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Effect of Irrigation System and Irrigation Interval on Seed Yield and Water Productivity of two Soybeans (*Glycine max* L. Merr.) Cultivars under Drip and Furrow Irrigation in Eastern Sudan

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Abstract: Water stress is one of the limiting factors of soybean yield in eastern Sudan. The objective of this study was to obtain basic information on soybean cultivation using two irrigation systems in eastern Sudan. This study examined the leaf area index, yield and irrigation water productivity (IWP) response using two soybean cultivars: $Sudan_1$ (V_1) and $Sudan_2$ (V_2) under drip (DS_1) and furrow (DS_2) irrigation systems. The experiment was carried out in the summer seasons of 2016 and 2017. Three irrigation intervals, every 4, 8 and 12 days designated as W_1, W2 and W_3, respectively, were used. A randomized complete block design was used as strip-split plot arrangement with three replications**.** The data were statistically analyzed using STATISTICS 10; mean separation was computed using LSD. The results showed that cultivar $Sudan_1$ gave higher leaf area index values under four days irrigation interval particularly with furrow irrigation system. Four days irrigation interval treatment increased seeds yield by more than 2.5 % relative to 8 days irrigation interval and 34 % relative to 12 days irrigation interval, as average for both seasons. Drip irrigation system significantly ($P \leq 0.05$) increased IWP compared to furrow irrigation system. Highest water productivity was obtained under four days irrigation interval. Eight days irrigation interval significantly ($P \leq 0.05$) inhibited the positive effect of irrigation system on seed yield and

IWP. The study concludes that IWP for drip irrigation, in both seasons, was 20.5 % higher than furrow irrigation. However, mean seed yield for furrow system, in both seasons, was 25.6% higher than drip irrigation system.

Keywords: Soybean, water deficit, irrigation system, water productivity**,** seed yield**.**

INTRODUCTION

Soybean (*Glycine max* L. Merr.) is an important grain and oil crop that plays an important role in nutrition of humans and animals, medicinal products and bio-energy production (Zhang *et al.* 2019).

In the Sudan, soybean trials started as early as 1925 at Gezira Research Farm where low yields were obtained. These low yields were attributed to lack of cultivars adaptable to the Sudan agro-ecological conditions, which has enormously contributed to the existing information gap on association of traits with seed yield (Tony *et al*. 2013). Momen *et al*. (1979) reported that, various soybean cultivars showed varying sensitivity to drought at their different developmental stages. Drought is the main reason for the loss of soybean plants productivity (Wang *et al*. 2022).

Water scarcity is a major constraint for food production particularly for agricultural production in arid and semi-arid environments where water resources are scarce. Thus, selecting the appropriate irrigation system is vital to overcome water scarcity and enhance water productivity with no yield losses (Okasha *et al*. 2022). Comparing surface drip irrigation to furrow irrigation with its seepage losses in the canals and furrows, and sprinkler irrigation with its direct evaporation from airborne water droplets, drip irrigation has no significant conveyance losses (Meshkat *et al*. 2000). Drip irrigation reduces evaporation from the soil surface, minimizes runoff and deep percolation, and enables even application of water in fields consequently increases irrigation efficiency (Chomsang, *et al*. 2021). Irrigation water productivity ranging between 0.92 and 1.68 kg m^{-3} was reported under furrow irrigation as compared to 0.82 and 1.96 kg m^{-3} under drip irrigation (Karimi and Gomrokchi 2011).

Lately, drip irrigation has become important because of the high cost of energy in pressurized irrigation methods and the incorporation of automation in its operation (Holzapfel *et al*. 2009). Further, according to FAOSTAT (2000), an experiment conducted on the comparative study between drip and furrow irrigation systems revealed that drip irrigation system saved 56.4 % water and gave 22 % more yield than furrow irrigation system. One reason why people are moving towards drip irrigation is the increasing awareness that water resources are finite and perhaps are even declining.

