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IMPACT OF POTASSIUM FERTILIZATION ON GROWTH, YIELD AND WATER PRODUCTIVITY OF CANOLA UNDER WATER STRESS CONDITION

Amina I. El-Shafey[1] and A.Kh. Abdelhalim[2]

[1]Crop physiol. Res. Dept., Field Crops Res. Inst., Agric. Res. Cent., Giza, Egypt.
[2]Water Requirements and Field Irrigation Res. Dept.; Soils, Water and Environment. Res. Inst., ARC, Egypt.

Abstract

A Field experiment was conducted at Etay El-Baroud Agricultural Research Station (30º 89'E, 30º 65'N, 5 m above sea level), El-Behera governorate, Egypt during 2017/2018 and 2018/2019 seasons to study the effect of three levels of crop evapotranspiration (ETc) and potassium applications on growth, yield, its components, some chemical constituents and irrigation water productivity (IWP) of canola (*Brassica napus* L.). The irrigation water treatments were: Full irrigation (I_1:100%ETc), moderate stress (I_2: 75% ETc) and high stress (I_3: 50% ETc) in combination with potassium treatments (K_0= 0, K_1= 30 kg K_2O/ha, K_2= 45 kg K_2O/ha, K_3= 60 kg K_2O/ha, K_4= spraying 2% K_2O, K_5= 30 kg K_2O/ha+ spraying 2% K_2O and K_6= 45 kg K_2O/ha+ spraying 2% K_2O). Results showed that seasonal applied water (AW) values for I_1, I_2 and I_3 treatments were 4436, 3327 and 2218 m^3/ha and were 4560, 3420 and 2280 m^3/ha in the first and second seasons, respectively. Results indicated that, increasing soil moisture stress up to 50% ETc significantly decreased shoot dry weight and leaf area/plant (in the second season only), chlorophyll a, b, carotenoids, relative water content (RWC), K^+ concentration in leaves and seed oil content in both seasons. Also, plant height, number of pods/plant, 1000-seed weight, seed weight/plant and seed yield/ha showed significant reduction under the high stress treatment (I_3). Whereas, proline content increased significantly when plants were under high stress treatment compared with full irrigation or moderate stress treatments. Potassium application resulted in a significant increase in all growth parameters, yield and physiological traits compared with untreated plants. Potassium applications of 45 or 60kg K_2O/ha had superior effect on all attributes in this study. The interaction between high water stress (I_3) and 45 kg K_2O/ha + spraying 2% K_2O treatment gave the highest values of proline content and irrigation water productivity (IWP) in both seasons. Results indicated that the lowest yield reductions (RYD %) were recorded from applying 45 kg K_2O/ha + spraying by 2% K_2O under moderate stress (I_2) in the first and second seasons. Generally, decreasing soil moisture stress up to full irrigation with potassium application significantly enhanced most of growth characters, yield, its components and physiological traits of canola. The results of this study showed that the application of potassium at 45 kg K_2O/ ha with spray by 2% of K_2O under water stress (I_3) improved irrigation water productivity (IWP) and gave the lowest reduction in seed yield under moderate stress (I_2).

Key words: Canola, Water stress, Potassium application, Physiological traits, Water productivity.

Introduction

Canola is one of the most important plants for oil source and it is the third source of oil seeds crop in the world after oil palm and soybean (FAO, 2011). Canola cultivation in Egypt may provide an opportunity to overcome the severe shortage of edible oil production in Egypt. New varieties, naturally contain 40-45% oil, are used as row materials to produce industrial and hydraulic oil, cleaner soap and biodegradable plastics (Friedt *et al.,* 2007). After extracting the oil, the remaining, which contains 38-44% high quality proteins, is used for animal nutrition (Walker and Booth, 2001).

Water is a main source of life and good management of this resource is fundamental for agricultural processes. It is a critical input for productivity improvement especially for field crops. In order to save water in agriculture, it is necessary to act at two directions at the same time; reduce water consumption through breeding programs and the efficient use of water resource. Drought is considered as one of the most important environmental stresses limiting plant growth and crop productivity (Terzi and Kadioglu, 2006). Up to 45% of the world agricultural lands are subject to continuous or frequent drought stress (Ashraf and Foolad, 2007). Fooladivanda *et al*., (2014) reported that water stress is known as the major threat to reduce growth and yield of plants in arid and semi-arid regions. Drought can be defined as the absence of adequate soil moisture necessary for plant to grow normally and complete its life cycle (Manivannan *et al*., 2008). Water stress had detrimental effects on many processes in plants, which include reducing photosynthesis, accumulation of dry matter, stomatal exchanges and protein synthesis that affect their growth stages (Larcher, 2003; Sarker *et al*., 2005; Ohashi *et al*., 2006; Petropoulos *et al*., 2008. Drought stress caused a significant reduction in the number of siliquae per plant, number of seeds per siliquae, 1000-seed weight, seed yield and seed oil content of five canola cultivars (Nasri *et al*., 2008). Also, Bahrani and Pourreza, (2016) found that water deficit reduced rapeseed yields by 20 and 25% compared to full irrigation. Drought stress causes an increase in solute concentration in the soil and root zone of the plant leading to an osmotic flow of water out of plant cells. This in turn causes the solute concentration inside plant cells to increase, thus lowering water potential and disrupting membranes. These drought stressed plants consequently exhibit poor growth and yield (Moaveni *et al*., 2010).

The adverse effects of moderate to severe drought can be mitigated by irrigation and/or using genotypes tolerant to water-stress (El-Ferjani and Soolanayakanahally, 2018). Other technique to mitigate water stress is to apply potassium fertilizer. Potassium plays a vital role in photosynthesis, translocation of photosynthates compounds, protein synthesis, control of ionic balance, regulation of plant stomata and water use, activation of plant enzymes and many other processes (Reddy *et al*., 2004).

Potassium is not only an essential macronutrient for plant growth and development, but also plays a primary role in the maintenance of low water potential of plant tissues. Therefore, accumulation of K^+ in plant tissues under drought stress may play an important role in water uptake along a soil-plant gradient (Fanaei*et al*., 2009). Fusheing, (2006) revealed that the lower water loss from plants supplied with sufficient K^+ is due to the reduction in transpiration, which not only depends on the osmotic potential of mesophyll cells, but also controlled a large extent by the opening and closing of stomata. Plants show a wide range of particular responses in order to minimize the effects of water shortage and to increase water absorbing rate (Morison *et al*., 2008). Generally, plants respond to water deficit stress through developmental, biochemical and physiological changes and the type of the observed response depends on several factors such as stress intensity, stress duration and genotype (Moradshahi *et al.,* 2004). Potassium application could ameliorate negative effects of water stress on seed yield and physiological properties of canola and it is one of the indicators of plant responses to water stress (Fanaei *et al*., 2009). Abdo and Anton, (2009) concluded that the maximum seed yield of sesame was obtained from wet treatment in combination with applying 24kg K_2O/fed and foliar spray of 1% K_2O. Aown *et al*., (2012) reported that foliar application of K^+ at all three critical growth stages of wheat improved the drought tolerance of plants and improved the growth and yield components.

