PHYSIOLOGICAL RESPONSE OF SESAME TO SOIL MOISTURE STRESS AND POTASSIUM FERTILIZATION IN SANDY SOIL.

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ABSTRACT

A field trail was conducted at Ismailia Agricultural Research Station during the two successive seasons 2006 and 2007 to study the physiological response of sesame cv. "Shandaweel-3" to three levels of available soil moisture depletion (ASMD) namly wet (20-25%), medium (45-50%) and dry (65-70%) as well as potassium fertilization at the rates of 0, 24, 48 kg K_2O/fed and spraying 1% K_2O alone or in combination with added 24 kg K_2O/fed. Results of combined analysis could be summarized as follows:

- Increasing soil moisture stress up to 65-70% ASMD significantly decreased plant height, fruiting zone length, leaf area index (LAI) at 56, 70 and 84 days after sowing (DAS), relative growth rate (RGR), net assimilation rate (NAR) at 56-70 and 70-84 DAS, total chlorophyll, carotenoides contents of leaves and chlorophyll fluorescence. Whereas, proline content in leaves was significantly increased. Dry treatment significantly reduced 1000-seed weight, number of capsules, capsules, straw and seed weights/plant, straw and seed yields/fed as well as total carbohydrates and oil contents in seeds. Exposing sesame plants to severe water deficit decreased relative water content of leaves (RWC), seasonal water consumptive use (WCU), water use efficiency (WUE) and transpiration rate (TR), while stomatal resistance (SR) was increased. The maximum value of WUE was obtained when plants received medium treatment compared with wet or dry treatments.
- Applying 24 kg K_2O/fed in combination with spraying 1% K_2O significantly increased plant height, fruiting zone length, LAI at 56, 70 and 84 DAS, RGR at 56-70 and 70-84 DAS, NAR at 56-70 DAS, total chlorophyll, carotenoides contents of leaves, chlorophyll fluorescence, 1000-seed weight, number of capsules, capsules and seed weights/plant, straw and seed yields/fed. While, straw weight/plant was significantly increased when plants received 48 kg K_2O/fed. Proline content of leaves and SR significantly increased without adding potassium fertilizer. The maximum value of total carbohydrates and oil contents in seeds, RWC, TR, WCU and WUE recorded the highest values when plants were treated with 24 kg K_2O / fed and sprayed by 1% K_2O.
- The interaction effect between water stress and potassium fertilization was found to be significant on LAI at 56 DAS, carotenoides content of leaves at 70 and 84 DAS, chlorophyll fluorescence, leaf proline content, number of capsules/plant, capsules, seed and straw weights/plant, total carbohydrates and oil contents in seeds, RWC at 70 and 84 DAS, SR and TR. The maximum value of WUE was obtained when plants were irrigated at 45-50% ASMD and received 24 kg K_2O / fed with spraying 1% K_2O.

Key words: Sesame, Water stress, Potassium fertilization, Sandy soil.

INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the most important oil crops due to its high seed oil content and it is most proper crop for growing in the newly reclaimed soil. The local consumption of sesame is increasing rapidly every year. Therefore, it is necessary to increase its production by improving the agronomic practices such as irrigation and fertilization.

Sandy soils had low water holding capacity and high permeability, thus, water management is very important factor affecting crop yield. Many investigators found significant increases in plant height and number of branches, number of capsules, seed yield/plant and 1000-seed weight as well as seed yield/fed by carrying irrigation frequently at high level of field capacity (**Majumdar and Roy, 1992; Tadrous, 1992; Prakash and Thimmegouoda, 1992; Galal–Anaam and El-Nagar, 1997; Ghallab** ***et al.*****, 2001).** On the other side, **Saeed and Abdel-Hameed (2001 a&b)** reported that exposing sesame plants to water stress (45% of water holding capacity) gave the lowest values of plant height and number of leaves, leaf area, number of capsules, number of seeds/plant as well as fresh and dry weights/plant. They stated that drought conditions decreased oil seed yield, total carbohydrates and crude protein. With respect to water consumptive use (WCU) by sesame in sandy soil, **Anton and El-Raies (2000)** reported that irrigated sesame at 25-30% of available soil moisture depletion (ASMD) increased WCU.

Potassium is one of the essential elements for plant nutrition and in the case of insufficient soil supply (sandy soils), it has a negative affect on plant growth. There is a grate need to add such element regularly as a fertilizer to improving crop productivity and it has several important roles in plant nutrition. Potassium is essential for many physiological processes, such as photosynthesis, translocation of photosynthates into sink organs, maintenance of turgidity, activation of enzyme, and reducing excess uptake of ions such as Na and Fe in saline and flooded soils (**Marschner, 1995; Mengel and Kirkby, 2001**). An important function of potassium is its role in plant water relation. Plants with adequate potassium lose less moisture because they have a slower transpiration rate. When plants were exposed to water stress conditions, they close their stomata much more quickly than potassium – deficient plants. Application of (k) helps to regulate stomatal movement and control water loss through osmo regulation.

Dasmahapatra ***et al*** **(1990)** found that the application of K_2O up to 80 kg/ha for sesame increased seed yield, 1000-seed weight and oil seed content compared with control treatment. **Tiwari** ***et al*** **(1994)** reported that sesame plants given 60 kg N + 30 kg P + 20 kg K/ha recorded the highest seed yield. **Mondal** ***et al*** **(1997)** mentioned that sesame seed and oil yields increased with increasing K rate up to 80 kg K_2O/ha.

Foliar application of potassium has attracted considerable attention in recent years because of its importance for the quick and adequate supply to plants at the time of seed formation to improve productivity. **Anton and Ahmed (2001)** found that raising foliar spray levels of potassium from 0.5% up to 2% on barley plants increased significantly plant height, spike length, grain weight/spike, 1000 grain weight, straw and grain yields/fed.

Concerning the interaction between water deficit and potassium fertilization, much attention has been focused by many investigators. **Abdel-Aziz and El-Bialy (2004)** reported that the highest values of grain, stover yields and seasonal water consumption were scored when maize plants were irrigated at 35-40% depletion in available soil moisture (wet treatment) and sprayed with 3% K_2O.

The present investigation is carried out to study the physiological response of sesame plants to water stress in combination with potassium fertilization as soil dressing and foliar spray under sandy soil conditions.

MATERIALS AND METHODS

The present work was carried out at Ismailia Agric. Res. Station, ARC under surface irrigation system during the two successive summer seasons 2006 and 2007 to study the effect of soil moisture stress in combination with potassium fertilization as soil dressing and foliar spray on growth, yield, yield components, photosynthetic pigments and proline contents of leaves, chlorophyll fluorescence and water relations i.e. relative water content of leaves (RWC), stomatal resistance (SR), transpiration rate (TR), water consumptive use (WCU) as well as water use efficiency (WUE).

The experiment was laid out in split plot design with four replicates. The main plots were occupied by soil moisture levels, while sub-plots contained potassium fertilization rate. Each sub-plot area was 12 m^2 (3×4 m) and included 6 rows, 4 m long, 50 cm apart.

Some physical and chemical properties of the experimental site are shown in the following Table:

Season	Particle size distribution				Tex.	O. M %	$CaCO_3$ %	pH (1: 2.5)	Available nutrients (ppm)		
	Coarse sand %	Fine sand %	Silt %	Clay %					N	P	K
2006	82.27	10.8	1.60	5.33	sandy	0.59	0.46	7.50	32.9	5.30	80.2
2007	82.80	10.6	1.55	5.05	sandy	0.62	0.48	7.40	34.5	5.20	75.3

20 m^3, organic matter/fed in the form of compost was added before planting to the experimental site. Sesame seeds cv. Shandaweel-3 were planted on 11/5/2006 and 17/5/2007 in the first and second seasons, respectively, in hills spaced 10 cm. Plants were thinned to one plant per hill at 21 days after sowing. 30 kg P_2O_5/fed was added as calcium super phosphate (15.5% P_2O_5) in two equal doses, the first before planting and the second at 21 days after sowing. 50 kg N/fed in the form of ammonium nitrate (33.5% N) was added in three doses, the first was 10 kg before planting immediately, the second was 15 kg at 21 days after sowing and the third was 25 kg at 35 days after sowing.

The treatments are as follows:

I- Main plots (irrigation treatments):

A- Irrigation when 20-25% of available soil moisture was depleted (ASMD) (wet treatment).

B- Irrigation when 45-50% of ASMD (medium treatment).

C- Irrigation when 65-70% of ASMD (dry treatment).

II- Sub-plots (potassium fertilization):

1- Spraying water (control)
2- 24 kg K_2O / fed
3- 48 kg K_2O / fed
4- Spraying 1% K_2O (in the form of Potassin, 30% K_2O)
5- 24 kg K_2O / fed + spraying 1% K_2O.

Potassium fertilizer as soil dressing treatments in the form of potassium sulphate (48% K_2O) were added in two equal doses at 21 and 35 days after sowing. Foliar spraying of 1% K_2O in the form of Potassin solution sprayed two times at 30 and 40 days after sowing, the volume of water was 1.5 L/plot, 0.5% wetting agent of Tween 20 was used. To avoid the interference between irrigation treatments, 1.5 meter beds were left between the experimental plots. Irrigation treatments were applied at 40 days after sowing. Other, cultural practices were applied according to the methods being adopted for growing sesame crop.

