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Amelioration of water stress by potassium fertilizer in two oilseed species

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Abstract

The effects of potassium fertilizer (K_2SO_4) levels K_0, (0), K_1,(150) and K_2,(250 kg/ha) in two species of *Brassica napus* (Hyola 401 Hybrid) and *Brassica juncea* (landrace cultivar), under three irrigation regimes, control (irrigation after 50%,), moderate stress, (irrigation after 70%), and severe stress (irrigation after 90% soil water depletion) were studied in a factorial experiment laid out in a randomized complete block design with three replications. Grain yield and physiological indices, including relative water content (RWC), stomatal conductance (g), chlorophyll content (SPAD values); leaf temperature (T_L), and the difference between canopy temperature and air temperature (T_c-T_a) were measured at two stages (50% flowering and 100% siliques formation. Both species maintained, higher RWC, SPAD values and g, in non stress condition, but decreasing soil water supply caused a lower RWC, SPAD values, g, Δt and increased T_L. Potassium application also improved above mentioned physiological traits. Grain yield was positively associated with RWC, g and SPAD values but showed a negative association with T_L and Δt in both stages. Results showed that with increasing stress severity grain yield reduced significantly, but potassium application conferred great increase on rapeseed yield. Overall, grain yield showed significant association with RWC, g, SPAD values, Δt and T_L under this experiment conditions. It is concluded that potassium application, could ameliorate negative effects of water stress on grain yield and physiological properties and consequently improved them. For selecting drought tolerant cultivars, due to easier measurement of g, SPAD values and T_L, they could be recommended for screening large numbers of rapeseed cultivars in a short time at critical stages of crop growth.

Keywords: Grain yield; Leaf stomatal conductance; Rapeseed; Relative Water Content; Chlorophyll content; Water Stress.

Introduction

Canola (*Brassica napus* L.) contains about 40 - 44 % oil and is one of the major oilseed crops that grown profitably in rotation with wheat (Carmody, 2001). Because of high water use efficiency, drought tolerance (Albarrak, 2006) and also moderately tolerance to saline soil conditions (Nielson, 1997), it has a special position for production in arid regions.

According to Bray et al. (2000) the relative decreases in maximum crop potential yield (*i.e.*, yields under ideal conditions) associated with abiotic stress vary between 54-82 %. Among the environmental stresses, drought is one of the most severe stresses for plant growth and productivity. Also it is estimated that around 60 % of cultivated soils have growth-limiting problems associated with mineral-nutrient deficiencies and toxicities (Cakmak, 2002). 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).

Kumar and Singh (1998) and Singh et al. (1985) reported close associations between osmotic adjustment and both stomatal conductance and canopy temperature in some Brassica species. Kumar and Singh (1987) showed that a cultivar of *B. carinata* produced twice as the yield of a cultivar of *B. napus* under drought conditions and this was associated with a greater degree of osmoregulation in *B. carinata*. Pasban-Eslam et al., (2000) have revealed that stomatal conductance (g), water potential (Ψ_W), relative water content (RWC), crop temperature stability (CTS), of leaves of all tested genotypes decreased significantly due to water stress, But genotypes with the highest osmotic adjustment ability under stress, appeared to have the least decrease in g, Ψ_W, RWC and CTS. Other researches also reported close associations between that osmotic adjustment and canopy temperature on wheat (Morgan et al., 1986) and sorghum (Eastern et al., 1990). Mustard produces greater grain yields than canola under water deficit and this is mainly due to its greater dry matter production (Wright et al., 1995). Under such conditions mustard leaves have greater leaf turgor pressures than those of canola and leaf turgor is positively associated with leaf area duration and crop growth rate (Wright et al., 1996). Gunasekara et al., (2006) observed that the mean biological yield is decreased by 17.9 and 32.1 % and the mean seed yield is decreased by 18.5 and 38.7 % in moderate and high water stresses during reproductive growth compared to the control, respectively. Seed yield of *Brassica napus*, *B. juncea* and *B.rapa* was decreased due to drought stress (Jenson, 1996).