In most of the crops, yield losses might be the result of decreasing in water supply during the vegetative phase, due to drought during reproductive development or due to terminal drought at the end of the crop cycle (Serraj *et al*. 2004). Kumagai *et al*. (2020) reported that drought during flowering and at the pod development stage significantly reduced soybean yield by 29%.

The increase in agricultural production in the world, including that in arid and semi-arid areas, has been achieved through application of modern agricultural technologies, comprising a combination of irrigation and heavy doses of fertilizer (Janmohammadi *et al.* 2016). Irrigation farming is not just application of water on crops to supplement deficit rainfall but the type of system of irrigation used is a key factor in determining successful irrigation farming. Water management will continue to be one of the major factors affecting crop production in Eastern Sudan. The great challenge of the agricultural sector is to produce more food from less water, which can be achieved by increasing crop water productivity (Zwart 2004). Higher pumping costs, water restriction and water shortage are all factors encouraging efficiency-improving irrigation practices. Efforts are now underway in Sudan to encourage the cultivation of oil seed crops to meet the domestic need as well as to earn the foreign exchange. Further, the ability to grow soybean in Kassala state, one of the arid regions of Sudan, with limited water resources using low-cost, water-efficient irrigation system may greatly increase oil seed productivity and, hence, the economic security of smallholder farmers. Therefore, the objective of this study was to examine the effects of irrigation water intervals, irrigation systems, variety and their interactions on the leaf area, seed yield and irrigation water productivity of soybeans at Kassala Eastern Sudan.

MATERIALS AND METHODS

The experiment was conducted at Kassala and Gash Research Station Farm in two successive summer seasons 2016 and 2017, latitude 15° 27′ N, longitude 36° 24′ E, altitude 500 m above sea level**.** The soil at the experimental site is silt- loamy in texture. Two released cultivars of soybean Sudan$_1$ (V_1) and Sudan$_2$ (V_2) were grown under two irrigation systems (drip irrigation DS_1 and furrow irrigation DS_2) and three irrigation intervals every 4, 8 and 12 days designated as W_1,W_2 and W_3, respectively. Randomized complete block design was used as strip-split plot arrangement with three replications.

Studied parameters:

Leaf area index (LAI):

Leaf area index expresses the ratio of leaf surface area to the ground area occupied by the crop.

Ten plants were randomly selected and tagged in each sub-plot to determine the leaf area index of soybean. The leaf area index was calculated according to Watson and Watson (1953).

Seed yield:

In each sub-plot, all plants grown in an area of 1.7 m^2 in the two central ridges were harvested, seeds were separated, air- dried and weighed to determine the average seed yield per unit area (kg/m^2).

Irrigation water productivity (IWP):

IWP was calculated as the ratio of the crop yield to seasonal irrigation water applied according to Al-Jamal *et al.* (2001) using the following formula:

$$\mathrm{IWP}\left(\mathrm{kg}/\mathrm{m}^3\right) = \frac{\text{yield } \left(\mathrm{kg\ ha}^{-1}\right)}{\text{Total water applied } \left(\mathrm{m}^3\mathrm{ha}^{-1}\right)}$$

Calculation of crop water requirement (CWR)

Crop water requirement was calculated according to the procedure described by (Allen *et al.* 1998).

Computation of reference evapotranspiration (ET_o)

Meteorological data (maximum and minimum air temperature, relative humidity, sunshine duration and wind speed at 2 meter height) were taken from Kassala Meteorological Station and used to compute the reference evapotranspiration (ET_o) according to (Allen *et al.* 1998).

Computation of crop coefficient (K_c)
The standard K_c for growth stages of soybean was taken from FAO-Paper 56 documentation (Allen *et al*. 1998).
The quantity of water to be applied by the drip irrigation system was calculated as described by (Bagalli, *et al*. 2012).