Growth analysis traits:

To calculate growth analysis, five plants were randomly taken from each sub-plot at 56, 70 and 84 days after sowing (DAS). Plants were separated into their components i.e. roots, leaves, stems and capsules, then dried at 70°C in a ventilated oven to a constant weight. To determine leaf area/plant, 10 disks (π=0.9 cm) were taken from leaves of each sample and dried, the disks area equal ($10\times3.14\times(0.9)^2 = 25.434$ cm^2). According to **Hunt (1990)** formulas, the following traits were determined:

1- Leaves area/plant, in cm^2:

$$LA = 25.434 \times \text{dry weight of leaves per plant/dry weight of leaves disks.}$$

2- Leaf area index:

$$LAI = \text{leaf area per plant/ground area occupied by plant}$$

3- Net assimilation rate, in mg/cm^2/week:

$$NAR = (W_2 - W_1)(\log_e A_2 - \log_e A_1) / (A_2 - A_1)(t_2 - t_1).$$

4- Relative growth rate, in g / g / week:

$$RGR = (\log_e W_2 - \log_e W_1) / (t_2 - t_1).$$

Where:

$A_2 - A_1$ = differences in leaf area between two successive samples in cm^2

$W_2 - W_1$ = differences in dry matter accumulation of whole plants between two successive samples in g.

$t_2 - t_1$ = Number of days between two successive samples (in week).

Log_e = Natural logarithm.

Leaf chlorophyll fluorescence was determined of each treatment at 70 days after sowing to calculate the maximum quantum yield of photo-system II (PSII) using Chlorophyll Fluorometer (OS-30, Opti – Sciences, Inc. USA) in four plants by the formula of **Maxwell and Johnson (2000)** as follow:

$$F_v / F_m = (F_m - F_o) / F_m$$

Where:

F_v / F_m is the maximal quantum efficiency of PSII (MQE), F_m is the maximal chlorophyll fluorescence and F_o minimum chlorophyll fluorescence (in the dark).

At 70 and 84 days after sowing, leaves samples were taken to determined total chlorophyll and carotenoides contents, in mg/g fresh weight, according to **Welburn and Lichtenthaler (1984)** and leaf proline concentration, in mg/g fresh weight, according to **Bates *et al* (1973).**

Harvesting took place at 2/9/2006 and 3/9/2007 in the first and second seasons, respectively. At harvest time, five individual guarded plants were randomly taken from the central row in each sub-plot to determine:

1- Plant height (cm)
2- Fruiting zone (cm)
3- Number of capsules / plant
4- Capsules weight / plant (g)

5- 1000 – seed weight (g)
6- Straw weight / plant (g)
7- Seed weight / plant (g)

Plants in a central area (4 m^2) in each sub-plot were harvested to determine seed and straw yields (kg) / fed.

Mature seeds were subjected to chemical analysis to determine oil content using Soxhlet apparatus, according to **AOAC (1990)** and total carbohydrates as glucose %, according to **Dubois *et al.*(1956).**

Water Relations:

A- Relative water content of leaves (%):

At 70 and 84 days after sowing, leaf samples were immediately weighed (fresh weight, FW) and transferred into sealed flasks, then rehydrated in water for 5 h until fully turgid at 4°C, surface swabbed and reweighed (turgid weight, TW). Leaf samples were oven dried at 70°C for 48 h and reweighed (dry weight, DW). RWC % was calculated according to **Lazcano-Ferrat and Lovatt (1999)** as follows:

$$RWC\% = \frac{(Fw - Dw)}{(Tw - Dw)} \times 100$$

B- Porometer measurements:

At 70 days after sowing, a Portable Steady state Porometer (LI – COR Model LI 1600) was used to measure stomatal resistance (SR), in S/cm and transpiration rate (TR), in $\mu g\ H_2O / Cm^2/S$.

C- Water consumptive use (WCU):

Soil samples were taken, using a regular auger, at planting time, just before and 48 hours after each irrigation and at harvesting time for soil moisture determination. Irrigation was applied when the moisture content reached the desired available soil moisture for each treatment. At each sampling date, duplicate of soil samples were taken from 0-15, 15-30, 30-45 and 45-60 cm depths and their moisture content was gravimetrically determined and presented in following Table.

Depth (cm)	Field capacity (%)	Wilting point (%)	Available moisture (%)	Bulk density (g/m^3)
0 – 15	6.85	2.93	3.92	1.75
15 – 30	6.71	2.91	3.80	1.77
30 – 45	6.42	2.80	3.62	1.86
45 – 60	6.12	2.73	3.39	1.88

The depleted soil moisture was detected after each irrigation and the following equation was used to calculating water consumptive use according to **(Israelsen and Hansen, 1962):**

$$Cu = D \times Bd \times (e_2 - e_1) / 100$$

Where:
Cu = Water consumptive use (ET) in mm.
D = Soil depth (cm)
Bd = Bulk density in g/cm^3
e_1 , e_2 = Soil moisture content before and after each irrigation.

D- Water use efficiency (WUE):

Water use efficiency in kg/m^3/fed was calculated for each treatment according to the equation described by **Pierre *et al* (1965)** as follows:

WUE = seed yield (kg/fed) / seasonal water consumption in m^3/fed.

Data of the tow seasons were combined and statistically analyzed according to **Steel and Torrie (1980).** The discussion of the results were carried out on the basis of combined analysis for the two seasons.

RESULTS AND DISCUSSION

I- Growth and growth analysis:

a- Plant height and fruiting zone length:

Data in Table (1) indicate that both soil moisture stress and potassium fertilization had significant effects on plant height and fruiting zone length. The maximum values of such traits were obtained from the wet treatment, which was watered at 20-25% available soil moisture depletion (ASMD). However, the minimum values were obtained from dry treatment (irrigation at 65-70% ASMD). These findings explain that, increasing available soil moisture level enhanced plant growth by controlling the elongation of the above ground part of plant. In this respect, **Saad El-Deen (2006)** reported that the negative effect of water stress on sesame was due to its effect on photosynthesis, cell divison and cell elongation during the vegetative growth stage which in turn reduced plant height.

Applying 24 kg K_2O/fed with spraying 1% K_2O significantly increased plant height and fruiting zone length. In this respect **Anton and Ahmed (2001)** reported that barley plant height was gradually increased with increasing foliar spray of potassium concentration from 0.5 up to 2% K_2O.

The interaction effect between soil moisture stress and potassium fertilization had no significant effect on plant height and fruiting zone length.

b- Leaf area index (LAI):

Data of Table (1) show that LAI increased by advancing sesame age up to 84 days after sowing (DAS). This is mainly due to the production of new leaves and leaves expansion through the growth of sesame plant. LAI was significantly affected by soil moisture stress and potassium fertilization at different stages of sesame growth i.e. 56, 70 and 84 DAS. The wet treatment (irrigated at 20-25% ASMD) significantly increased LAI at all tested growth stages compared with medium or dry treatments. Whereas, dry treatment (irrigated at 65-70% ASMD) resulted the lowest values of LAI at all growth stages. Such reduction may be due to water deficit which induced a reduction in leaf area and number of leaves/plant. Medium treatment (irrigated at 45-50% ASMD) recorded intermediate values. These results are in harmony with those obtained by **Saren *et al* (2004)** who found that irrigated sesame by four irrigations significantly increased LAI compared with one, two and three irrigations.

Concerning the effect of potassium fertilization on LAI at all growth stages, plants treated with 24 kg K_2O/fed and sprayed by 1% K_2O had the highest values of LAI at all growth stages viz. 56, 70 and 84 DAS compared with other potassium treatments. These findings due to potassium activates at least 60 different enzymes involved in plant growth **(Robert, 2005)**. In this connection, **Abdel-Aziz and El-Bialy (2004)** found that spraying 3% K_2O on maize plants significantly increased LAI.