The main objective of this work is to study the effects of various levels of moisture stress and potassium application treatments on growth, yield, some metabolic processes, irrigation water productivity as well as the role of potassium in amelioration of the adverse effects of water stress.

Materials and Methods

A field experiment was conducted at Etay El-Baroud Agricultural Research Station (30º 89'E, 30º 65'N, 5m above sea level), El-Behera Government, Egypt in the two successive winter growing seasons of 2017/2018 and 2018/2019 to evaluate the role of irrigation water stress and potassium fertilization on growth, yield, yield components, photosynthetic pigments, proline, oil and some water relations of canola (*Brassica napus* L.).

The experiment was laid out in a split plot design with four replications. Treatments included three irrigation water treatments (I_1:full irrigation; 100%ETc; I_2: moderate stress;75%ETc and I_3: high stress;50%ETc) applied in main plots and seven potassium fertilization (soil application and foliar spray) including, K_0 = without K fertilization; K_1= soil application of 30kg K_2O/ha; K_2= soil application of 45kg K_2O/ha; K_3= soil application of 60kg K_2O/ha; K_4= foliar application of 2% K_2O, K_5= soil application of 30kg K_2O/ha+ foliar application of 2% K_2O and K_6= soil application of 45kg K_2O/ha+ foliar application of 2% K_2O, distributed in the sub-plots. Each plot area was 14.4m^2 (3.6 × 4.0m) including 6 ridges (4.0m long and 60cm apart). Plots were separated by 1.5 meters distance to avoid the interference between irrigation treatments. Canola seeds (Serw 4 cultivar) obtained from Oil Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt, were used in this study. Canola seeds were sown in hills 15cm apart on the 14th and 16th of November and plants were harvested on the 10th and 13th of April in the first and second seasons, respectively.

Table 1: Mean values of some physical and chemical properties of the soil at the study site.

Depth (cm)	Physical parameters				Chemical analysis									
					pH	EC dS/m	Cations				Anions			
	Sand (%)	Silt (%)	Clay (%)	Textural Class			K^+	Na^+	Ca^{2+}	Mg^{2+}	CO_3	HCO_3	Cl	SO_4
							meq/l							
0-30	11.9	33.5	54.6	Clay	8.12	2.22	3.3	11.8	4.9	2.1	-	7.6	12.8	1.2
30-60	10.7	35.1	54.2	Clay	8.47	2.35	3.1	12.1	6.3	2.1	-	9.8	11.8	1.6

All agricultural practices were carried out according to the recommendation of Ministry of Agriculture, Egypt, except the factors under the study. Nitrogen fertilizer at the rate of 144kg N/ha as ammonium nitrate (33.5% N) was applied in two equal doses before the first and second irrigations. Phosphorus at the rate of 72kg P_2O_5/ha as calcium super phosphate (15.5% P_2O_5) was applied during soil preparation. Potassium as potassium sulphate (48% K_2O) was added before the first irrigation according to the dose of every treatment. Foliar spraying with 2% K_2O was applied after 45, 60 and 75 days from sowing. Irrigation treatments were applied after 30 days from sowing.

Soil analysis

Soil samples from the experimental site were collected from 0-30 and 30-60cm depths before sowing and were prepared for laboratory analyses. Soil physical (particle sizes and textural class) and chemical (EC, pH, cations and anions concentrations) properties were determined according to Page *et al.*, (1982) and FAO, (1970) and the mean values of the two seasons are presented in table 1. Soil hydro-physical properties (field capacity, wilting point, available soil moisture and bulk density) at the research site are given in table 2.

Mean monthly values of some metrological data representing the period from sowing to harvest were collected from meteorological station at Etay El-Baroud Agricultural Research Station and were used to calculate reference crop evapotranspiration (ET_o) values (table 3).

Growth characters

Five plants were randomly collected after 95 days from sowing to determine shoot dry weight and leaf area (LA). For leaf area/plant, the area of 10 disks ($10 \times 3.14 \times (1.5)^2$)= 70.65 cm^2 was calculated and the leaf area was determined according to Hunt, (1990) using the following formula:

$$LA = 70.65\,\frac{\text{Dry weight of leaves per plant}}{\text{Dry weight of leaves disks}}$$

Plant samples were dried in an electric oven with drift fan at 70°C for 48 hr, till constant dry weight.

Table 2: Field capacity (FC), wilting point (WP), available soil moisture (ASM) and bulkdensity values of the soil at experimental site.

Soil depth (cm)	FC (%)	WP (%)	ASM (%)	Bulk density (g/cm^3)
0-30	36.0	17.4	18.6	1.05
30-60	31.9	15.1	16.8	1.10
Average	33.95	16.25	17.70	1.08

Yield and yield components

The crop harvest was done after 147 and 148 days from sowing in the first and second seasons, respectively. At harvesting time, five plants from the central row of each sub-plot were randomly taken to determine plant height (cm), number of branches/plant, number of pods/plant, 1000-seed weight (g) and seed weight/plant (g). Plants in the central area of each sub-plot were harvested and weighed then converted to seed yield (kg/ha).

Relative yield reduction (RYD)

Relative yield reduction (RYD %) was determined using the following formula (Popova *et al.,* 2015):

$RYD\ (\%) = (1 - Y_d/Y_c) \times 100$

Where, Y_d and Y_C are yields of stressed and control treatments, respectively.

Physiological traits: Photosynthetic pigments

Chlorophyll a, b and carotenoids in fresh leaves (mg/g fresh weight) after 95days from sowing were determined according to Metzener *et al.*, (1965).

Proline content Prolinecontent (mg/g dry weight) in leaves after 95 days from sowing was determined according to Bates *et al.*, (1973).

Potassium content

Potassium concentration in leaves (mg/g dry weight) after 95 days from sowing was determined according to FAO method (FAO, 2008).

Oil content

Oilcontent in the dried seeds (%, on dry weight basis) was determined using Soxhlet extraction apparatus using petroleum ether as solvent (AOAC, 1990).

Water relations

- Relativewater content (RWC %)

Table 3: Meanmonthly values of some metrological data and the calculated ET_o for the 2017/2018 and 2018/2019 growing seasons.

Year	Month	Maximum Temp. (°C)	Minimum Temp. (°C)	Relative Humidity (%)	Wind Speed (km/day)	Total rainfall (mm)	ET_o (mm/day)
2017	**Nov.**	23.6	13.9	62.3	164.1	18.0	3.6
2017	**Dec.**	21.3	13.4	67.8	189.1	67.0	3.9
2018	**Jan.**	18.8	10.7	67.6	214.2	73.0	4.0
2018	**Feb.**	21.1	11.6	62.1	128.3	26.0	4.5
2018	**Mar.**	24.4	13.8	47.1	160.7	4.0	5.7
2018	**Apr.**	27.4	15.8	44.1	148.0.9	4.0	6.1
Average/ total		**22.77**	**13.10**	**58.50**	**167.42**	**192.0**	**-**
2018	**Nov.**	26.5	15.2	59.1	144.1	13.1	4.2
2018	**Dec.**	20.6	11.1	65.2	215.8	22.8	4.1
2019	**Jan.**	18.7	6.6	55.6	197.9	8.6	4.1
2019	**Feb.**	20.7	7.8	59.1	180.6	8.0	4.4
2019	**Mar.**	23.5	9.7	55.6	187.5	17.1	5.3
2019	**Apr.**	27.7	12.4	48.5	170.2	3.4	5.5
Average/ total		**22.95**	**10.46**	**57.18**	**182.68**	**73.00**	**-**