Potassium plays a vital role in: photosynthesis, translocation of photosynthates, protein synthesis, control of ionic balance, regulation of plant stomata and water use, activation of plant enzymes and, many other processes (Marschner, 1995; Reddya et al., 2004). Potassium is not only an essential macronutrient for plant growth and development, but also is a primary osmoticum in maintaining low water potential of plant tissues. Therefore, for plants growing in drought conditions, accumulating abundant K^+ in their tissues may play an important role in water uptake along a soil–plant gradient. In general, K^+ is accumulated in response to soil water deficits, while Na^+ is accumulated under saline conditions (Glenn et al., 1996). The accumulation and release of potassium by stomatal guard cells lead to changes in their turgor, resulting in stomatal opening and closing (Fischer and Hsiao, 1968). In water stressed plants, increased abscisic acid (ABA) levels are known to stimulate the release of potassium from guard cells, giving rise to stomatal closure (Assmann and Shimazaki, 1999). Numerous studies have shown that the application of K fertilizer mitigates the adverse effects of drought on plant growth (Andersen et al., 1992; Sangakkara et al., 2001). Potassium increases the plant's drought resistance through its functions in stomatal regulation, osmoregrulation, energy status, charge balance, protein synthesis, and homeostasis (Marschner, 1995). In plants coping with drought stress, the accumulation of K^+ may be more important than the production of organic solutes during the initial adjustment phase, because osmotic adjustment through ion uptake like K^+ is more energy efficient (Hsiao, 1973). Fusheing (2006) has revealed that lower water loss of plants well supplied with K^+ is due to a reduction in transpiration which not only depends on the osmotic potential of mesophyll cells but also is controlled to a large extent by opening and closing of stomata.

The objective of this study was to test effectiveness of potassium application in alleviation of drought stress adverse effects. Understanding the physiological and morphological responses under different amounts of water and nutrients is imperative for efficient management of agronomical inputs (irrigation and nutrient). It also can be used as screening basics for drought tolerance in breeding programs.

Materials and Methods

A field experiment was conducted in 2007-2008 at Zahak Agricultural and Natural Resources Research Center of Sistan and Baluchestan Province (31°54′N; 61°41′E, and 483 m above sea level). Long-term (>75 years) average annual rainfall is approximately 53 mm and evaporation is 4000-4500 mm/year. This site is recognized as the main sites for environmental stress studies in the south and southeast of Iran. The experimental field was under wheat cultivation in the previous season. The climatic data of the region are representing in (Table 1). The soil texture of the experimental field was sandy loam. Eexperimental design was a factorial arrangement based on randomized complete block with three replications. Three irrigation regimes including: control (irrigation after 50 %), moderate stress (irrigation after 70%), and severe stress (irrigation after 90% soil water depletion), two Brassica species (Hyola 401 Hybrid of canola and landrace cultivar of mustard) and three fertilizer K_2SO_4 levels ($K_{0,}$ (0), $K_{1,}$(150) and $K_{2,}$(250 kg/ha) comprised the experimental factors. Seeds of canola (*Brassica napus L.*) and mustard (*Brassica juncea L.*) were sown on 27 October using Winterashtiger Seeder Plotmen. Each plot consists of 12 rows of 4 m length, with distance of 20 cm between rows. Irrigation regimes time were determined by using from soil water curve with application digital hygrometer equipment of Time-Domain Reflectometry (TDR, Model Trim, FM_3, and Germany). A ratio of 380 and 150 kg/ha urea and super-phosphate, were applied respectively, (according to results of soil analysis). All plots received one-third of urea and all super-phosphate at sowing. Other two-third of urea was applied at the start of stem elongation, and before flowering, respectively. Potassium fertilizer in the form of sulphate dipotash was applied as broadcast and in front of the seeder at sowing. Measurements of physiological traits were made at a fix time of day between 11.00 to 13.00 h at 50% flowering and 100% siliques formation stages. The youngest fully-expanded leaf (third from the apex), intact and full sunlit leaves per plot was used for various measurements.

For RWC determination leaf disks taken from three to four leaves of similar physiological maturity and weighted (FW), the samples were immediately hydrated to full turgidity for 4h, under normal room light and temperature, and then turgid leaf disks weight were measured (TW). Samples in oven dried at 80°C for 24 h and weighted (DW). RWC was calculated according following formula:

$$RWC(\%) = \left[\frac{(FW - DW)}{(TW - DW)} \right] \times 100 \qquad (1)$$

Where, FW is fresh weight, DW dry weight and TW turgid weight (Ferrat and Loval, 1999). Leaf stomatal conductance (Autoporometer, AP4, Delta-T Devices Ltd, Cambridge, UK), and SPAD values or leaf chlorophyll content (SPAD- 502, Minolta Co Ltd, Osaka, Japan), were measured as an average of ten leaf (Pasban-Eslam et al., 2000), also canopy temperature (Tc), was measured by a portable infrared thermometer (USA) and air temperature (Ta), was measured by a Hydrargyric thermometer (Azizi et al., 2000). In each plot, plants of four central rows were harvested to determine seed yield. Data were analyzed by using MSTAT-C statistical package (MSTAT-C, Version 1.41, Crop and Sciences Departmen, Michigan State University, USA). Duncan Multiple Range Test was used to comparing means (P≤0.05).