Amount of applied water for each irrigation system:
The total amount of water applied per drip irrigation and furrow irrigation was 3622 m^3 and 8500 m^3, respectively, in 2016 and 5312 m^3 and 9400 m^3, respectively, in 2017.
Statistical analysis: The data were analyzed according to the standard statistical procedure as described by Gomez and Gomez (1984) using STATISTICS 10. Mean separation for the different parameters was computed using least significant difference (LSD).

RESULTS AND DISCUSSION

The highest values of leaf area index were observed under 4 days irrigation interval in furrow irrigation system (DS_2) in both seasons (Table 1). Also, $Sudan_1$ variety (V_1) gave higher leaf area index values under (W_1) with DS_2 as compared with their relative treatments (Table 1). The $W_1 \times V_1$ treatment significantly ($P \leq 0.05$) increased the mean leaf area index by more than 6% relative to $W_1 \times V_2$ treatment in both seasons. The increase in this character might be due to the positive effect of water on cell enlargement and cell division as described by Baret and Vinila (2003) who found that, increasing the number of irrigations resulted in a progressively higher leaf area index. The results also support the view of Mustapha *et.al* (2014), who concluded that water deficit significantly decreased leaf area and hastened leaf senescence.
Differences in the mean seed yield per unit area between watering treatments were much marked under W_1 interval in the second season under DS_2 (Table 2). W_1 treatment increased seeds yield by more than 2.5 % relative to W_2 and by more than 34 % relative to W_3 as average for both seasons (Table 2). Moreover, sowing soybean under DS_2 system significantly ($P \leq 0.05$) increased seed yield relative to DS_1 under W_1 in both seasons. Furthermore, prolonged watering interval W_3) significantly ($P \leq 0.05$) inhibited the positive effect of irrigation system on mean seeds yield per unit area (Table 2). The increase in seed yield per unit area might be due to increased leaf area resulting from the aforementioned

treatments. These results are in agreement with those obtained by Ahmed *et al.* (2017) who found that deficit irrigation caused a significant decrease in yield and yield components of soybean. These results are also in accordance with those of Candoğan, and Yazgan (2016), who reported that irrigation system and soybean variety had statistically significant positive impact on soybean grain yield.

Table 1. Effect of variety, irrigation system and irrigation interval on mean leaf area index of soybean in 2016 and 2017

Treatment	DS1				DS2			
Season 2016								
	W1	W2	W3	Mean	W1	W2	W3	Mean
V1	10.15	8.46	7.69	8.80	11.30	9.32	6.97	9.27
V2	9.04	7.23	7.73	8.00	8.96	6.84	5.68	7.16
Mean	9.60	7.85	7.71	8.39	10.13	8.08	6.33	8.43
$LSD_{0.05}$ W				0.65				
$LSD_{0.05}$ V				0.50				
$LSD_{0.05}$ DS				1.00				
$LSD_{0.05}$ VxW				0.87				
$LSD_{0.05}$ VxDS				0.71				
$LSD_{0.05}$ WxDS				0.80				
$LSD_{0.05}$ VxDSxW				1.23				
Season 2017								
V1	8.39	9.21	6.36	7.99	8.98	8.97	7.55	8.50
V2	8.37	8.31	7.23	7.97	8.71	8.12	6.74	7.86
Mean	8.38	8.76	6.79	7.98	8.85	8.55	7.15	8.18
$LSD_{0.05}$ W				0.52				
$LSD_{0.05}$ V				0.27				
$LSD_{0.05}$ DS				0.60				
$LSD_{0.05}$ VxW				0.4				
$LSD_{0.05}$ VxDS				0.38				
$LSD_{0.05}$ WxDS				0.71				
$LSD_{0.05}$ VxDSxW				0.66				

W_1, W_2, W_3 = watering intervals of 4, 8 and 12 days, respectively. V_1= Sudan 1; V_2 = $Sudan_2$ soybean varieties; DS_1=drip irrigation, DS_2= surface irrigation; $LSD_{0.05}$: least significant difference at 5% level of probability.