After 95 days from sowing, leaf samples were collected and immediately weighed (fresh weight, FW) and transferred into sealed flasks then immersed in distilled water for 5 hrs until fully turgid at 4°C, surface swabbed and reweighed (turgid weight, TW). Leaf samples were oven dried at 70°C for 48 hrs and reweighed (dry weight, DW). Relative water content (RWC %) was calculated according to Lazcano-Ferrat and Lovatt, (1999) using the following equation:

$$RWC\ (\%) = \frac{(FW - DW)}{(TW - DW)} \times 100$$

- Crop evapotranspiration (ET_C)

The crop water requirements were calculated by FAO crop evapotranspiration method. Crop evapotranspiration was determined by using reference evapotranspiration (ET_o) and crop coefficient (K_C) values for canola crop according to Allen *et al.*, (1998) as follow:

$$ET_C = ET_o \times K_C$$

Reference evapotranspiration for both investigated seasons were calculated using the weather data from meteorological station at Etay El-Baroud Agricultural Research Station, using CROPWAT model (Smith, 1992) based on FAO, Penman-Monteith equation.

- Applied irrigationwater (AIW)

The amount of applied irrigation water was measured by a flow meter and was calculated as follows (Vermeiren and Jopling, 1984):

$$AIW = \frac{ET_C}{E_Q}$$

Where, AIW is applied irrigation water (mm/day), ET_C is crop evapotranspiration (mm/day) and Eais irrigation efficiency (60% for the surface irrigation system used at the experimental site).

Seasonal applied water was calculated as described by Giriappa, (1983) as follows:

$$AW = AIW + Peff + S$$

Where, AW is seasonal applied water, AIW isapplied irrigation water, Peff is effective rainfall during growing season and S is the contribution of the ground water to crop water use (neglected, because the water table was deeper than 2.0m).

- Irrigation water productivity (IWP)

The irrigation water productivity (IWP,kg/m^3) was calculated according to Jensen, (1983) as follows:

$$IWP = \frac{Y_a}{AW}$$

Where, Yais the seed yield of various treatments (kg/ha) and AW is seasonal applied water (m^3/ha).

Statistical Analysis

Data were statistically analyzed according to Snedecor and Cochran, (1982). Comparisons among means of different treatments were carried out using Duncan's multiple range tests as presented by Steel and Torrie, (1984).

Results and Discussion

1. Effect of irrigation treatments, potassium application and their interaction on shoot dry weight and leaf area/plant.

The results given in table 4 showed thatshoot dry weight and leaf area/plant were significantly affected by irrigation treatments, potassium application and their interaction in both studied seasons, except leaf area/plant

Table 4: Effect of irrigation treatments, potassium application and their interaction on shoot dry weight and leaf area/plant in 2017/ 2018 and 2018/ 2019 seasons.

Treatments		**Shoot dry weight (g)**		**Leaf area/plant (cm^2)**	
		2017/18	**2018/19**	**2017/18**	**2018/19**
Irrigation (I)	**I_1**	37.07^a	39.03^a	1495.00^a	1602.73^a
	I_2	28.71^b	31.28^b	1380.25^a	1349.22^b
	I_3	23.83^c	26.00^b	1191.82^a	1263.76^c
	Average	**29.87**	**32.10**	**1355.69**	**1405.24**
Potassium (K)	**K_0**	23.30^c	25.44^c	968.51^b	1061.88^c
	K_1	28.93^b	31.01^b	1237.24	1310.64^b
	K_2	31.82^{ab}	34.17^a	1406.94^a	1472.90^{ab}
	K_3	34.26^a	36.25^a	1450.45^a	1585.15^a
	K_4	26.48^b	29.47^b	1307.75^a	1402.07^{ab}
	K_5	31.25^{ab}	33.43^a	1346.69^a	1424.48^{ab}
	K_6	33.06^{ab}	34.97^a	1538.92^a	1579.52^a
	Average	**29.87**	**32.11**	**1322.36**	**1405.23**
Interaction (I × K)					
I_1	**K_0**	27.60	29.84	1082.32	1129.96
	K_1	37.35	37.79	1369.82	1447.06
	K_2	41.03	42.36	1634.76	1746.06
	K_3	43.17	44.82	1756.93	1886.61
	K_4	28.93	32.21	1432.14	1644.88
	K_5	39.21	40.72	1460.10	1591.03
	K_6	42.27	42.99	1728.96	1773.00
	Average	**37.08**	**38.68**	**1495.00**	**1602.66**
I_2	**K_0**	23.57	25.83	987.18	1055.68
	K_1	28.93	31.71	1224.60	1281.51
	K_2	29.04	33.36	1303.10	1360.97
	K_3	32.01	34.18	1534.68	1531.70
	K_4	26.37	29.33	1257.48	1318.24
	K_5	30.48	32.78	1326.92	1351.13
	K_6	30.63	31.85	1498.86	1545.35
	Average	**28.72**	**31.29**	**1304.69**	**1349.23**
I_2	**K_0**	18.74	20.67	836.05	1000.01
	K_1	20.51	23.54	1117.32	1203.37
	K_2	25.40	26.81	1282.99	1311.18
	K_3	27.61	29.77	1291.33	1337.15
	K_4	24.18	24.37	1173.09	1243.11
	K_5	24.12	26.80	1253.06	1331.29
	K_6	26.29	30.08	1388.96	1420.24
	Average	**23.84**	**26.01**	**1191.83**	**1263.76**
LSD$_{0.05}$ Irrigation (I)		**4.29**	**2.83**	**NS**	**74.25**
LSD$_{0.05}$ Potassium (K)		**5.19**	**2.38**	**273.35**	**177.12**
LSD$_{0.05}$ Interaction (I × K)		**7.56**	**NS**	**286.34**	**190.20**

Means in the same column followed by the same letter (s) were not significantly different according to LSD$_{0.05}$ values.

for irrigation in the first season and shoot dry weight for interaction in the second season. Results revealed that, increasing soil moisture depletion level from full irrigation (I_1) up to high stress irrigation (I_3) decreased shoot dry weight and leaf area. The reduction in the leaf area and shoot dry weight can be due to the decrease in absorbed CO_2 because of blocked or half-blocked stomata. On the other hand, the plants consume a lot of energy to absorb water, these cause a reduction in producing photosynthetic matters, thus reduced the growth of canola, as evident in the lower dry weight of shoot under water stress (Moaveni *et al.*, 2010; Bahrani and Pourreza, 2016 and El-Sabagh *et al.*, 2019). The high stress irrigation treatment (I_3) gave the lowest shoot dry weight (23.83 and 26.00 g) and leaf area/ plant (1191.8 and 1263.7cm^2), whereas the maximum values were obtained from full irrigation treatment (I_1) in both respective studied seasons. Similar results were obtained by Ali *et al.*, (2014); El-Shafey, (2017) and El-Mantawy and El-Bialy, (2018), who showed that increasing water stress from 25-30% up to 65-70% of available soil moisture depletion (ASMD) decreased growth and metabolic processes for soybean and sunflower.