Table 1. Meteorological data during growth period of canola (2007-2008).

year and month 2007-2008	Rainfall (mm)	Min temp (°C)	Average temp (°C)	Max temp (°C)	F.D (day)	RH (%)
October	0	14.1	21.6	29.1	0	20
November	0	9.2	18.02	27.1	0	30
December	4.3	5.4	12.8	20.2	1	49
July	13.4	-4.2	1.7	7.6	17	60
February	0.3	-0.7	6.2	13.1	19	42
March	0	8.3	17.2	26.1	0	32
April	0	14.95	24.26	33.56	0	33
May	0	22.79	29.55	36.31	0	23

Table 2. Some chemical and physical traits of experimental soil*.

Depth (Cm)	P(Ava) (ppm)	K(Ava) (ppm)	O.M (%)	EC dS/m	pH	FC (%)	PWP (%)
0-30	9.2	125	0.44	1.04	7.9	13.1	5.3
0-60	6	115	0.35	0.95	8	.-	.-

*Soil analysis was done at the laboratories of Soil and Water Research Department, Karaj.

Results and Discussion

Analysis of variance showed that the effects of irrigation regimes, species and potassium application on measured traits was significant at both 50% flowering and 100% siliques formation stages. Interaction effects of species × irrigation regimes on grain yield, stomatal conductance, SPAD values; Leaf temperature T_l, Δt and interaction effects of irrigation regimes × potassium application on grain yield, stomatal conductance and SPAD values were significant (Table 3). Water stress not only reduced plant growth and grain yield (G.Y), but also affected plant physiological properties, such as RWC, g, SPAD values, T_l and the difference between canopy temperature and air temperature, Δt, in both species, irrespective of sampling stage (Table 4).

Grain yield

Results showed that irrigation regimes, species and potassium fertilizer significantly affected on grain yield (Table 3). *Brassica napus* (Hyola 401 cultivar), produced 17 % grain yield more than *Brassica juncea* (landrace cultivar), (Table 4). Gunasekera et al., (2006) reported that, mustard produced more dry matter than canola, but it was not lead to higher grain yield because of its lower efficiency in converting dry matter into grain yield (lower harvest index). But interaction effects between species and irrigation regime showed that under severe stress yield decreases in *Brassica juncea* than *Brassica napus* was least (Table 5) that can be associated to physiological characteristics of it. With increasing stress severity, grain yield reduced significantly. Grain yield of severe water stress treatment was 27 % lower than the control. Gunasekara et al., (2006) and Jenson (1996) also reported reduction of *Brassica napus*, and *Brassica juncea* grain yield due to drought stress. Application of 250 kg/ha K_2SO_4 produced the maximum seed yield (2975 kg/ha), which was 21 % more than the no potassium application. Jianwei1 et al. (2007), showed that rapeseed grain yield were significantly affected by potassium application, they observed significant increase about 17.5 and 31.7 % by using 150 and 300 kg/ha K_2O in compare to control, respectively.

Interaction effects of irrigation regime and potassium was significant on grian yield (Table 3). Result showed that the efficiency of potassium fertilizer in water stress is much more than well watered treatment. For example, differences between grain yield in highest level and no potassium application in sever water stress was 727 kg/ha more than the control (Fig 1a). Numerous studies have shown that the application of potassium fertilizer mitigates the adverse effects of drought on plant growth in barley (Andersen et al., 1992), sunflower (Lindhauer, 1985), faba beans (Abdelvahab and Abdalla, 1995), sugar cane (Sudama et al., 1998) and rice (Tiwari et al., 1998), that confirmed result of this study. 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).