Table 1. Plant height, fruiting zone length and leaf area index of sesame plant as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Plant height (cm)			Fruiting zone length (cm)			Leaf area index (LAI)								
Irrigation level	Potassium fertilization								56 DAS			70 DAS			84 DAS		
	Soil dressing kg K_2O/fed	Foliar spray K_2O%	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.
(20-25)% in ASMD (wet)	0	0	126.5	131.7	129.1	71.3	74.0	72.7	1.54	1.60	1.57	2.94	3.02	2.98	3.05	3.30	3.18
	24	0	128.0	133.5	130.8	74.8	77.3	76.1	2.13	2.37	2.25	3.12	3.06	3.09	3.41	3.38	3.40
	48	0	134.0	136.5	135.3	85.8	83.7	84.8	2.67	2.86	2.77	3.28	3.46	3.37	3.87	3.81	3.84
	0	1	130.3	134.3	132.3	78.0	80.7	79.4	2.21	2.54	2.38	3.16	3.24	3.20	3.61	3.55	3.58
	24	1	145.5	142.0	143.8	92.7	88.7	90.7	2.80	2.89	2.85	3.36	3.49	3.43	4.02	3.90	3.96
Mean			132.9	135.6	134.3	80.5	80.9	80.7	2.27	2.45	2.36	3.17	3.25	3.21	3.59	3.59	3.59
(45-50)% in ASMD (medium)	0	0	105.0	115.8	110.4	67.2	67.8	67.5	1.21	1.31	1.26	2.47	2.62	2.55	1.92	2.92	2.42
	24	0	117.5	117.5	117.5	72.2	70.8	71.5	1.92	2.05	1.99	2.62	2.95	2.79	2.95	3.27	3.11
	48	0	123.0	124.8	123.9	82.2	76.7	79.5	2.42	2.51	2.47	3.07	3.36	3.22	3.58	3.70	3.64
	0	1	119.5	120.8	120.2	79.8	74.8	77.3	2.37	2.10	2.24	2.89	3.07	2.98	3.03	3.39	3.21
	24	1	127.2	129.8	128.5	88.7	80.5	84.6	2.58	2.60	2.59	3.11	3.39	3.25	3.64	3.80	3.72
Mean			118.4	121.7	120.1	78.0	74.1	76.1	2.10	2.11	2.11	2.83	3.08	2.96	3.02	3.42	3.22
(65-70)% in ASMD (Dry)	0	0	94.3	101.3	97.8	54.2	52.2	53.2	1.11	1.09	1.10	1.71	1.63	1.67	1.80	1.89	1.85
	24	0	95.7	104.3	100.0	57.0	57.8	57.4	1.20	1.25	1.23	1.97	1.86	1.92	2.01	2.14	2.08
	48	0	101.0	111.3	106.2	65.7	60.8	63.3	1.94	1.98	1.96	2.09	2.47	2.28	2.43	2.81	2.62
	0	1	97.0	108.7	102.9	64.8	59.3	62.1	1.34	1.38	1.36	2.01	2.09	2.05	2.23	2.37	2.30
	24	1	105.2	117.2	111.2	67.2	63.5	65.4	2.00	2.02	2.01	2.20	2.79	2.50	2.62	3.14	2.88
Mean			98.6	108.6	103.6	61.8	58.7	60.3	1.52	1.54	1.53	2.00	2.17	2.08	2.22	2.47	2.35
General mean of potassium fertilization	0	0	108.6	116.3	112.4	64.2	64.7	64.5	1.29	1.33	1.31	2.37	2.42	2.40	2.26	2.70	2.48
	24	0	113.7	118.4	116.1	68.0	68.6	68.3	1.75	1.89	1.82	2.57	2.62	2.60	2.79	2.93	2.86
	48	0	119.3	124.2	121.8	77.9	73.7	75.9	2.34	2.45	2.40	2.81	3.10	2.96	3.29	3.44	3.37
	0	1	115.6	121.3	118.5	74.2	71.6	72.9	1.97	2.01	1.99	2.69	2.80	2.74	2.96	3.10	3.03
	24	1	126.0	129.7	127.8	82.9	77.6	80.2	2.46	2.50	2.48	2.89	3.22	3.06	3.43	3.61	3.52
L.S.D. 0.05	Irrig.		5.1	5.4	3.1	3.5	3.5	2.1	0.16	0.15	0.09	0.26	0.24	0.15	0.33	0.30	0.19
	K_2O		4.8	5.0	2.9	3.2	3.1	1.9	0.10	0.11	0.06	0.23	0.21	0.13	0.29	0.26	0.17
	Irrig. x K_2O		NS	NS	NS	NS	NS	NS	0.17	0.19	0.11	NS	NS	NS	NS	NS	NS

ASMD = available soil moisture depletion.

The interaction between water stress and potassium fertilization on LAI was found to be significant at the first stage only i.e. 56 DAS. The maximum values of LAI at different growth stages were obtained from plants irrigated at 20-25% ASMD (wet) in combination with adding 24 K_2O/fed and sprayed by 1% K_2O.

c- Relative growth Rate (RGR):

Table (2) show that water stress and potassium fertilization significantly affected RGR in the two periods under study i.e. 56-70 and 70-84 DAS. RGR was lower in the second period (70-84 DAS) than in the first period (56-70 DAS). Increasing soil moisture depletion level from 20-25% up to 65-70% significantly decreased RGR in the two studied growth periods. Such trend may be due to the importance of water to dry matter accumulation or formation of photosynthesiate compounds. In this respect, **Saren *et al* (2004)** found that irrigated sesame plants by four irrigations (frequent irrigation) significantly increased dry matter production at different growth stages.

Regarding the effect of potassium fertilization, adding 24 kg K_2O/fed and spraying 1% K_2O significantly increased RGR at the two periods under study. Such finding was attributed to the role of K in dry matter accumulation. In this respect **Mahendera-Sing *et al* (1992)** found that spraying 200 ppm potassium on maize plants increased leaves dry matter.

The interaction effect between water stress and potassium fertilization on RGR was found to be insignificant in the two periods of plant growth under study.

d- Net Assimilation Rate (NAR):

It was noticed from Table (2) that there was significant difference in NAR values observed among the three irrigation levels at the first and second growth periods. NAR was significantly decreased by increasing water stress from 20-25% up to 65-70% ASMD. Such reduction may be attributed to exposing plants to severe water stress which induce a reduction in dry matter accumulation more than the reduction in leaf area. In this connection, **Mourad and Anton (2007)** found that NAR of grain sorghum significantly decreased by increasing water stress up to 65-70% ASMD.

Concerning the effect of potassium fertilization, NAR significantly increased at the first period (56-70 DAS) when plants received 24 kg K_2O/fed and sprayed by 1% K_2O, without significant difference with adding 48 kg K_2O/fed. Whereas, at second period (70-84 DAS), NAR significantly increased when plants received 48 kg K_2O/fed, with insignificant variance between adding 24 kg K_2O/fed in combination with spraying 1% K_2O.

The interaction between water stress and potassium fertilization had insignificant effect on NAR at the two growth periods under study.

II- Total chlorophyll and carotenoides:

Combined data in Table (3) show that both photosynthetic pigments of leaves i.e. total chlorophyll and carotenoides contents were significantly increased when sesame plants watered with wet treatment (irrigated at 20-25% ASMD) in the two stages of plant growth under study viz. 70 and 84 DAS, compared with medium or dry treatments. On the other hand, dry treatment scored the lowest values of such pigments in the two stages. This trend may be due to that water play an important role for pigments formation in leaves. In this respect, **Saad El-Deen (2006)** found that the prolonged irrigation intervals by irrigation every 21 days (dry treatment) significantly decreased chlorophyll a, b and carotenoides concentration of sesame leaves.

Table 2. Relative growth rate and net assimilation rate of sesame plant as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Relative growth rate (RGR, g/g/week)						Net assimilation rate (NAR, $mg/cm^2/week$)					
Irrigation level	Potassium fertilization		(56-70) DAS			(70-84) DAS			(56-70) DAS			(70 - 84) DAS		
	Soil dressing kg K_2O/fed	Foliar spray K_2O%	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.
(20-25)% in ASMD (wet)	0	0	0.325	0.304	0.315	0.298	0.291	0.295	6.63	4.21	5.42	5.73	5.48	5.61
	24	0	0.360	0.335	0.348	0.316	0.301	0.309	6.76	5.80	6.28	6.65	6.59	6.62
	48	0	0.454	0.461	0.458	0.396	0.404	0.400	7.78	6.78	7.28	7.99	7.94	7.97
	0	1	0.392	0.421	0.407	0.356	0.311	0.334	6.59	6.23	6.41	6.80	7.33	7.07
	24	1	0.479	0.444	0.462	0.385	0.391	0.388	7.30	6.72	7.01	7.80	7.82	7.81
Mean			0.402	0.393	0.398	0.350	0.340	0.345	7.01	5.95	6.48	6.99	7.03	7.01
(45-50)% in ASMD (medium)	0	0	0.250	0.295	0.273	0.230	0.234	0.232	2.76	3.44	3.10	4.43	5.01	4.72
	24	0	0.290	0323	0.307	0.244	0.252	0.248	4.75	4.58	4.67	6.28	6.11	6.20
	48	0	0.360	0.371	0.366	0.284	0.272	0.278	5.28	5.89	5.59	6.85	7.21	7.03
	0	1	0.311	0.341	0.326	0.266	0.269	0.268	5.18	5.16	5.17	6.32	6.18	6.25
	24	1	0.404	0.371	0.388	0.292	0.299	0.296	5.89	6.33	6.11	6.82	6.70	6.76
Mean			0.323	0.340	0.332	0.263	0.265	0.264	4.77	5.08	4.93	6.14	6.24	6.19
(65-70)% in ASMD (Dry)	0	0	0.110	0.186	0.148	0.168	0.118	0.143	1.96	3.08	2.52	3.51	3.21	3.36
	24	0	0.167	0.206	0.187	0.186	0.149	0.168	3.23	3.22	3.23	4.26	3.90	4.08
	48	0	0.243	0.252	0.248	0.229	0.200	0.215	3.46	5.82	4.64	6.36	5.08	5.72
	0	1	0.192	0.227	0.210	0.205	0.172	0.189	3.44	4.10	3.77	5.46	4.46	4.96
	24	1	0.259	0.266	0.263	0.237	0.206	0.222	3.98	5.47	4.73	6.19	5.24	5.72
Mean			0.194	0.227	0.211	0.205	0.169	0.187	3.21	4.34	3.78	5.16	4.38	4.77
General mean of potassium fertilization	0	0	0.228	0.262	0.245	0.232	0.214	0.223	3.78	3.58	3.68	4.56	4.57	4.56
	24	0	0.272	0.288	0.280	0.249	0.234	0.242	4.91	4.53	4.72	5.73	5.53	5.63
	48	0	0.352	0.361	0.357	0.303	0.292	0.298	5.51	6.16	5.84	7.07	6.74	6.91
	0	1	0.298	0.330	0.314	0.276	0.251	0.264	5.07	5.16	5.12	6.19	5.99	6.09
	24	1	0.381	0.360	0.371	0.305	0.299	0.302	5.72	6.17	5.95	6.94	6.59	6.76
L.S.D. 0.05	Irrig.		0.069	0.085	0.045	0.057	0.048	0.032	0.91	0.89	0.54	0.99	0.97	0.59
	K_2O		0.063	0.079	0.043	0.049	0.044	0.030	0.83	0.81	0.49	0.90	0.88	0.53
	Irrig. x K_2O		NS	NS	NS	NS	NS	NS	N.S	1.38	N.S	NS	NS	NS

ASMD = available soil moisture depletion.