Potassium application at 60 kg K_2O/ ha or 45 kg K_2O/ha plus spraying by 2% K_2O had superior effect on shoot dry weight and leaf area/plant compared with the other treatments in both seasons. These results agreed with those obtained by Fanaei *et al.*, (2009); Sattar *et al.*, (2011); Cheema *et al.*, (2012) and Ali *et al.*, (2014). They concluded that, potassium increased leaf expansion which helps in subsequent interception and efficient utilization of solar radiation, resulting in increase of dry matter accumulation in leaves and shoots. Khan *et al.*, (2004) stated that, because of the osmotic activity, potassium attracts water and inflates the cell, stretching it to a new large size. Also, potassium-deficient of plants can exhibit low growth rates and small cells of canola.

With regard to the interaction effect, results indicated that water stress (I_3) and application of 60 kg K_2O/ha or 45 kg K_2O/ha plus foliar spray had the highest values for leaf area (1388.96 and 1291.33 cm^2) in the first and (1420.24 and 1337.15 cm^2) in the second seasons,

Table 5: Effect of irrigation treatments, potassium application and their interaction on yield and yield components in the first season (2017/ 2018).

Treatments		Plant height (cm)	No. of branches/plant	No. of pods/plant	1000-seed weight (g)	Seed weight/plant (g)	Seed yield/ha (kg)
Irrigation (I)	I_1	141.54^{a}	6.37^{a}	593.14^{a}	3.23^{a}	37.16^{a}	4144.61^{a}
	I_2	134.25^{ab}	6.37^{a}	477.28^{a}	3.16^{b}	28.02^{b}	3720.24^{b}
	I_3	126.34^{b}	5.82^{a}	397.74^{b}	2.86^{c}	24.22^{c}	3057.34^{c}
	Average	**134.04**	**6.19**	**489.39**	**3.08**	**29.80**	**3640.73**
Potassium (K)	K_0	117.73^{b}	5.33^{b}	333.40^{c}	2.70^{c}	21.72^{c}	3433.99^{c}
	K_1	131.86^{ab}	5.86^{ab}	455.80^{b}	2.97^{b}	27.85^{b}	3588.98^{b}
	K_2	137.20^{ab}	6.26^{ab}	537.00^{ab}	3.15^{ab}	31.86^{ab}	3748.99^{b}
	K_3	143.40^{a}	6.93^{ab}	576.80^{a}	3.39^{a}	33.47^{a}	3748.58^{ab}
	K_4	132.93^{ab}	6.13^{ab}	466.40^{b}	3.03^{b}	29.38^{ab}	3610.20^{b}
	K_5	135.86^{ab}	6.13^{ab}	510.13^{ab}	3.08^{b}	30.88^{ab}	3650.78^{b}
	K_6	139.33^{ab}	6.66^{ab}	546.20^{ab}	3.27^{ab}	33.42^{a}	3823.58^{a}
	Average	**134.04**	**6.19**	**489.39**	**3.08**	**29.80**	**3657.86**
Interaction (I × K)							
I_1	K_0	121,00	5.80	385.80	2.92	24.98	3896.4
	K_1	142.40	6.20	546.40	3.10	33.99	4102.2
	K_2	144.00	6.40	660.40	3.26	40.08	4140.6
	K_3	151.00	7.20	716.20	3.59	41.05	4246.8
	K_4	141.40	6.20	560.80	3.16	38.25	4203.0
	K_5	145.20	6.20	611.40	3.18	40.05	4152.0
	K_6	146.00	6.60	674.00	3.41	41.25	4255.2
	Average	**141.57**	**6.37**	**593.57**	**3.23**	**37.09**	**4142.31**
I_2	K_0	118.40	5.40	351.20	2.78	21.52	3478.8
	K_1	132.00	6.00	429.40	3.03	25.80	3613.2
	K_2	138.00	6.60	525.20	3.20	29.60	3668.4
	K_3	143.80	6.80	555.80	3.50	32.44	3891.0
	K_4	130.20	6.60	437.80	3.11	26.38	3624.0
	K_5	136.80	6.40	503.20	3.16	27.64	3705.6
	K_6	140.60	6.80	538.40	3.38	32.77	4060.8
	Average	**143.63**	**6.37**	**477.29**	**3.17**	**28.02**	**3720.26**
I_2	K_0	113.80	4.80	225.00	2.40	18.67	2926.8
	K_1	121.20	5.40	394.00	2.79	23.81	3051.6
	K_2	129.60	5.80	425.40	2.99	25.91	3078.0
	K_3	135.40	6.80	458.40	3.09	26.93	3108.0
	K_4	127.40	5.60	400.60	2.84	23.51	2987.4
	K_5	125.60	5.80	415.80	2.91	24.97	3094.8
	K_6	131.40	6.60	426.20	3.04	25.77	3154.8
Average		**126.36**	**5.83**	**392.20**	**2.87**	**24.22**	**3057.34**
LSD$_{0.05}$ Irrigation (I)		**10.25**	**NS**	**56.31**	**0.14**	**2.70**	**67.39**
LSD$_{0.05}$ Potassium (K)		**15.26**	**0.95**	**72.00**	**0.20**	**3.15**	**131.69**
LSD$_{0.05}$ Interaction (I × K)		**NS**	**NS**	**NS**	**0.34**	**5.10**	**199.54**

Means in the same column followed by the same letter (s) were not significantly different according to LSD$_{0.05}$ values.

respectively. The same trend was obtained for shoot dry weight in the first season. Potassium application had positive effect on shoot dry weight (Bahrani and Pourreza, 2016) and on plant growth of canola (Fanaei *et al.*, 2009) under water deficit conditions.

2. Effect of irrigation treatments, potassium application and their interaction on yield and yield components.

Results in tables 5 and 6, showed that the irrigation treatments had a significant effect on yield and its

Table 6: Effect of irrigation treatments, potassium application and their interaction on yield and yield components in the second season (2018/ 2019).