Table 2. Effect of variety, irrigation system and irrigation interval on seed yield (kg ha^{-1}) of soybean in 2016 and 2017

Treatment	DS1				DS2			
	W1	W2	W3	Mean	W1	W2	W3	Mean
				Season 2016				
V1	363.19	387.22	295.39	348.60	670.57	467.10	263.69	467.12
V2	394.62	348.21	264.89	335.91	433.95	363.67	252.66	350.09
Mean	378.91	367.72	280.14	342.25	552.26	415.39	258.18	408.61
$LSD_{0.05}$ W				28.48				
$LSD_{0.05}$ V				15.50				
$LSD_{0.05}$ DS				38.90				
$LSD_{0.05}$ VxW				26.86				
$LSD_{0.05}$ WxDS				49.64				
$LSD_{0.05}$ VxDSxW				37.98				
				Season 2017				
V1	296.98	292.17	232.10	273.75	420.88	792.17	238.67	483.91
V2	292.17	287.66	211.82	263.88	394.20	783.06	226.55	467.94
Mean	294.58	289.66	221.96	268.82	407.54	787.62	232.61	372.37
$LSD_{0.05}$ W				4.01				
$LSD_{0.05}$ DS				8.37				
$LSD_{0.05}$ VxW				10.44				
$LSD_{0.05}$ VxDS				8.50				
$LSD_{0.05}$ WxDS				17.90				
$LSD_{0.05}$ VxDSxW				14.76				

W_1, W_2, W_3 = watering intervals of 4, 8 and 12 days, respectively. V_1= Sudan 1; V_2 = $Sudan_2$ soybean varieties; DS_1=drip irrigation, DS_2= surface irrigation; $LSD_{0.05:}$ least significant difference at 5% level of probability.

Irrigation water productivity (IWP)

All treatments significantly ($P \leq 0.05$) affected mean IWP in both seasons. Drip irrigation system DS_1 significantly ($P \leq 0.05$) increased IWP as compared to furrow irrigation system in both seasons (Table 3). Irrigation interval W_1 significantly ($P \leq 0.05$) increased IWP by more than (67% and 44%) relative to W_3 in first and second season, respectively. This might be due to increase of grain yield resulting from W_1. Variety $Sudan_2$ showed significant ($P \leq 0.05$) differences in IWP as compared to Sudan1 in the first season but the situation was reversed in the second season in both irrigation systems.

The effect of irrigation interval W_1 on IWP was clear for both varieties particularly under drip irrigation in both seasons (Table 3). However, irrigating soybean V_2 every 4 days using drip irrigation significantly ($P \leq 0.05$) increased IWP as compared to V_1 under W_1 watering interval even using either or both irrigation systems in both seasons. These results are confirmed by the findings of Colaizzi *et al*. (2006) who observed that soybean crop yield, crop water use efficiency (also known as crop water productivity and irrigation water use efficiency) were higher with drip irrigation systems. Okasha *et al*. (2022) reported maximum water productivity and highest yield of cauliflower under drip irrigation as compared to furrow irrigation and alternate furrow irrigation. Generally, drip irrigation system minimizes runoff and deep percolation, consequently increases irrigation efficiency (Chomsang, *et al*., 2021). However, furrow irrigation significantly increased seed yield, which is an important role.

Table 3. Effect of variety, irrigation system and irrigation interval on irrigation water productivity (kg/m^3) of soybean in 2016 and 2017