Table 3. Total chlorophyll and carotenoides contents of sesame plant as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Photosynthetic pigments of leaves (mg/g fresh weight)												
			Total chlorophyll						Carotenoides					
Irrigation level	Potassium fertilization		70 DAS			84 DAS			70 DAS			84 DAS		
	Soil dressing kg K_2O/fed	Foliar spray K_2O%	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.
(20-25)% in ASMD (wet)	0	0	2.92	2.88	2.90	4.82	4.78	4.80	0.481	0.463	0.472	0.091	0.073	0.082
	24	0	3.44	3.36	3.40	5.46	5.39	5.43	0.510	0.493	0.502	0.120	0.093	0.107
	48	0	3.97	3.92	3.95	6.21	6.38	6.30	0.553	0.527	0.540	0.193	0.170	0.182
	0	1	3.68	3.60	3.64	5.69	5.67	5.68	0.500	0.507	0.504	0.150	0.121	0.136
	24	1	4.18	4.14	4.16	6.65	6.60	6.63	0.591	0.550	0.571	0.241	0.193	0.217
Mean			3.64	3.58	3.61	5.77	5.76	5.77	0.527	0.508	0.518	0.159	0.130	0.145
(45-50)% in ASMD (medium)	0	0	2.43	2.37	2.40	4.51	4.35	4.43	0.420	0.410	0.415	0.060	0.047	0.054
	24	0	2.85	2.73	2.79	4.98	4.85	4.92	0.451	0.427	0.439	0.091	0.070	0.081
	48	0	3.42	3.36	3.39	5.75	5.69	5.72	0.513	0.480	0.497	0.143	0.107	0.125
	0	1	3.04	2.98	3.01	5.10	5.13	5.12	0.470	0.450	0.460	0.120	0.090	0.105
	24	1	3.65	3.58	3.62	6.11	6.25	6.18	0.531	0.507	0.519	0.161	0.123	0.142
Mean			3.08	3.00	3.04	5.29	5.25	5.27	0.477	0.455	0.466	0.115	0.087	0.101
(65-70)% in ASMD (Dry)	0	0	2.04	1.85	1.95	4.09	3.91	4.00	0.381	0.370	0.376	0.020	0.021	0.021
	24	0	2.31	2.18	2.25	4.65	4.54	4.60	0.400	0.377	0.389	0.033	0.033	0.033
	48	0	2.83	2.71	2.77	5.26	5.19	5.23	0.463	0.433	0.448	0.073	0.051	0.062
	0	1	2.55	2.46	2.51	4.72	4.80	4.76	0.420	0.410	0.415	0.050	0.033	0.042
	24	1	3.15	3.02	3.09	5.34	5.27	5.31	0.491	0.440	0.466	0.111	0.053	0.082
Mean			2.58	2.44	2.51	4.81	4.74	4.78	0.431	0.406	0.419	0.057	0.038	0.048
General mean of potassium fertilization	0	0	2.46	2.37	2.42	4.47	4.35	4.41	0.427	0.414	0.421	0.057	0.047	0.052
	24	0	2.87	2.76	2.81	5.03	4.93	4.98	0.454	0.432	0.443	0.081	0.065	0.074
	48	0	3.41	3.33	3.37	5.74	5.75	5.75	0.510	0.480	0.495	0.136	0.109	0.123
	0	1	3.09	3.01	3.05	5.17	5.20	5.19	0.463	0.456	0.460	0.107	0.081	0.094
	24	1	3.66	3.58	3.62	6.03	6.04	6.04	0.538	0.499	0.519	0.171	0.123	0.147
L.S.D. 0.05	Irrig.		0.29	0.28	0.17	0.34	0.32	0.20	0.031	0.029	0.018	0.017	0.015	0.010
	K_2O		0.25	0.24	0.15	0.28	0.27	0.17	0.026	0.024	0.015	0.014	0.012	0.008
	Irrig. x K_2O		NS	NS	NS	NS	NS	NS	0.044	0.041	0.026	0.024	0.021	0.014

ASMD = available soil moisture depletion.

The effect of potassium fertilization indicated that adding 24 kg K_2O/fed and spraying 1% K_2O significantly increased total chlorophyll and carotenoides concentration of leaves at 70 and 84 DAS. Such finding may be due to that potassium activates the enzymes involved in the formation of leaf pigments.

The interaction between soil moisture stress and potassium fertilization had insignificant effect on total chlorophyll concentration at 70 and 84 DAS, whereas, carotenoides content recorded a significant effect at 70 and 84 DAS. The highest values of such pigments content were obtained when sesame plants irrigated at 20-25% ASMD (wet treatment) and adding 24 kg K_2O/fed with spraying 1% K_2O.

III- Chlorophyll fluorescence and proline content:

a- Chlorophyll fluorescence:

In recent years chlorophyll fluorescence can be used to study the components of the photosynthetic apparatus and their reaction to changes in the environment as well as photosynthesis as a whole. This is interesting in the view that photosynthesis is a good indicator for plants adaptation to their environment. Since the measurements are non-intrusive, fast and reliable, this makes chlorophyll fluorescence an attractive tool for environmental research such as water and nutrient stresses.

Data presented in Table (4) show that both irrigation and potassium fertilization treatments recorded a significant effect on chlorophyll fluorescence at 70 DAS. Increasing water stress up to 65-70% ASMD gradually decreased the values of photosystem II (PSII) quantum yield as a proxy measure of photosynthesis (chlorophyll fluorescence). These result due to the harmful effect was accrue on PSII by exposing sesame plants to severe water stress (dry treatment). Similar result was obtained by **Abdo (2007)** on maize plants.

Concerning the effect of potassium fertilization, data indicated that chlorophyll fluorescence value at 70 DAS was significantly increased by treated plants with 24 kg K_2O/fed and sprayed by 1% K_2O compared with other potassium treatments under study.

The interaction between water stress and potassium fertilization on chlorophyll fluorescence was found to be significant. Maximum value of such trait was obtained when plants were subjected to wet treatment and received 24 kg K_2O/fed in combination with spraying 1% K_2O.

b- Proline content of leaves:

Proline accumulation can be met with the stresses such as temperature, drought and starvation. High levels of proline enabled the plant to maintain low water potentials. By lowering water potentials, the accumulation of compatible osmolytes, involved in osmoregulation allows additional water to be taken up from the environment, thus buffering the immediate effect of water shortages within the organism.

From Table (4), leaf proline content increased generally with advancing sesame plants in age from 70 to 84 DAS. The two factors under study, i.e., water stress and potassium fertilization recorded significant effects at 70 and 84 DAS. Exposed sesame plants to water stress (dry treatment) significantly increased leaf proline content at 70 and 84 DAS compared with wet and medium treatments. These results are in harmony with those obtained by **Manivannan *et al.* (2007)** who found that praline content increased under water deficit condition in root, stem and leaf of all sunflower varieties under study. They added that the decrease in proline oxidase activity with increasing Y-glutamyl kinase activity might be the reason for higher proline accumulation in drought stressed sunflower plants.

Regarding the effect of potassium fertilization, leaf proline content significantly increased at 70 and 84 DAS in untreated plants (control) compared with other potassium treatments.

The interaction between soil moisture stress and potassium fertilization on leaf proline content was found to be significant at the two stages under study. The highest values of leaf proline content at 70 and 84 DAS were obtained from dry treatment without adding potassium fertilization.