Treatments		**Plant height (cm)**	**No. of branches/plant**	**No. of pods/plant**	**1000-seed weight (g)**	**Seed weight/plant (g)**	**Seed yield/ha (kg)**
Irrigation (I)	**I_1**	151.77^{a}	7.22^{a}	725.22^{a}	4.04^{a}	39.69^{a}	4173.84^{a}
	I_2	144.80^{ab}	6.71^{a}	525.6^{b}	3.67^{b}	30.95^{b}	3804.24^{b}
	I_3	136.85^{b}	6.4^{a}	424.45^{c}	3.33^{b}	25.69^{c}	3084.41^{c}
	Average	**144.47**	**6.78**	**558.42**	**3.68**	**32.11**	**3687.50**
Potassium (K)	**K_0**	124.26^{b}	5.53^{c}	345.26^{c}	2.96^{b}	24.08^{b}	3474.19^{c}
	K_1	142.86^{a}	5.93^{c}	529.46^{b}	3.80^{a}	30.45^{a}	3612.79^{b}
	K_2	148.93^{a}	7.53^{b}	606.53^{ab}	3.80^{a}	33.92^{a}	3698.59^{b}
	K_3	154.93^{a}	8.86^{a}	707.80^{a}	3.95^{a}	36.01^{a}	3780.19^{b}
	K_4	143.73^{a}	6.26^{c}	537.93^{b}	3.69^{a}	30.97^{a}	3653.59^{b}
	K_5	146.53^{a}	6.26^{c}	541.13^{b}	3.72^{a}	33.95^{a}	3705.38^{b}
	K_6	150.06^{a}	7.06^{c}	640.86^{ab}	3.85^{a}	35.40^{a}	3886.06^{a}
	Average	**144.47**	**7.06**	**558.42**	**3.68**	**32.11**	**3687.26**
Interaction (I × K)							
I_1	**K_0**	129.60	5.80	415.20	3.19	27.81	3928.9
	K_1	147.60	6.40	630.20	3.94	37.20	4107.6
	K_2	155.60	7.60	810.80	4.12	43.58	4227.0
	K_3	170.00	10.20	1027.00	4.30	45.43	4276.8
	K_4	149.40	7.00	641.80	4.02	38.08	4204.8
	K_5	155.40	6.60	638.00	4.10	40.42	4188.0
	K_6	154.80	7.00	913.80	4.21	44.95	4284.0
	Average	**151.77**	**7.23**	**725.26**	**3.98**	**39.64**	**4173.87**
I_2	**K_0**	123.80	5.60	346.40	3.06	23.79	3562.8
	K_1	147.20	6.00	514.80	3.74	28.63	3693.0
	K_2	149.20	7.20	577.00	3.79	30.94	3783.6
	K_3	148.40	8.80	619.00	3.92	35.51	3958.8
	K_4	145.40	6.20	532.60	3.71	29.27	3759.6
	K_5	146.80	6.20	527.60	3.67	30.69	3810.6
	K_6	152.80	7.00	581.80	3.84	33.59	4061.4
	Average	**144.80**	**6.71**	**528.46**	**3.68**	**30.35**	**3804.26**
I_2	**K_0**	119.40	5.20	294.20	2.64	20.64	2931.0
	K_1	133.80	5.40	443.40	3.32	25.55	3037.8
	K_2	142.06	7.80	431.80	3.49	27.26	3085.2
	K_3	146.40	7.60	477.40	3.64	27.10	3104.9
	K_4	136.40	5.60	439.40	3.36	25.58	2996.4
	K_5	137.40	6.00	458.00	3.40	26.06	3117.6
	K_6	142.60	7.20	427.00	3.52	27.68	3318.0
Average		**136.87**	**6.40**	**424.46**	**3.34**	**25.70**	**3084.41**
$LSD_{0.05}$ Irrigation (I)		**11.37**	**NS**	**79.93**	**0.35**	**3.70**	**99.07**
$LSD_{0.05}$ Potassium (K)		**9.69**	**0.93**	**87.64**	**0.49**	**3.98**	**132.0**
$LSD_{0.05}$ Interaction (I × K)		**16.27**	**1.10**	**95.20**	**0.55**	**7.02**	**207.36**

Means in the same column followed by the same letter (s) were not significantly different according to $LSD_{0.05}$ values.

components (plant height, number of pods/plant, 1000-seeds weight (g), seed weight/plant (g) and seed yield/ha (kg), except number of branches in both studied seasons. Such characters were decreased when plants exposed to high stress irrigation (I_3). These results revealed that increasing soil moisture stress reduced growth of canola, which in turn affected yield and its components. Similar results were obtained by (El-Shafey, 2017; El-Mantawy and El-Bialy, 2018 and Jahan *et al*., 2019). Moreover, the exposure canola plants to water stress in the flowering and pods formation stages resulted in a considerable reduction for number of pods per plant through more severe flower and pods abscissions (Sinaki *et al*., 2007).

On the contrary, high moisture level enhanced growth plants there by improving yield and its components. Taller plants were obtained when 100% irrigation was applied followed by 80% irrigation level on canola (Ali *et al*., 2014). Seed yield (kg)/ha decreased with increasing water stress, for full irrigation it was (4151.81 and 4173.84 kg), moderate (3720.24 and 3804.24 kg) and stress irrigation (3057.34 and 3084.41 kg) in the two seasons, respectively. These results are in line with those reported by (Zare *et al*., 2010 and Gharelo *et al*., 2017). Also, water stress through disrupting the plant photosynthesis, decreased assimilates synthesis which is necessary for seed filling and consequently resulted in seed shrinkage and weight loss (Shirani Rad and Zandf, 2012).

Concerning potassium application, results presented in tables 5 and 6 showed that yield and its components were significantly affected by potassium application in both studied seasons. The most effective treatments on plant height, number of branches/ plant, number of pods/ plant, 1000- seed weight, seed weight/ plant and seed yield/ha were 60 kg K_2O/ha or 45 kg K_2O/ha plus foliar spraying with 2% K_2O in both seasons. The highest value for seed yield/ ha was obtained by adding 45 kg K_2O/ha with spraying 2% K_2O (3823.58 and 3886.06 kg) in the two respective seasons (Tables 5 and 6). Cheema *et al.,* (2012) reported that potassium application at the rate of 120 kg ha^{-1} increased the growth and yield (plant height, number of seeds per/ pod, 1000- seed weight, biological and seed yield) of canola. Also, the possible reason could be that the potassium balance gave favorable environment to the plants, which helped in the absorption of more nutrients and hence more yield of canola was produced (Ahmad *et al*., 2000).

The results in tables 5 and 6, showed that the interaction between irrigation treatments and potassium application had significant effect on yield and its components in both seasons, except plant height, number of branches/ plant and number of pods/ plant in the first season only. Potassium application on canola plants plus 100% irrigation revealed maximum plant height, plant dry weight and grain yield (Ali *et al*., 2014). The maximum values for seed yield/ha (4255.2 and 4284.0 kg) were obtained when plants irrigated by full irrigation (I_1) with 45 kg K_2O/ ha plus foliar spray by 2% K_2O and the minimum values (2926.8 and 2931.0 kg) were by stress irrigation (I_3) without potassium application (control) in the two seasons. Potassium treatments improved grain yield and physiological properties of canola, mung bean and tomato under water stress (Fanaei *et al*., 2009, Fooladivanda *et al*., 2014; Bahrani and Pourreza, 2016 and Liu *et al*., 2019).

3. Effect of irrigation treatments, potassium applications and their interaction on photosynthetic pigments.

The results in table 7 showed that irrigation treatments, potassium application and their interaction had significant effect on photosynthetic pigments (chlorophyll a-chlorophyll b-chlorophyll a+ b and carotenoids. Stress irrigation (I_3) scored the lowest values of such pigments. On the other hand, chlorophyll content and carotenoids were increased when canola plants were watered with full irrigation (I_1) as compared to moderate irrigation (I_2) or high stress (I_3) in both seasons. Similar results were obtained by (Vishkaee *et al*., 2015; El-Shafey, 2017 and El-Mantawy and El-Bialy, 2018). Moreover, moisture stress causes reduction in leaf chlorophyll content of canola plants. Therefore, for better yields under stress condition, higher chlorophyll content might contribute to higher plant productivity (Rao *et al*., 2012 and Kheradmand *et al*., 2014). Stomata closer in response to leaf turgor decline to high vapor pressure deficit in the atmosphere or to root- generated chemical signals, the latter being common in drought conditions (Chaves *et al*., 2009). Thus, photosynthesis is one of the key processes to be affected by water deficit via decreased CO_2, diffusion to the chloroplast and metabolic constraints (Ali *et al*., 2014).

