3.53 g	28.09 ± 8.09 e
2012	WI 1	Determinate variety	41.80 ± 4.48 e	26.67 ± 0.90 cd	28.58 ± 3.98 e
		Indeterminate variety	51.33 ± 4.39 c	30.81 ± 1.71 bc	36.96 ± 2.36 c
	WI 2	Determinate variety	53.93 ± 7.88 bc	41.74 ± 2.53 a	41.13 ± 12.46 bc
		Indeterminate variety	53.40 ± 5.83 bc	35.10 ± 0.66 b	49.82 ± 1.22 a
	WI 3	Determinate variety	44.28 ± 0.70 de	21.11 ± 1.29 de	44.16 ± 2.73 ab
		Indeterminate variety	49.68 ± 1.67 cd	19.52 ± 0.48 ef	35.64 ± 0.86 cd

Notes: Different letters at the same line and column show significant differences at 0.05 level, WI 1the plants were watered to field capacity every 7 days, WI 2 = the plants were watered to field capacity every 14 days, and WI 3 = the plants were watered to field capacity every 21 days

Figure.1 Effects of interaction between water interval and varieties on [a] plant height [cm] and [b] number of leaves per plant of soybean varieties. Columns without a common letter are statistically different at the 0.05 probability level.

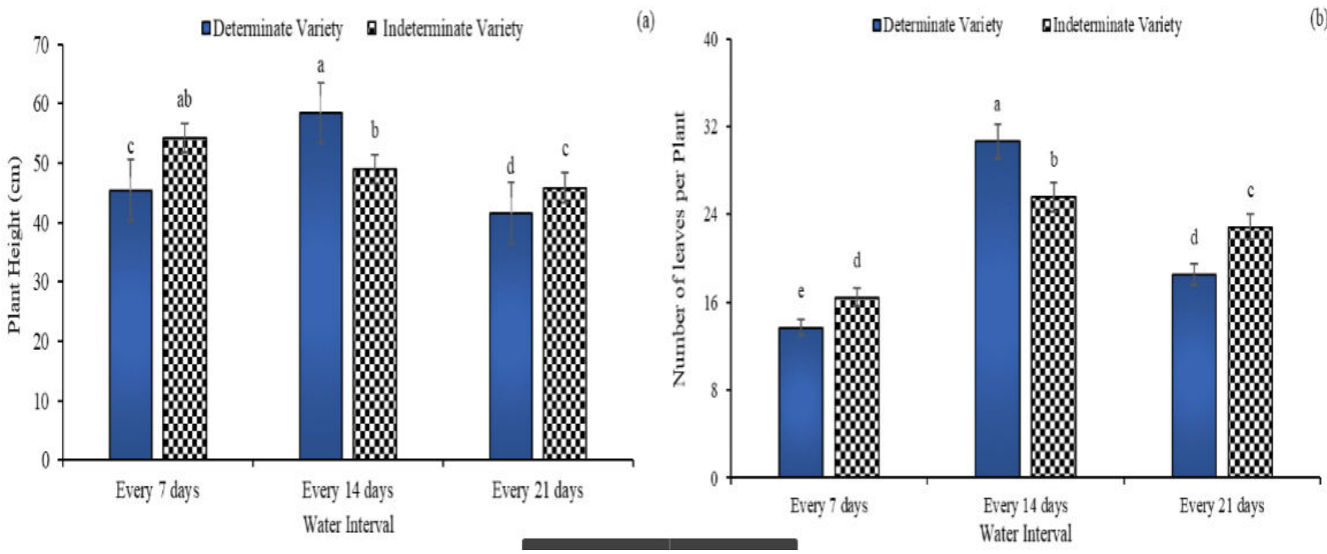


Figure.2 Effects of interaction between water interval and varieties on [a] number of pods per plant and [b] weight of pods per plant [g per plant] of soybean varieties. Columns without a common letter are statistically different at the 0.05 probability level.