Table 4. Chlorophyll fluorescence and leaf proline content (mg/g fresh weight) of sesame plant as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Chlorophyll fluorescence			Leaf proline content (mg/g fresh weight)					
Irrigation Level	Potassium fertilization		70 DAS			70 DAS			84 DAS		
	Soil dressing kg K_2O/fed	Foliar spray K_2O%	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.
(20-25)% in ASMD (wet)	0	0	0.568	0.531	0.550	0.553	0.561	0.557	0.602	0.624	0.613
	24	0	0.678	0.664	0.671	0.539	0.554	0.547	0.520	0.534	0.527
	48	0	0.776	0.754	0.765	0.497	0.501	0.499	0.501	0.488	0.495
	0	1	0.731	0.681	0.706	0.522	0.534	0.528	0.507	0.544	0.526
	24	1	0.899	0.815	0.857	0.479	0.487	0.483	0.450	0.463	0.457
Mean			0.730	0.689	0.710	0.518	0.527	0.523	0.516	0.531	0.524
(45-50)% in ASMD (medium)	0	0	0.420	0.391	0.406	0.712	0.723	0.718	0.943	0.952	0.948
	24	0	0.573	0.449	0.511	0.698	0.703	0.701	0.901	0.919	0.910
	48	0	0.612	0.521	0.567	0.653	0.681	0.667	0.857	0.885	0.871
	0	1	0.653	0.481	0.567	0.675	0.692	0.684	0.874	0.895	0.885
	24	1	0.745	0.533	0.639	0.631	0.670	0.651	0.840	0.861	0.851
Mean			0.601	0.475	0.538	0.674	0.694	0.684	0.883	0.902	0.893
(65-70)% in ASMD (Dry)	0	0	0.278	0.267	0.273	0.947	0.961	0.954	1.658	1.674	1.666
	24	0	0.433	0.363	0.398	0.920	0.952	0.936	1.593	1.647	1.620
	48	0	0.513	0.434	0.474	0.891	0.919	0.905	1.590	1.621	1.606
	0	1	0.466	0.389	0.428	0.903	0.944	0.924	1.601	1.676	1.639
	24	1	0.557	0.454	0.506	0.874	0.903	0.889	1.586	1.622	1.604
Mean			0.449	0.381	0.416	0.907	0.936	0.922	1.606	1.648	1.627
General mean of potassium fertilization	0	0	0.422	0.396	0.410	0.737	0.748	0.743	1.068	1.083	1.076
	24	0	0.561	0.492	0.527	0.719	0.736	0.728	1.005	1.033	1.019
	48	0	0.634	0.570	0.602	0.680	0.700	0.690	0.983	0.998	0.991
	0	1	0.617	0.517	0.567	0.700	0.723	0.712	0.994	1.038	1.017
	24	1	0.734	0.601	0.667	0.661	0.687	0.674	0.959	0.982	0.971
L.S.D. 0.05	Irrig.		0.032	0.028	0.018	0.012	0.015	0.009	0.025	0.027	0.018
	K_2O		0.022	0.019	0.012	0.011	0.013	0.008	0.016	0.018	0.012
	Irrig. x K_2O		0.038	0.033	0.021	0.019	0.022	0.014	0.028	0.031	0.021

ASMD = available soil moisture depletion.

IV- Yield and yield components:

Soil moisture stress resulted significant effects on 1000-seed weight and number of capsules, capsules weight, seed and straw weights / plant (Table 5) as well as seed and straw yields/fed (Table 6). The highest values of such traits were scored from wet treatment (irrigated at 20-25% ASMD) followed by medium treatment (irrigated at 45-50% ASMD). While, the lowest values were recorded from severe water deficit (irrigated at 65-70% ASMD), with significant difference between such treatment and wet or medium treatments. This trend could be attributed to the effect of water deficit on sesame growth and yield components which were in tern reflected on straw and seed yields/ fed. in this connection, **El-Serogy *et al* (1998)** reported that the reduction in sesame seed yield by exposing plants to drought at pod development stage may be directly attributed to the reduction in dry matter accumulation, plant height, fruiting zone length, number of capsules/plant and seed index. In addition, **Mensah *et al* (2006)** found that growth and seed yield of sesame were adversely affected by continuous flooding and severe drought.

As for the effect of potassium fertilization, results indicated that applying 24 kg K_2O/fed with spraying 1% K_2O significantly increased number of capsules, capsules weight, seed weight/plant, straw and seed yields/fed compared with other potassium treatments. No significant differences were observed between such treatment and adding 48 kg K_2O/fed or foliar spray of 1% K_2O with respect to 1000-seed weight. Whereas, the maximum value of straw weight/plant was recorded when plants received 48 kg K_2O/fed, with no significant difference between those of plants treated by 24 kg K_2O/fed in combination with spraying 1% K_2O. These results could be ascribed to the enhanced effect of potassium on sesame growth which resulted in turn higher yield components, seed and straw yields/fed. **Tandon (1990)** explained such results that potassium involves in the activation of large number of enzymes in the production and translocation of photosynthates from source to sink. These results are in harmony with those obtained by **Thakur and Patel (2003)** who found that the application of 24.9 or 37.3 kg K/ha on sesame plants significantly increased yield attributes and seed yield compared to applying 12.4 kg/ha.

Data in Tables (5 and 6) and Fig. (1) show the interaction effect between soil moisture stress and potassium fertilization was found to be significant on number of capsules, capsules weight, seed and straw weights/plant. However, 1000-seed weight, seed and straw yields/fed did not affected significantly. The maximum values of yield and its components were obtained when plants irrigated at 20-25% ASMD in combination with 24 kg K_2O/fed and sprayed by 1% K_2O.

V- Total carbohydrates and oil contents of seeds:

Table (6) show that total carbohydrates and oil contents in sesame seeds were significantly increased under wet conditions (irrigation at 20-25% ASMD).While, increasing water deficit up to 65-70% ASMD (dry treatment) significantly decreased both total carbohydrates and oil contents in seeds. Plants received irrigation at 45-50% ASMD (medium treatment) had intermediate values of both traits. **El-Kalla *et al.* (1985)** on maize plant, explained the carbohydrates reduction under water stress conditions, that water shortage causes stomatal closure and this in turn prevents CO_2 diffusion into the air inside the tissue of plants and consequently the photosynthetic efficiency becomes low. Similar results were obtained by **Anton and El-Raies (2000)** who found that increasing soil moisture stress up to 70-75% ASMD in sandy soils decreased total carbohydrates and oil contents of sesame seeds.

Concerning the effect of potassium fertilization, Table (6) indicate that treated sesame plants by 24 kg K_2O/fed in combination with spraying 1% K_2O significantly increased total carbohydrates and oil contents of seeds compared with all potassium treatments and control one. These finding may be due to the role of potassium in enzymes activation involved in ATP production which is more important to regulating the rate of photosynthesis, sugar formation and translocation from source to sink. These results are in the line with those reported by **Thakur and Patel (2003)** for oil content of sesame seed. In addition **Abdel-Aziz and El-Bialy (2004)** concluded that increasing foliar spray level of K_2O up to 3% K_2O increased total carbohydrates in maize grains.

Table 5. Some yield components of sesame plant as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Number of capsules / plant			Capsules weight / plant (g)			Straw weight / plant (g)			Seed weight / plant (g)			1000-seed weight (g)		
Irrigation level	Potassium fertilization: Soil dressing kg K_2O/fed	Potassium fertilization: Foliar spray K_2O%	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.
(20-25)% in ASMD (wet)	0	0	55.3	51.7	53.5	19.78	16.83	18.31	23.22	24.64	23.93	8.85	7.87	8.36	3.42	3.29	3.36
	24	0	62.3	58.7	60.5	23.62	21.98	22.80	30.60	29.73	30.17	12.28	11.83	12.06	3.47	3.38	3.43
	48	0	78.7	80.3	79.5	34.60	33.32	33.96	40.66	35.51	38.09	15.63	15.17	15.40	3.57	3.60	3.59
	0	1	66.3	73.2	69.8	28.81	30.29	29.55	32.61	31.96	32.29	12.99	13.30	13.15	3.55	3.52	3.54
	24	1	91.5	91.8	91.7	44.84	38.29	41.57	39.89	38.15	39.02	18.45	16.63	17.54	3.60	3.63	3.62
Mean			70.8	71.1	71.0	30.33	28.14	29.24	33.40	32.00	32.70	13.64	12.96	13.30	3.52	3.48	3.51
(45-50)% in ASMD (medium)	0	0	47.3	48.0	47.7	17.32	15.18	16.25	20.70	21.88	21.29	7.23	6.09	6.66	3.34	2.93	3.14
	24	0	55.0	58.5	56.8	21.60	20.24	20.92	26.27	27.44	26.86	10.20	9.16	9.68	3.35	2.97	3.16
	48	0	60.2	65.2	62.7	27.33	26.01	26.67	35.66	31.74	33.70	12.36	11.34	11.85	3.36	3.33	3.35
	0	1	58.7	60.0	59.4	24.26	23.96	24.11	29.59	29.76	29.68	11.22	10.99	11.11	3.36	3.30	3.33
	24	1	69.7	70.0	69.9	29.23	30.56	29.90	32.44	34.97	33.71	12.78	12.19	12.49	3.38	3.40	3.39
Mean			58.2	60.3	59.3	23.95	23.19	23.57	28.93	29.16	29.05	10.76	9.95	10.36	3.36	3.19	3.27
(65-70)% in ASMD (Dry)	0	0	40.8	40.7	40.8	14.37	14.66	14.52	17.68	19.65	18.67	4.19	4.74	4.47	3.09	2.72	2.91
	24	0	43.7	52.5	48.1	16.16	16.38	16.27	21.64	22.79	22.22	4.99	5.10	5.05	3.15	2.88	3.02
	48	0	47.3	59.2	53.3	16.89	17.23	17.06	24.86	26.95	25.91	6.45	6.40	6.43	3.23	2.97	3.10
	0	1	44.2	55.0	49.6	17.02	17.77	17.40	22.20	23.36	22.78	5.66	5.76	5.71	3.23	2.93	3.08
	24	1	56.8	60.2	58.5	18.44	18.93	18.69	23.46	24.43	23.95	6.83	6.86	6.85	3.32	3.10	3.21
Mean			46.6	53.5	50.1	16.58	16.99	16.79	21.97	23.44	22.71	5.62	5.77	5.70	3.20	2.92	3.06
General mean of potassium fertilization	0	0	47.8	46.8	47.3	17.16	15.56	16.36	20.53	22.06	21.30	6.76	6.23	6.50	3.28	2.98	3.13
	24	0	53.7	56.6	55.1	20.46	19.53	20.00	26.17	26.65	26.42	9.16	8.70	8.93	3.32	3.08	3.20
	48	0	62.1	68.2	65.2	26.27	25.52	25.90	33.73	31.40	32.57	11.48	10.97	11.23	3.39	3.30	3.35
	0	1	56.4	62.7	59.6	23.36	24.01	23.69	28.13	28.36	28.25	9.96	10.02	9.99	3.38	3.25	3.32
	24	1	72.7	74.0	73.4	30.84	29.26	30.05	31.93	32.52	32.23	12.69	11.89	12.29	3.43	3.38	3.41
L.S.D. 0.05	Irrig.		3.79	3.93	2.32	1.71	1.64	1.01	2.33	2.45	1.43	0.83	0.79	0.49	0.20	0.19	0.12
	K_2O		3.61	3.74	2.21	1.63	1.56	0.96	2.22	2.34	1.37	0.78	0.75	0.46	N.S	0.17	0.11
	Irrig. x K_2O		6.25	6.47	3.82	2.80	2.68	1.65	3.82	4.05	2.35	1.35	1.30	0.79	N.S	N.S	N.S

ASMD = available soil moisture depletion.