With regard to the effect of potassium application on photosynthetic pigments, the highest values of chlorophyll (a, b and a+ b) and carotenoids were obtained in leaves of plants treated with 60 kg K_2O/ha or 45 kg K_2O/ha plus foliar spray by 2% K_2O in the first and second season, respectively. Potassium treatments increased leaf area index (LAI) of canola plants, thus LAI of the crop at a particular growth stage indicates its photosynthetic potential or the level of its dry matter accumulation (Cheema *et al*., 2012).

Moreover, the highest values of chlorophyll content and carotenoids were resulted from the interaction between full irrigation (I_1) plus 45 kg K_2O/ha + foliar spray of 2% K_2O for the first and the second seasons. High drought stress intensity increases the potassium requirement for improving the water status and maintaining photosynthesis (Umar, 2006). However, fertilization of canola and cotton with potassium could protect chlorophyll, membranes and also improved the water relations under water deficit condition (Alam *et al*., 2011 and Zahoor *et al*., 2017). Moreover, the larger potassium requirement of plants under different abiotic stresses appears to be related to the inhibitory role of potassium against reactive oxygen species (ROS) production during photosynthesis and NADPH oxidase (Cakmak, 2005).

Table 7: Effect of irrigation treatments, potassium application and their interaction on photosynthetic pigments (mg/ g fresh weight) in 2017/ 2018 and 2018/ 2019 seasons.

Treatments		**Chlorophyll a**		**Chlorophyll b**		**Chlorophyll a + b**		**Carotenoids**	
		2017/18	**2018/19**	**2017/18**	**2018/19**	**2017/18**	**2018/19**	**2017/18**	**2018/19**
Irrigation (I)	**I_1**	1.36^{a}	1.39^{a}	1.17^{a}	1.20^{a}	2.53^{a}	2.59^{a}	0.819^{a}	0.849^{a}
	I_2	1.19^{b}	1.22^{b}	0.90^{b}	0.92^{b}	2.09^{b}	2.15^{b}	0.640^{b}	0.660^{b}
	I_3	1.00^{c}	1.03^{c}	0.75^{c}	0.77^{c}	1.75^{c}	1.77^{c}	0.500^{c}	0.510^{c}
	Average	**1.18**	**1.21**	**0.94**	**0.96**	**2.12**	**2.17**	**0.653**	**0.673**
Potassium (K)	**K_0**	1.02^{f}	1.06^{f}	0.80^{e}	0.81^{d}	1.82^{f}	1.88^{e}	0.56^{d}	0.57^{e}
	K_1	1.13^{e}	1.16^{e}	0.90^{d}	0.92^{c}	2.03^{e}	2.09^{d}	0.66^{c}	0.68^{c}
	K_2	1.18^{c}	1.22^{d}	0.97^{b}	1.00^{b}	2.16^{c}	2.23^{b}	0.66^{c}	0.68^{c}
	K_3	1.28^{a}	1.31^{b}	1.00^{a}	1.04^{a}	2.29^{a}	2.35^{a}	0.68^{b}	0.71^{b}
	K_4	1.15^{d}	1.25^{c}	0.93^{c}	0.94^{c}	2.09^{d}	2.11^{d}	0.64^{c}	0.63^{d}
	K_5	1.22^{b}	1.16^{e}	0.96^{b}	0.99^{b}	2.19^{b}	2.19^{c}	0.66^{c}	0.69^{c}
	K_6	1.28^{a}	1.33^{a}	1.00^{a}	1.04^{a}	2.29^{a}	2.34^{a}	0.71^{a}	0.74^{a}
	Average	**1.18**	**1.21**	**0.94**	**0.96**	**2.12**	**2.17**	**0.65**	**0.67**
Interaction (I × K)									
I_1	**K_0**	1.21	1.28	0.94	0.98	2.15	2.26	0.72	0.76
	K_1	1.31	1.36	1.11	1.18	2.42	2.54	0.84	0.85
	K_2	1.37	1.40	1.21	1.27	2.58	2.67	0.84	0.86
	K_3	1.45	1.48	1.25	1.28	2.70	2.75	0.85	0.87
	K_4	1.34	1.33	1.17	1.18	2.51	2.52	0.81	0.82
	K_5	1.38	1.41	1.24	1.24	2.62	2.65	0.80	0.84
	K_6	1.47	1.47	1.29	1.32	2.76	2.79	0.86	0.90
	Average	**1.36**	**1.39**	**1.17**	**1.25**	**2.53**	**2.60**	**0.82**	**0.84**
I_2	**K_0**	1.07	1.08	0.79	0.79	1.86	1.87	0.55	0.56
	K_1	1.10	1.14	0.86	0.87	1.96	2.00	0.63	0.67
	K_2	1.21	1.23	0.94	0.98	2.15	2.21	0.66	0.68
	K_3	1.30	1.32	0.97	1.01	2.27	2.33	0.68	0.71
	K_4	1.16	1.19	0.89	0.90	2.05	2.09	0.63	0.59
	K_5	1.24	1.26	0.90	0.94	2.14	2.20	0.66	0.70
	K_6	1.28	1.35	0.96	1.00	2.24	2.35	0.73	0.74
	Average	**1.19**	**1.22**	**0.90**	**0.95**	**2.10**	**2.15**	**0.65**	**0.66**
I_2	**K_0**	0.80	0.84	0.67	0.68	1.47	1.52	0.41	0.41
	K_1	0.98	0.99	0.74	0.74	0.72	1.73	0.52	0.52
	K_2	0.99	1.05	0.76	0.77	1.76	1.83	0.50	0.50
	K_3	1.12	1.13	0.80	0.85	1.92	1.98	0.57	0.57
	K_4	0.96	0.97	0.75	0.75	1.71	1.72	0.49	0.49
	K_5	1.05	1.10	0.77	0.79	1.82	1.89	0.52	0.55
	K_6	1.09	1.17	0.79	0.81	1.88	1.99	0.57	0.59
	Average	**1.00**	**1.04**	**0.75**	**0.79**	**1.61**	**1.81**	**0.51**	**0.52**
$LSD_{0.05}$ Irrigation (I)		**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.03**	**0.01**	**0.01**
$LSD_{0.05}$ Potassium (K)		**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**
$LSD_{0.05}$ Interaction (I × K)		**0.03**	**0.03**	**0.02**	**0.03**	**0.03**	**0.05**	**0.03**	**0.03**

Means in the same column followed by the same letter (s) were not significantly different according to $LSD_{0.05}$ values.

4. Effect of irrigation treatments, potassium application and their interaction on relative water content (RWC %), proline content (mg/ g dry weight), K% in leaves and oil% of seeds.