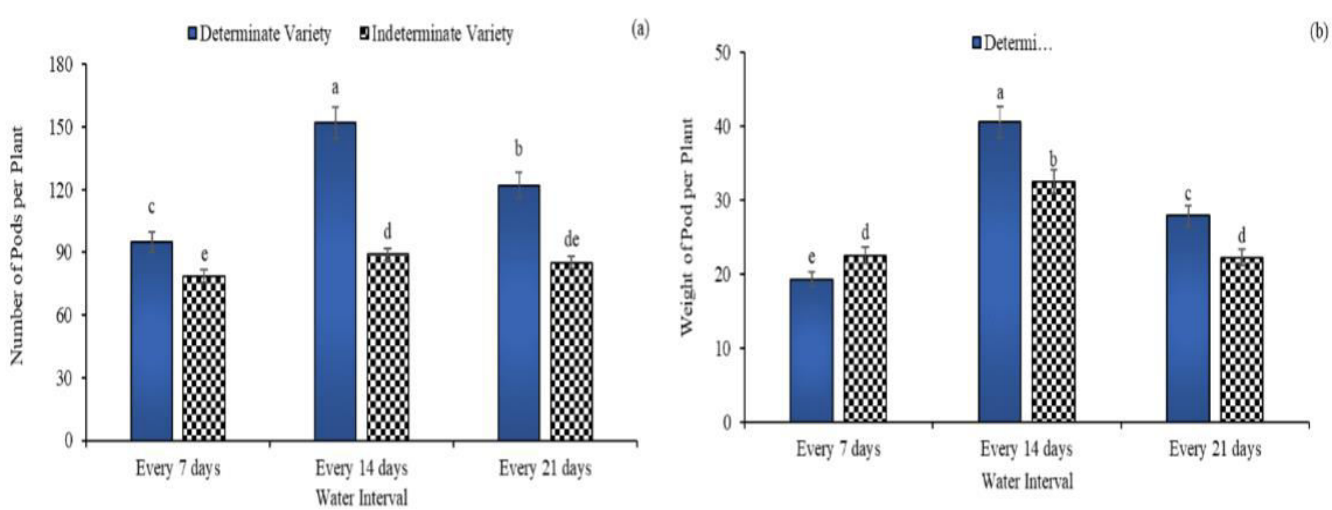
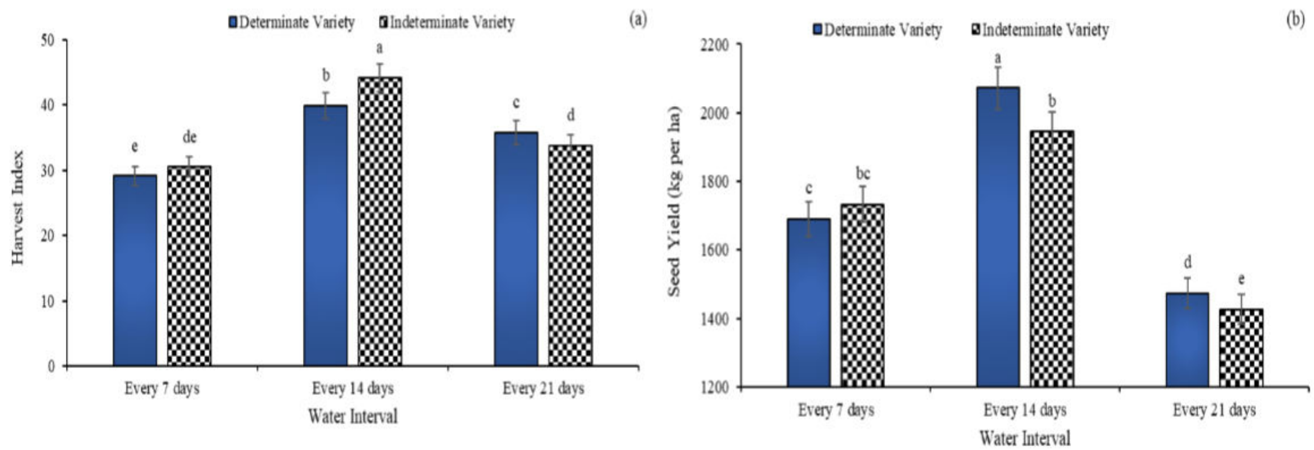


Figure.3 Effects of interaction between water interval and varieties on [a] harvest index and [b] seed yield [kg per ha] of soybean varieties. Columns without a common letter are statistically different at the 0.05 probability level.



Stress at vegetative stage results in less development of fruit bearing branches, which ultimately affect the number of pods per plant. Kobraee *et al.,* (2011) reported that water deficit at flowering stage has more effect on the yield through affecting and decreased the number of pod per plant. In addition, this results confirmed with Mirzaei *et al.,* (2013) suggested that number of pods per plant have more sensitive effects on drought stress.

Drought stress especially at pod formatting stage plays an important role for high yield and desired quality and it can gravely decrease the yield (Sionit and Kramer, 1977). Water stress reduced number of pods per plant, and that if it would reduce the yield sharply (Smiciklas *et al.,* 1992). The results showed that Egyptian was more sensitive to water stress than 1448 under different water stress. The possible reasons for such difference could be associated with their work which was conducted in different environmental conditions with other maturity groups of soybean.