Table 6. Straw and seed yields as well as total carbohydrates and oil contents of sesame plant as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Straw yield (ton / fed)			Seed yield (kg/fed)			Total carbohydrates content of seeds (%)			Oil content of seeds (%)		
Irrigation level	Potassium fertilization: Soil dressing kg K_2O/fed	Potassium fertilization: Foliar spray K_2O%	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.	2006	2007	Comb.
(20-25)% in ASMD (wet)	0	0	1.618	2.068	1.843	617.98	590.23	604.11	10.75	10.22	10.49	55.22	51.72	53.47
	24	0	2.181	2.103	2.142	689.26	669.10	679.18	12.40	11.26	11.83	57.98	53.81	55.90
	48	0	2.696	2.693	2.695	838.42	745.75	792.09	14.32	13.36	13.84	59.20	55.10	57.15
	0	1	2.492	2.495	2.494	746.06	700.20	723.13	13.60	12.31	12.96	57.77	52.24	55.01
	24	1	2.965	2.958	2.962	938.88	805.73	872.31	15.56	14.48	15.02	60.42	56.32	58.37
Mean			2.390	2.463	2.427	766.12	702.20	734.16	13.33	12.33	12.83	58.12	53.84	55.98
(45-50)% in ASMD (medium)	0	0	1.581	1.941	1.761	545.90	534.01	539.96	10.11	9.60	9.86	50.16	47.63	48.90
	24	0	1.681	2.064	1.873	602.30	628.72	615.51	10.80	10.51	10.66	53.47	50.80	52.14
	48	0	2.289	2.120	2.205	730.92	651.19	691.06	12.51	11.89	12.20	56.31	51.14	53.73
	0	1	1.908	2.190	2.049	677.10	638.32	657.71	11.46	11.12	11.29	52.13	49.35	50.74
	24	1	2.720	2.748	2.734	815.51	695.96	755.74	13.63	12.35	12.99	57.63	52.76	55.20
Mean			2.036	2.213	2.124	674.35	629.64	652.00	11.70	11.09	11.40	53.94	50.34	52.14
(65-70)% in ASMD (Dry)	0	0	0.959	1.450	1.205	255.86	379.44	317.65	8.10	7.82	7.96	43.62	41.20	42.41
	24	0	1.443	1.681	1.562	310.30	406.09	358.20	8.78	8.21	8.50	45.81	44.50	45.16
	48	0	1.546	1.986	1.766	388.44	460.96	424.70	10.47	10.00	10.24	47.37	45.81	46.59
	0	1	1.505	1.773	1.639	314.98	435.40	375.19	9.98	9.12	9.55	44.51	42.17	43.34
	24	1	2.036	2.164	2.100	442.50	492.44	467.47	11.14	10.53	10.84	51.20	47.26	49.23
Mean			1.498	1.811	1.654	342.42	434.87	388.64	9.69	9.14	9.42	46.50	44.19	45.35
General mean of potassium fertilization	0	0	1.386	1.820	1.603	473.25	501.23	487.24	9.65	9.21	9.44	49.67	46.85	48.26
	24	0	1.768	1.949	1.859	533.95	567.97	550.96	10.66	9.99	10.33	52.42	49.70	51.07
	48	0	2.177	2.266	2.222	652.59	619.30	635.95	12.43	11.75	12.09	54.29	50.68	52.49
	0	1	1.968	2.153	2.061	579.38	591.31	585.34	11.68	10.85	11.27	51.47	47.92	49.70
	24	1	2.574	2.623	2.599	732.30	664.71	698.51	13.44	12.45	12.95	56.42	52.11	54.27
L.S.D. 0.05	Irrig.		0.194	0.178	0.112	38.07	41.34	23.82	1.14	1.05	0.66	2.61	2.34	1.68
	K_2O		0.182	0.167	0.105	35.72	38.78	28.35	1.07	1.00	0.61	2.51	2.15	1.54
	Irrig. x K_2O		N.S	N.S	N.S	N.S	N.S	N.S	1.84	1.72	1.05	4.32	3.70	2.64

ASMD = available soil moisture depletion.

The interaction effect between soil moisture stress and potassium fertilization recorded a significant effect on both total carbohydrates and oil contents of seeds. The highest values of such traits were obtained from plants irrigated at 20-25% ASMD and received 24 kg K_2O/fed with spraying 1% K_2O.

VI- Water relations:

a- Relative water content of leaves (RWC %)

RWC was proposed as a good indicator of plant water status **(Sinclair and Ludlow, 1985)** because RWC through its relation to cell volume, may be more closely reflects the balance between water supply to the leaf and transpiration rate.

Table (7) show that RWC at 70 and 84 DAS significantly affected by two factors under study. Data revealed that RWC decreased by advancing age up to 84 DAS. Regarding the effect of water stress on RWC, results indicated that increasing water stress from 20-25% up to 65-70% ASMD significantly decreased RWC at 70 and 84 DAS. Such finding show the water status in plant cells which affected by water stress conditions. In this respect, **Beltrano *et al* (2006)** stated that RWC of flag leaves was significantly lower for stressed wheat plants compared to control. Similar results was obtained by **Abdo (2007)** on maize plants.

Concerning the effect of potassium fertilization RWC significantly increased at 70 and 84 DAS when sesame plants received 24 kg K_2O/fed and spraying 1% K_2O compared with other potassium treatments, indicating that applying potassium fertilizer as soil dressing in combination with foliar spray is more effective to regulate the osmotic pressure of plant cells. In this respect, **Robert (2005)** concluded that accumulation of K in plant roots produced a gradient of osmotic pressure that draws water into the plant roots and transport to leaves.

The interaction between soil moisture stress and potassium fertilization on RWC of leaves was significant at 70 and 84 DAS. The highest value of RWC was scored from plants irrigated at 20-25% ASMD and received 24 kg K_2O/fed with foliar spray by 1% K_2O.

b- Transpiration rate (TR) and stomatal resistance (SR):

Results in Table (7) show that the values of TR were significantly decreased, while SR values were significantly increased by increasing soil moisture stress from 20-25% up to 65-70% ASMD. Such results may explained on the basis that when water supply is short, by exposed plants to drought conditions, RWC of leaves decrease which causing guard cells loses its turgidity thereby stomatal close tightly to prevent water loss which in turn decreased TR. In this regard, **Mourad and Anton (2007)** mentioned that grain sorghum plants exposed to drought condition increased SR and decreased TR values.

Concerning the effect of potassium fertilization, the maximum value of SR was obtained without adding potassium fertilization (control), whereas the lowest value achieved when plants treated by 24 kg K_2O/fed in combination with spraying 1% K_2O. Reverse trend was observed with respect to TR. Similar results were obtained by Abu-**Grab and Othman (1999)** on maize plants.