The results in table 8 showed that irrigation treatment, potassium application and their interaction had significant effect on proline content, K^+ % in leaves and oil % of seeds. The RWC, K^+ % in leaves and oil % of seeds decreased with increasing water stress level, while proline content takes reverse direction, since it increased with increasing water stress from full irrigation (0.778 and 0.788) up to water stress (0.885 and 0.895) in both seasons. Similar results were obtained by (Ali *et al.*, 2014;

Table 8: Effect of irrigation treatments, potassium application and their interaction on relative water content (RWC %), proline content (mg/g dry weight), K% in leaves and seed oil % in 2017/ 2018 and 2018/ 2019 seasons.

Treatments		**RWC (%)**		**Proline**		**K$^+$ (%)**		**Oul (%)**	
		2017/18	**2018/19**	**2017/18**	**2018/19**	**2017/18**	**2018/19**	**2017/18**	**2018/19**
Irrigation (I)	**I$_1$**	79.04^{a}	79.98^{a}	0.779^{c}	0.788^{c}	1.59^{a}	1.64^{a}	39.58^{a}	39.90^{a}
	I$_2$	75.29^{b}	75.95^{b}	0.809^{b}	0.820^{b}	1.55^{b}	1.56^{b}	39.56^{a}	39.67^{b}
	I$_3$	67.15^{c}	68.53^{c}	0.885^{a}	0.895^{a}	1.38^{c}	1.41^{c}	38.38^{b}	38.39^{c}
	Average	**73.83**	**74.82**	**0.824**	**0.834**	**1.51**	**1.54**	**39.17**	**39.32**
Potassium (K)	**K$_0$**	67.19^{c}	68.02^{c}	0.779^{e}	0.791^{e}	1.35^{e}	1.41^{e}	38.60^{d}	38.80^{c}
	K$_1$	72.96^{b}	72.88^{b}	0.806^{c}	0.819^{c}	1.49^{d}	1.51^{d}	39.24^{b}	39.30^{b}
	K$_2$	75.17^{ab}	76.02^{ab}	0.836^{c}	0.847^{a}	1.53^{c}	1.55^{c}	39.26^{b}	39.46^{a}
	K$_3$	77.43^{a}	78.31^{a}	0.855^{a}	0.863^{a}	1.64^{a}	1.60^{b}	39.44^{a}	39.55^{a}
	K$_4$	72.91^{b}	73.85^{b}	0.800^{d}	0.814^{d}	1.48^{d}	1.53^{cd}	39.20^{bc}	39.29^{b}
	K$_5$	74.40^{ab}	75.85^{a}	0.833^{b}	0.844^{b}	1.49^{d}	1.54^{c}	39.10^{c}	39.27^{b}
	K$_6$	76.71^{ab}	78.80^{a}	0.859^{a}	0.862^{a}	1.56^{b}	1.62^{a}	39.36^{ab}	39.59^{a}
	Average	**73.82**	**74.82**	**0.820**	**0.830**	**1.51**	**1.54**	**39.17**	**39.32**
Interaction (I × K)									
I$_1$	**K$_0$**	70.71	72.31	0.754	0.767	1.45	1.53	39.36	39.71
	K$_1$	79.11	78.60	0.762	0.776	1.58	1.61	39.76	39.92
	K$_2$	80.46	81.49	0.791	0.802	1.63	1.64	39.57	40.05
	K$_3$	82.07	82.75	0.798	0.807	1.69	1.71	39.65	40.06
	K$_4$	78.88	79.42	0.761	0.789	1.61	1.63	39.77	39.90
	K$_5$	79.27	80.68	0.774	0.810	1.57	1.62	39.24	39.50
	K$_6$	82.83	84.66	0.808	0.792	1.65	1.75	39.72	40.18
	Average	**79.06**	**79.99**	**0.778**	**0.792**	**1.60**	**1.64**	**39.58**	**39.90**
I$_2$	**K$_0$**	68.94	69.45	0.783	0.792	1.39	1.42	38.71	38.86
	K$_1$	75.19	74.19	0.793	0.808	1.49	1.51	39.77	39.70
	K$_2$	77.62	78.00	0.824	0.830	1.53	1.56	39.74	39.85
	K$_3$	78.59	79.09	0.827	0.833	1.79	1.63	39.79	39.98
	K$_4$	74.11	74.59	0.796	0.810	1.52	1.57	39.56	39.62
	K$_5$	75.85	77.39	0.823	0.832	1.54	1.60	39.66	39.80
	K$_6$	76.74	78.96	0.825	0.838	1.59	1.65	39.75	39.94
	Average	**75.29**	**75.95**	**0.810**	**0.820**	**1.55**	**1.56**	**39.54**	**39.68**
I$_2$	**K$_0$**	61.93	62.33	0.802	0.817	1.22	1.28	37.76	37.85
	K$_1$	64.58	65.87	0.803	0.874	1.40	1.41	38.21	38.29
	K$_2$	67.44	68.58	0.896	0.911	1.44	1.44	38.49	38.50
	K$_3$	71.65	73.11	0.943	0.951	1.45	1.47	38.89	38.70
	K$_4$	65.77	67.56	0.844	0.865	1.36	1.40	38.28	38.27
	K$_5$	68.11	69.98	0.903	0.913	1.39	1.43	38.41	38.41
	K$_6$	70.59	72.79	0.946	0.940	1.45	1.48	38.63	38.71
	Average	**67.15**	**68.60**	**0.877**	**0.896**	**1.39**	**1.42**	**38.38**	**38.39**
LSD$_{0.05}$ Irrigation (I)		**2.82**	**2.38**	**0.001**	**0.004**	**0.01**	**0.01**	**0.07**	**0.05**
LSD$_{0.05}$ Potassium (K)		**2.54**	**2.90**	**0.004**	**0.003**	**0.01**	**0.02**	**0.12**	**0.11**
LSD$_{0.05}$ Interaction (I × K)		**NS**	**NS**	**0.008**	**0.005**	**0.05**	**010**	**0.21**	**0.19**

Means in the same column followed by the same letter (s) were not significantly different according to LSD$_{0.05}$ values.

El-Shafey, 2017 and El-Mantawy and El-Bialy, 2018). Drought stress reduces both nutrient uptake by the roots and transport from roots to the shoots, due to restricted transpiration rates and impaired active transport and membrane permeability (Yuncai and Schmidhalter, 2005). Water stress is generally characterized by decrease in RWC and water potential, resulting in wilting, stomatal closure and reduced growth (Lawlor and Cornic, 2002), which leads to reduction in leaf mineral contents (Pagter *et al*., 2005). The reduction of seed filling time which, occurs due to water stress would lead to reduced oil accumulation of canola seeds (Shirani Rad and Zandf, 2012; Seyedmohammadi *et al*., 2013 and Kheradmand *et al*., 2014).

Table 9: Amounts of applied water (AW), relative yield reduction (RYD %) and irrigation water productivity (IWP) as affected by irrigation treatments and potassium application in 2017/2018 and 2018 /2019 seasons.