Number of seeds per pod is considered as an important factor that directly affects potential yield in leguminous crops. The high number of seeds per pod is a benefit and has well effect on increasing of seed yield. As traits correlation indicated, the seeds number per pod has positive and significant correlation with seed yield. It is evident from the results that number of seeds per pod significantly affected and decreased with drought stress increase, but under medium water stress the number of seeds per pod increased.

This reduction in number of seeds per pod is due to adverse effect of irrigation stress on the production of assimilates. Irrigation stress reduced the photosynthetic activity of crop plants resulting in less photosynthates required by the sink, so there was a smaller number of seeds per pod. These findings are supported by those of Siag and Verma (1990) and Mirzaei *et al.,* (2013) who reported higher number of pods and number of seeds per pod at higher irrigation frequencies.

Weight of seeds per plant and number of seeds per plant is an important factor for determining the yield of leguminous crops. Seed weight per plant had directly impact on the final yield of any crop. Drought stress also decreased the weight and number of seeds per plant. The cause of seeds numbers reduction during deficit water stress are decreasing number of flowers and lowering number of flowers, which converted to seeds. Deficit water stress caused a reduction indirectly of the photosynthesis and consumption of photosynthesis matters by growing leaves, and finally assimilation amount which leads to increased vulnerability of seed formatting under deficit water conditions (Mirzaei *et al.,* 2013). The variation in weight and number of seeds per plant can be attributed to differences in number of pods per plant and number of seeds per pod. Positive and significant correlation between seed yield, number of seeds per plant and weight of seeds per plant indicated that change of these traits caused the change in seed yield (Mirzaei *et al.,* 2013). The reduction in seed weight per plant might be due to less development of seeds under stress conditions. Results of Ma *et al.,* (2006) studies

indicated that concurrency of reproductive stage during drought stress causes the reduce of most attributes related to seeds yield such as number of seeds per plant, number seeds per pod and weight of seeds per plant, reducing seed yield is mostly due to reducing number and weight of seeds per plant. Poma *et al.,* (1999) observed that all seed yield components were decreased in deficit water condition as seed yield. Environmental stresses such as deficit stress especially at seed forming and filling decrease the seed filling speed and duration and finally its weight due to photosynthesis reduction (Mirzaei *et al.,* 2013).
Final yield is the combined effect of various yield components under irrigation intervals. Thus, any variation in them is liable to bring about variation in seed yield. Water deficits have been shown to increase seed abortion, and the duration of the maturation period has been reduced by water stress during seed filling, leading to accelerated senescence, and decreased seed yield and yield components (Jaidee *et al.,* 2012).

Drought stress also significantly decreased soybean genotype seeds yield. The highest and lowest seed yield was obtained at full irrigation and high drought, respectively. The difference in the seed yield among different irrigation levels is because of variable crop stand at harvest, number of pods per plant, number of seeds per pod and variation in 1000-seed weight indicated that change of these traits caused the change in seed yield. These results are in line with the findings of Kobraee *et al.,* (2011) they reported that the deficit irrigation treatments exhibited variable grain yield and biological yield.

The results showed that Egyptian was more sensitive to water stress than 1448 under different water stress. The relative yield increased under fall irrigation and medium water stress. Similar results reported by Rosadi *et al.,* (2007) and Demirtas *et al.,* (2010). Gungadurdoss and Hanoomanjee (1999) reported that fresh pod yield of ten vegetable soybean cultivars ranged from 11 to 15 t ha^{-1}.

The possible reasons for such difference could be associated with their work which was conducted in different environmental conditions with other maturity groups of soybeans (Comlekcioglu and Simsek, 2011).

Drought stress seed yield, yield components as well as the growth yield were studied in this study. By noticing the positive and efficient correlation of yield components and seed yield, it seems that the yield components reduction leads to decrease of seed yield under drought stress condition. Determinate variety had the more seed yield and growth parameters at normal and drought stress conditions. Interaction effects of drought stress cultivar had an effect on growth parameters, seed yield as well as yield components. In addition, the results of this experiment indicated that drought stress at different stages of soybean plants is more sensitive to water deficit due to pod numbers per plant and number of seeds per pod. Determinate variety is recommended due to having higher seed yield and yield components in north Khartoum.

Author Contributions

Adam Yousif Adam Ali: Investigation, formal analysis, writing—original draft. Muhi eldeen Hussien Ibrahim: Validation, methodology, writing—reviewing. Samia Osman Yagoub:—Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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