Table 7. Relative water content of leaves, stomatal resistance and transpiration rate as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Relative water content of leaves (%) (RWC)						Stomatal resistance (SR, S / cm)			Transpiration rate (TR, μg $H_2O/cm^2/S$)		
Irrigation level	Potassium fertilization		70 DAS			84 DAS								
	Soil dressing kg K_2O/fed.	Foliar spray K_2O%	2006	2007	comb.	2006	2007	comb.	2006	2007	comb.	2006	2007	comb.
(20-25)% in ASMD (wet)	0	0	74.36	79.43	76.90	70.65	70.06	70.36	2.07	2.20	2.14	3.85	3.61	3.73
	24	0	78.45	82.74	80.60	74.12	74.74	74.43	1.80	1.97	1.89	4.36	3.95	4.16
	48	0	84.52	88.67	86.60	75.03	81.35	78.19	1.41	1.59	1.50	4.75	4.53	4.64
	0	1	81.60	85.32	83.46	72.69	77.52	75.11	1.64	1.78	1.71	4.41	4.35	4.38
	24	1	86.22	91.35	88.79	76.25	81.22	78.74	1.32	1.45	1.39	5.20	4.85	5.03
Mean			81.03	85.50	83.27	73.75	76.98	75.37	1.65	1.80	1.73	4.51	4.26	4.39
(45-50)% in ASMD (medium)	0	0	70.11	73.21	71.66	59.11	61.60	60.36	3.09	3.11	3.10	2.66	2.49	2.58
	24	0	72.43	76.89	74.66	61.50	66.52	64.01	2.70	2.86	2.78	3.02	2.81	2.92
	48	0	78.56	81.15	79.86	64.88	70.40	67.64	2.35	2.44	2.40	3.32	3.22	3.27
	0	1	74.28	78.39	76.34	63.72	67.16	65.44	2.46	2.60	2.53	3.15	2.99	3.07
	24	1	80.17	81.23	80.70	67.98	71.36	69.67	2.15	2.29	2.22	4.13	3.74	3.94
Mean			75.11	78.17	76.64	63.44	67.41	65.42	2.55	2.66	2.61	3.26	3.05	3.16
(65-70)% in ASMD (Dry)	0	0	58.70	61.36	60.03	47.81	49.68	48.75	3.21	3.34	3.28	2.85	2.61	2.73
	24	0	59.30	62.99	61.15	50.51	55.06	52.79	3.74	3.78	3.76	2.38	2.28	2.33
	48	0	65.95	70.56	68.26	57.26	61.86	59.56	3.85	3.95	3.90	2.20	2.17	2.19
	0	1	64.60	67.97	66.29	54.91	58.07	56.49	3.90	4.03	3.97	2.14	1.99	2.07
	24	1	66.73	70.96	68.85	60.21	62.28	61.25	4.10	4.16	4.13	1.95	1.80	1.88
Mean			63.06	66.77	64.92	54.14	57.39	55.77	3.76	3.85	3.81	2.30	2.17	2.24
General mean of potassium fertilization	0	0	67.72	71.33	69.53	59.19	60.45	59.82	2.79	2.88	2.84	3.12	2.90	3.01
	24	0	70.06	74.21	72.14	62.04	65.44	63.74	2.75	2.87	2.81	3.25	3.01	3.14
	48	0	76.34	80.13	78.24	65.72	71.20	68.46	2.54	2.66	2.60	3.42	3.31	3.37
	0	1	73.49	77.23	75.36	63.77	67.58	65.68	2.67	2.80	2.74	3.23	3.11	3.17
	24	1	77.71	81.18	79.45	68.15	71.62	69.89	2.52	2.63	2.58	3.76	3.46	3.62
L.S.D. 0.05	Irrig.		1.37	1.44	0.84	1.20	1.26	0.74	0.42	0.43	0.26	0.58	0.51	0.33
	K_2O		1.00	1.05	0.62	0.88	0.92	0.54	0.31	0.32	0.19	0.45	0.40	0.23
	Irrig. x K_2O		1.72	1.81	1.06	1.51	1.63	0.95	0.54	0.55	0.33	0.77	0.69	0.39

ASMD = available soil moisture depletion.

With regard to the interaction effect between water stress and potassium fertilization, both SR and TR significantly affected. The highest value of TR scored from plants irrigated at 20-25% ASMD with adding 24 kg K_2O/fed and sprayed by 1% K_2O. In this connection, **Robert (2005)** reported that under natural water supply conditions, K moves into the guard cells around the stomata, the cells accumulate water and swell, causing the pores to open and allowing gases to move freely in and out. On the other hand, the maximum value of SR was obtained when plants irrigated at 65-70% ASMD (dry treatment) with adding 24 kg K_2O/fed and sprayed by 1% K_2O. In this respect, **Robert (2005)** concluded that, when water supply is short, K is pumped out of the guard cells, the pores close tightly to prevent loss of water and minimize drought stress to the plant.

c- Seasonal water consumptive use (WCU):

Seasonal water consumptive use by sesame plant under various treatments is presented in Table (8). The values of WCU ranged from 337.11 to 557.84 mm for the mean of both seasons. Results revealed that the highest value of WCU was achieved under wet treatment, however the lowest value was obtained from dry treatment. The medium treatment had intermedium value. In other words, the rate of evapotranspiration was increased with increasing soil moisture level as the following ranking:

wet > medium > dry

Such results could be explained on the basis that, frequent irrigation (wet treatment) provides chance for more luxuriant use of water. These finding could be ascribed to the availability of soil water to sesame plants in addition to higher evaporation rate from wet than from dry soil surface. In this connection, **Ibrahim (1981)** showed that the increase in evapotranspiration rate by maintaining soil moisture at high level can be attributed to excess available water in the root zone to be consumed by the plants. These results are in line with those reported by **Anton and El-Raies (2000)** on sesame plant.

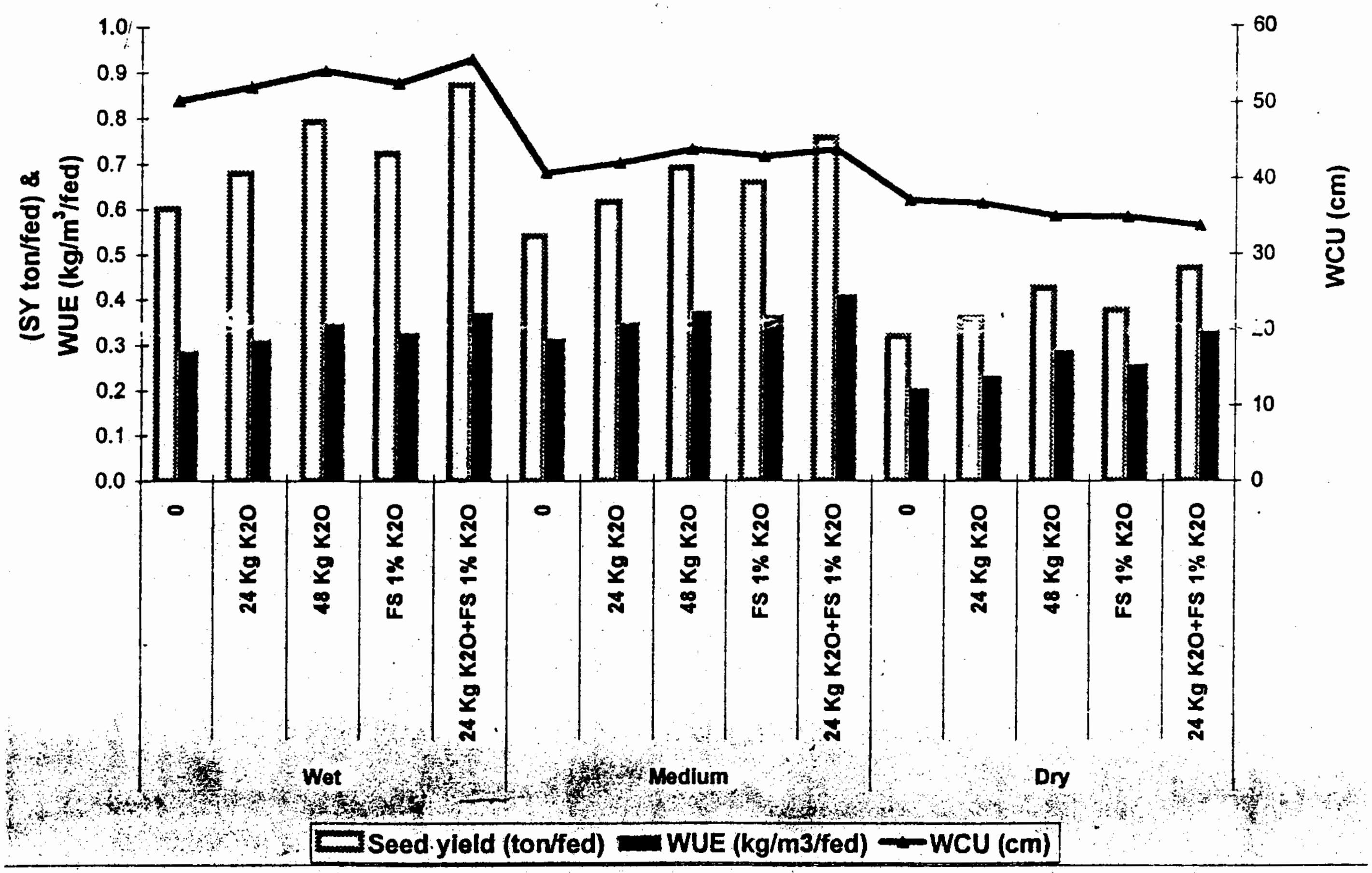
Table 8. Seasonal water consumptive use and water use efficiency as affected by soil moisture stress and potassium fertilization in 2006 and 2007 summer seasons.

Treatment			Seasonal water consumptive use (WCU, mm)			Water use efficiency (WUE, kg / m^3 / fed)		
Irrigation level	Potassium fertilization: Soil dressing KgK_2O/fed	Foliar Spray K_2O%	2006	2007	mean	2006	2007	Mean
(20-25)% in ASMD (wet)	0	0	509.14	498.51	503.83	0.289	0.282	0.286
	24	0	531.62	511.42	521.52	0.309	0.312	0.311
	48	0	552.72	531.89	542.31	0.361	0.334	0.348
	0	1	536.92	515.71	526.32	0.331	0.323	0.327
	24	1	561.85	553.83	557.84	0.398	0.346	0.372
Mean			538.45	522.27	530.36	0.338	0.319	0.329
(45-50) % ASMD (medium)	0	0	402.47	414.10	408.29	0.323	0.307	0.315
	24	0	418.65	424.70	421.68	0.343	0.352	0.348
	48	0	444.71	434.01	439.36	0.391	0.357	0.374
	0	1	430.12	428.69	429.41	0.375	0.355	0.365
	24	1	434.58	442.58	438.58	0.447	0.374	0.411
Mean			426.11	428.82	427.46	0.376	0.349	0.363
(65-70)% In ASMD (Dry)	0	0	373.11	369.85	371.48	0.163	0.244	0.204
	24	0	371.32	364.13	367.73	0.199	0.266	0.233
	48	0	343.71	356.88	350.30	0.269	0.308	0.289
	0	1	350.21	346.95	348.58	0.214	0.299	0.257
	24	1	322.51	351.71	337.11	0.327	0.333	0.330
Mean			352.17	357.90	355.04	0.234	0.290	0.262
General mean of potassium fertilization	0	0	428.24	427.49	427.87	0.258	0.278	0.268
	24	0	440.53	433.42	436.98	0.284	0.310	0.297
	48	0	447.05	440.93	443.99	0.340	0.333	0.337
	0	1	439.08	430.45	434.77	0.307	0.326	0.316
	24	1	439.65	449.37	444.51	0.391	0.351	0.371

ASMD = available soil moisture depletion.