Irrigation (I)	Potassium (K)	2017/ 2018					2018 / 2019				
		AW (mm)	AW (m^3/ha)	Seed yield/ ha(kg)	RYD (%)	IWP (kg/m^3)	AW (mm)	AW (m^3/ha)	Seed yield/ ha(kg)	RYD (%)	IWP (kg/m^3)
I_1	K_0	443.6	4436	3896.4	-	0.878	456	4560	3928.9	-	0.862
	K_1	443.6	4436	4102.2	-	0.925	456	4560	4107.6	-	0.901
	K_2	443.6	4436	4140.6	-	0.933	456	4560	4227.0	-	0.927
	K_3	443.6	4436	4246.8	-	0.957	456	4560	4276.8	-	0.938
	K_4	443.6	4436	4203.0	-	0.948	456	4560	4204.8	-	0.922
	K_5	443.6	4436	4152.0	-	0.936	456	4560	4188.0	-	0.918
	K_6	443.6	4436	4255.2	-	0.959	456	4560	4284.0	-	0.940
	Average	**443.6**	**4436**	**4142.31**	-	**0.934**	**456**	**4560**	**4173.87**	-	**0.915**
I_2	K_0	332.7	3327	3478.8	10.72	1.045	342	3420	3562.8	9.32	1.042
	K_1	332.7	3327	3613.2	11.92	1.086	342	3420	3693.0	10.09	1.080
	K_2	332.7	3327	3668.4	11.40	1.102	342	3420	3783.6	10.49	1.106
	K_3	332.7	3327	3891.0	8.38	1.169	342	3420	3958.8	7.44	1.158
	K_4	332.7	3327	3624.0	13.78	1.089	342	3420	3759.6	10.59	1.099
	K_5	332.7	3327	3705.6	10.75	1.114	342	3420	3810.6	9.01	1.114
	K_6	332.7	3327	4060.8	4.57	1.221	342	3420	4061.4	5.20	1.188
	Average	**332.7**	**3327**	**3720.26**	**10.22**	**1.118**	**342**	**3420**	**3804.26**	**8.88**	**1.112**
I_3	K_0	221.8	2218	2926.8	24.89	1.319	228	2280	2931.0	25.40	1.286
	K_1	221.8	2218	3051.6	25.61	1.376	228	2280	3037.8	26.04	1.332
	K_2	221.8	2218	3078.0	25.66	1.388	228	2280	3085.2	27.01	1.353
	K_3	221.8	2218	3108.0	26.82	1.401	228	2280	3104.9	27.40	1.362
	K_4	221.8	2218	2987.4	28.92	1.347	228	2280	2996.4	28.74	1.314
	K_5	221.8	2218	3094.8	25.46	1.395	228	2280	3117.6	25.56	1.367
	K_6	221.8	2218	3154.8	25.86	1.422	228	2280	3318.0	22.55	1.456
	Average	**221.8**	**2218**	**3057.34**	**26.17**	**1.378**	**228**	**2280**	**3084.41**	**26.10**	**1.353**

Concerning, potassium application, the results revealed that, plants treated with 60 kg K_2O/ha and 45 kg K_2O/ha + spraying with 2% K_2O had the highest values for RWC (77.43 and 76.71%), proline (0.855 and 0.859), K^+% in leaves (1.64 and 1.56%) and oil% of seed (39.44 and 39.59%) in the first season. Also, the same trend was obtained in the second season. Adequate potassium fertilization of crop plants facilitates osmotic adjustment, which maintains turgor pressure at lower leaf water potentials and improves the ability of plants to tolerate drought stress (Egilla *et al.*, 2001) and it controlled to a large extent of stomata opening and closing (Fusheing, 2006). Potassium application increased the oil quality and proline content of canola (Cheema *et al.*, 2012 and Ali *et al.*, 2014).

The highest values for RWC were verified by the interaction between full irrigation (I_1) and application of 45 kg K_2O/ha + spraying by 2%, K_2O, the results were (82.83 and 84.66%) for the first and the second seasons, respectively. The same trend was obtained with K^+ percent in leaves and oil % of seeds. Ma *et al.,* (2004) showed that K^+ accumulation in the expanding leaves in genotypes of three canola accounted for about 25% of drought- induced changes in osmotic adjustment. Potassium application increased RWC and seed oil of canola plants under water stress (Bahrani and Pourreza, 2016). On the other hand, the highest values for proline content found with the interaction between water stressed treatments (I_3) plus 45 kg K_2O/ ha + spraying by 2%, K_2O (0.946 and 0.940) for the first and the second seasons, respectively. Similar results were obtained by Ali *et al.*, (2014) who, reported that maximum proline and minimum relative water content in canola leaves were obtained when water stress (I_3) was applied with potassium treatments. Accumulation of proline under stress conditions is used as adaptive mechanism by many plant species (Hayat *et al.*, 2013 and Ali *et al.*, 2014).

5. Relative yield reduction (RYD %) and irrigation water productivity (IWP) as affected by irrigation treatments and potassium application.

The effect of irrigation and potassium application treatments on relative yield reduction (RYD %) and irrigation water productivity (IWP) is presented in table 9. Results showed that the seasonal values of applied water for I_1, I_2 and I_3 treatments were 4436, 3327 and 2218m^3/ha and were 4560, 3420 and 2280m^3/ha in the first and second seasons, respectively. Results indicated also that the lowest relative yield reductions (RYD %) values of 4.57 and 5.20% were recorded from treated plants with 45kg K_2O/ha + spraying by 2% K_2O (K_6) under moderate stress (I_2) in the 1st and 2nd seasons, respectively. Also, the same treatment had the lowest relative yield reductions (22.55%) under high water stress (I_3) treatment in the second season. Similar results were obtained by (Ali *et al*., 2014 and Bahraniand Pourreza, 2016). Results revealed that, the highest IWP values of 1.422 and 1.456 kg/m^3 were obtained from the combined effect of stressed irrigation (I_3) & 45 kg K_2O/ha+ spraying with 2% K_2O(K_6) treatment in the first and the second seasons, respectively. On the other hand, the lowest values (0.878 and 0.862 kg/m^3) were recorded for full irrigation (I_1) without potassium application (k_0) treatment in the two respective seasons. The results were close with those reported by Moteva *et al*., (2016); Djaman *et al*., (2018) and El-Mantawy and El-Bialy, (2018). Also, the results with Taha *et al*., (2019a) showed that water stress on forage saved irrigation water by 25-50% of total irrigation water. Moreover, Taha *et al*., (2019b) found that the highest water use efficiency and water productivity values were obtained under irrigation with 80% ET_o. The obtained results agreed also with those reported by Cakmak, (2005); Wiebold and Scharf, (2006) and Liu *et al*., (2019), they showed that potassium fertilization alleviated the negative effect on water use efficiency (WUE) for tomato plants under water deficit and concluded that potassium regulates stoma closer and prevents water wasting by regulating osmosis, increases water use efficiency (WUE) and cause more water to be available for use by plants.

Conclusion

It can be concluded that, water stress had negative effect on growth, yield components and metabolic processes of canola. Generally, potassium treatments reduced, to some extent, the harmful effect of water stress on the growth, yield and yield components, also led to regulate plant metabolism and canola performance under water stress condition. The results of this study showed that the application of potassium at 45 kg K_2O/ha with spray by 2% of K_2O under water stress (I_3) improved irrigation water productivity (IWP) and gave the lowest reduction in seed yield (RYD %) under moderate stress (I_2).

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