Treatment	DS1				DS2			
	W1	W2	W3	Mean	W1	W2	W3	Mean
				Season 2016				
V1	1.39	1.00	0.83	1.07	0.78	0.62	0.42	0.61
V2	1.44	1.20	0.87	1.17	0.79	0.62	0.41	0.61
Mean	1.42	1.10	0.85	1.12	0.76	0.62	0.42	0.61
$LSD_{0.05}$ W				0.06				
$LSD_{0.05}$ V				0.03				
$LSD_{0.05}$ DS				0.02				
$LSD_{0.05}$ VxW				0.03				
$LSD_{0.05}$ VxDS				0.01				
$LSD_{0.05}$ WxDS				0.02				
				Season 2017				
V1	0.93	1.20	0.77	0.97	0.77	0.80	0.53	0.70
V2	0.97	1.00	0.70	0.89	0.70	0.80	0.57	0.69
Mean	0.95	1.10	0.71	0.93	0.74	0.80	0.55	0.70
$LSD_{0.05}$ W				0.02				
$LSD_{0.05}$ V				0.02				
$LSD_{0.05}$ DS				0.07				
$LSD_{0.05}$ VxW				0.01				
$LSD_{0.05}$ VxDS				0.02				
$LSD_{0.05}$ WxDS				0.01				
$LSD_{0.05}$ VxDSxW				0.03				

W_1, W_2, W_3 = watering intervals of 4, 8 and 12 days, respectively. V_1= Sudan 1; V_2 = $Sudan_2$ soybean varieties; DS_1=drip irrigation, DS_2= surface irrigation; $LSD_{0.05:}$ least significant difference at 5% level of probability.

CONCLUSION

1. There were significant differences in the yield and IWP between the studied irrigation systems.
2. The findings of this study indicate that furrow irrigation system increased seed yield by 19 % over drip irrigation, which, on the other hand leads to more effective utilization and resource conservation of available water.
3. Economic aspects of both irrigation systems need to be further studied before recommendation.

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تأثير نظام وفترة الرى على إنتاج البذور والإنتاجية المائية لصنفين من فول الصويا (*Glycine max* L. Merr.)تحت نظامى الرى بالتنقيط والرى السطحى فى شرق السودان

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المستخلص: الإجهاد المائى هو أحد معيقات إنتاج فول الصويا فى العالم. الهدف من هذه الدراسة هو الحصول على معلومات أساسية عن زراعة فول الصويا بإستخدام نظامين للرى فى كسلا شرق السودان. تمت دراسة معامل مساحة الورقة، إنتاج البذور و الإنتاجية المائية بإستخدام صنفين من فول الصويا سودان 1 (V_1) و سودان 2 (V_2) تحت نظامى الرى بالتنقيط (DS_1) والرى بالسراب (DS_2). تمت زراعة التجارب فى موسمى صيف 2016 و 2017. إستُخدمت ثلاثة فترات للرى كل 4 ، 8، و12 يوم W_2,W_1 وW_3 على التوالى . صُممت التجربة على تصميم القطاعات الكاملة العشوائية بإستخدام تنظيم الشرائح المنشطرة بثلاث مكررات. تم تحليل البيانات إحصائيا بإستخدام برنامج STATISTICS 10، إستُخدم أقل فرق معنوي لفصل المتوسطات. أظهرت النتائج أن الصنف سودان1 سجل أعلى قيمة لمعامل سطح الورقة تحت فترة الرى كل 4 يوم مقارنة بالصنف سودان2 بإستخدام نظام الرى بالسراب. معاملة فترة الرى كل 4 يوم أدت الى زيادة إنتاج البذور بمقدار 2.5% مقارنة بمعاملة الرى كل 8 يوم و 34% مقارنة بمعاملة الرى كل 12 يوم كمتوسط للموسمين. كانت الإنتاجية المائية أعلى معنوياً تحت نظام الرى بالتنقيط مقارنةً بنظام الرى بالسراب. أعلى إنتاجية مائية سُجلت تحت الرى كل 4 أيام. الرى كل 12 يوم أثر تأثيراً معنوياً سلبياً على الأثر الإيجابى لنظام الرى والإنتاجية المائية فى إنتاج البذور. عليه تخلص الدراسة بأن إنتاجية الماء بإستخدم نظام الرى بالتنقيط فى الموسمين كانت 20.5% أعلى من نظام الرى بالسراب، ولكن والأهم أن إنتاجية البذور فى الموسمين كانت 25.6% أفضل فى نظام الرى بالسراب مقارنة بنظام الرى بالتنقيط.