Regarding the effect of potassium fertilization, results indicated that maximum value of WCU was achieved when plant received 24 kg K_2O/fed and foliar spray by 1% K_2O. Such results may be due to the applying of potassium fertilizer as soil dressing in combination with foliar spray was more effective to enhancing sesame growth which in turn increased plant canopy

(Fig 1) Effect of water stress and potassium fertilization on sesame seed yield (SY), water consumptive use (WCU) and water use efficiency (WUE)



thereby increasing transpiring surface which reflected on seasonal water consumptive use. In this respect, **Robert (2005)** reported that potassium play a key role vast array of physiological processes vital to plant growth, its activates at least 60 different enzymes involved in plant growth.

As for the interaction effect between water stress and potassium fertilization (Table 8 and Fig. 1). It is clear that the maximum value of WCU was obtained when sesame plants watered at 20-25% ASMD in combination with applying 24 kg K_2O/fed and spraying 1% K_2O.

d- Water use efficiency (WUE):

Water use efficiency by sesame expressed as kg seeds produced per m^3 of water consumed in complete evapotranspiration are presented in Table (8). WUE recorded the maximum value when plants irrigated at 45-50% ASMD (medium treatment), whereas it was lower under both wet and dry treatments due to the high seed yield/fed which obtained from medium treatment in proportion to the low water consumed. It could be concluded that medium soil moisture level seemed to be more efficient in consuming water compared with either low water deficit (wet treatment) or severe soil moisture stress (dry treatment). In other words, from the stand point of water conservation, medium treatment seemed to be more economic for saving water and gained a suitable seed yield. In this respect, **Vites (1965)** reported that water use efficiency is not clearly depend on the water available and evapotranspiration limit, even the crop yield and the opportunity to increase it do depend on the adequacy of water supply. Similar results on maize was obtained by **Abdel-Aziz and El-Bialy (2004).**.

As for the effect of potassium fertilization, applying 24 kg K_2O/fed in combination with spraying 1% K_2O recorded the maximum value of WUE. Such results revealed that the application of potassium fertilization as soil dressing and foliar spray increased K accumulation insed cells which reflected on high seed yield more than the increase in water consumed, resulting an increase in WUE. In this connection, **Pendleton (1965)** pointed out that fertilization practices which provide adequate nutrition for crop plants play a major role in the efficient use and conservation of water resources. The previous results are in line with those reported by **Welch and Flannery (1985)** who concluded that water use efficiency of corn plants was increased by raising potassium supply.

The interaction between soil moisture stress and potassium fertilization in Table (8) and Fig. (1) show that the maximum value of WUE was scored from plants irrigated at 45-50% ASMD in combination with adding 24 kg K_2O/fed and spraying by 1% K_2O. In this respect, **Abdel-Aziz and El-Bialy (2004)** found that maize plant watered at 55-60% ASMD (medium) and sprayed by 3% K_2O had the highest WUE value.

CONCLUSION

In the light of the present results, it clearly that the maximum seed yield of sesame was obtained from wet treatment (irrigated at 20-25% ASMD) in combination with applying 24 kg K_2O/fed and foliar spray of 1% K_2O. However, from economic point of view and water conservation its more efficiency to practices medium treatment (irrigated at 45-50% ASMD) in combination with adding 24 kg K_2O/fed and foliar spray of 1% K_2O under Ismailia region conditions.

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استجابة السمسم الفسيولوجية للإجهاد الرطوبى الارضى والتسميد البوتاسي فى الاراضى الرملية

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أجريت تجربة حقلية بمحطة بحوث الاسماعيلية خلال موسمى صيف ٢٠٠٦، ٢٠٠٧ لدراسة الاستجابة الفسيولوجية للسمسم صنف شندويل -٣ لثلاث مستويات من الرطوبة الارضية وهى الرى عند استنفاذ ٢٠-٢٥% و ٤٥-٥٠% و ٦٥-٧٠% من الماء الميسر (وهى معاملات رطبة ومتوسطة وجافة على التوالى) وكذلك التسميد البوتاسي بدون، ٢٤، ٤٨ كجم K_2O / فدان والرش الورقى بتركيز ١% K_2O منفرداً أو مع إضافة ٢٤ كجم K_2O / فدان أوضحت النتائج الآتى:

- أدى الرى عند استنفاذ ٦٥-٧٠% من الماء الميسر إلى نقص معنوى فى طول النبات وطول المنطقة الثمرية ودليل مساحة الأوراق (LAI) عند ٥٦ و ٧٠ و ٨٤ يوم من الزراعة ومعدل النمو النسبى (RGR) وصافى معدل التمثيل الضوئى (NAR) عند فترتى ٥٦ -٧٠ ، ٧٠-٨٤ يوم من الزراعة ومحتوى الأوراق من الكلوروفيل الكلى والكاروتينيد وعائد الكوانتم للنظام الصبغى الثانى (PSII) فى عملية التمثيل الضوئى وعلى العكس زاد معنويا محتوى الأوراق من البرولين.
- أدى الرى بالمعاملة الجافة إلى نقص معنوى فى وزن الـ ١٠٠٠ بذرة وكذلك عدد الكبسولات ووزن الكبسولات ووزن القش ووزن البذور للنبات وكذلك وزن محصولى القش والبذور للفدان.

- أدى نقص الماء فى معاملة الرى عند إستنفاذ ٦٥-٧٠% من الماء الميسر إلى نقص معنوى فى محتوى البذور من الكربوهيدرات الكلية والزيت والمحتوى النسبى للماء بالأوراق (RWC) والاستهلاك المائى الموسمى (WCU) وكفاءة استخدام المياه (WUE) ومعدل النتح (TR) وعلى العكس ارتفعت قيمة مقاومة الثغور (SR). وكانت أعلى قيمة لكفاءة استخدام المياه (WUE) عند الرى بالمعاملة المتوسطة مقارنة بالمعاملة الرطبة والجافة.
- أدت إضافة ٢٤ كجم K_2O / فدان مع الرش الورقى بـ ١% K_2O إلى زيادة معنوية فى طول النبات وطول المنطقة الثمرية ودليل مساحة الأوراق (LAI) عند ٥٦ و ٧٠ و ٨٤ يوم من الزراعة ومعدل النمو النسبى (RGR) عند فترتى ٥٦-٧٠ و ٧٠-٨٤ يوم من الزراعة وصافى معدل التمثيل الضوئى (NAR) عند فترة ٥٦-٧٠ يوم من الزراعة ومحتوى الأوراق من الكلوروفيل الكلى والكاروتنيد وعائد الكوانتم للنظام الصبغى الثانى (PSII) فى عملية التمثيل الضوئى وكذلك وزن الـ ١٠٠٠ بذرة وعدد الكبسولات ووزن الكبسولات والبذور للنبات ووزن محصولى القش والبذور للفدان، بينما كانت أعلى قيمة لوزن القش للنبات عند إضافة ٤٨ كجم K_2O / فدان.
- زاد معنويا محتوى الأوراق من البرولين ومقاومة الثغور (SR) عند عدم إضافة البوتاسيوم (الكنترول) وذلك مقارنة بمعاملات البوتاسيوم الاخرى.
- سجلت أعلى قيمة لمحتوى البذور من الكربوهيدرات الكلية والزيت والمحتوى النسبى للماء بالاوراق (RWC) ومعدل النتح (TR) والاستهلاك المائى الموسمى (WCU) وكفاءة استخدام المياه (WUE) أعلى قيمة عند إضافة ٢٤ كجم K_2O / فدان مع الرش الورقى بـ ١% K_2O.
- كان تأثير التفاعل بين معاملات الإجهاد الرطوبى والتسميد البوتاسى معنويا على كل من دليل مساحة الأوراق (LAI) عند ٥٦ يوم من الزراعة ومحتوى الأوراق من الكاروتينيد عند ٧٠ و ٨٤ يوم من الزراعة وعائد الكوانتم للنظام الصبغى الثانى (PSII) فى عملية التمثيل الضوئى ومحتوى الأوراق من البرولين وكذلك عدد الكبسولات ووزن الكبسولات ووزن البذور ووزن القش للنبات ومحتوى البذور من الكربوهيدرات الكلية والزيت والمحتوى النسبى للماء بالاوراق (RWC) عند ٧٠ و ٨٤ يوم من الزراعة ومقاومة الثغور (SR) ومعدل النتح (TR).
- سجلت أعلى قيمة لكفاءة استخدام المياه (WUE) فى معاملة الرى عند استنفاذ ٤٥-٥٠% من الماء الميسر بالإضافة إلى التسميد بـ ٢٤ كجم K_2O / فدان والرش الورقى بـ ١% K_2O.