Relative water content

Relative water content (RWC) is the appropriate trait of plant water status in terms of the physiological consequence of cellular water deficit. The results showed that RWC decreased by advancement of plant age in both species. Under normal condition and early growth stages *Brassica napus* (Hyola 401), showed a higher RWC, but under water deficit its reduction was faster than the *Brassica juncea* (landrace cultivar). RWC decreased with increasing water stress and had 22 and 19 % at two sampling stages, respectively. The highest RWC were found in control treatment (Table 4). Water stress is generally characterized by decrease in RWC and water potential, resulting in wilting, stomatal closure and reduced growth (Lawlor and Cornic, 2002). Similar results were reported by

Unyayar et al., 2004; Jing and Huang, 2002, under drought stress that decreased the leaves RWC.

Potassium application significantly caused RWC incresent in both species irrespective of stress levels (Table 4). Fusheing, (2006) revealed that Potassium applied from level K_1 (0.125), to K_3 (1 g kg^{-1} soil) increased RWC from 92 to 94 % in tobacco leaf. Such increase with potassium application may be ascribed to improve cell turgor through osmotic adjustment. Pinhero et al., (2001) reported that synthesis and accumulation of osmolytes varies between and within plant species and osmolytes play a major role in osmotic adjustment and also protect the cells by scavenging reactive oxygen species (ROS).

Plants absorb the bulk of K^+ from soil to maintain normal growth and development (Maathuis and Sanders, 1996; Elumalai et al., 2002). Interaction effects of irrigation regime and potassium on RWC was significant at 50% flowering stage ($P \leq 0.05$) (Table 3). Potassium application imposed a positive effect on leaf RWC in both control and drought conditions, but its influence in water stress was outstanding (Table 4). A study by Ma et al., (2004) showed that K^+ accumulation in the expanding leaves in genotypes of three, *Brassica napus* accounted for about 25% of drought-induced changes in osmotic adjustment.

Table 3. Mean squares of analysis variance for measured traits in two Brassica species under irrigation regimes and potassium fertilizer.

S.O.V	Df	Grain Yield	RWC	g	T_L	Δt
				50% flowering stage		
species	1	3570759.185**	46.296*	0.004*	0.074$^{n.s}$	0.145$^{n.s}$
Irrigation Regime	2	3164978.963**	1566.056**	0.556**	60.139**	59.780**
S×I	2	972658.963**	17.130^{ns}	0.008**	11.361**	11.370**
Potasium	2	1756132.907**	268.722**	0.038**	26.023**	26.927**
S×P	2	24337.241$^{n.s}$	3.907$^{n.s}$	0.001$^{n.s}$	0.254$^{n.s}$	0.316$^{n.s}$
I×P	4	77971.491*	2.111$^{n.s}$	0.017*	0.358$^{n.s}$	0.359$^{n.s}$
S×P×I	4	12210.269$^{n.s}$	2.241$^{n.s}$	0.001$^{n.s}$	0.448$^{n.s}$	0.382$^{n.s}$
Error	34	30566.574	11.296	0.001	0.621	0.651
				100% siliques formation stage		
species	1	3570759.185**	32.667*	0.001$^{n.s}$	13.400**	13.350**
Irrigation Regime	2	3164978.963**	984.222**	0.085**	97.659**	97.338**
S×I	2	972658.963**	40.222**	0.001$^{n.s}$	0.785$^{n.s}$	0.774$^{n.s}$
Potasium	2	1756132.907**	264.500**	0.006**	14.414**	13.974**
S×P	2	24337.241$^{n.s}$	1.056$^{n.s}$	0.000$^{n.s}$	0.056$^{n.s}$	0.059$^{n.s}$
I×P	4	77971.491*	.0556$^{n.s}$	0.000$^{n.s}$	0.405$^{n.s}$	0.405$^{n.s}$
S×P×I	4	12210.269$^{n.s}$	1.444$^{n.s}$	0.000$^{n.s}$	0.221$^{n.s}$	0.194$^{n.s}$
Error	34	30566.574	4.426	0	0.785	0.793

*, ** Significant at the 0.05 and 0.01 probability levels, respectively; n. s.: not significant ($P \leq 0.05$)
S= Species; I=Irrigation; P= Potassium

Table 4. Grain yield and measured traits in two Brassica species under irrigation regimes and potassium fertilizer at 50% flowering and 100 % siliques formation stages.

Treatment	RWC (%)	g Cm s^{-1}	T_L (°C)	Δt (°C)	SPAD	G.Y Kg ha^{-1}
			50% flowering stage			
Species						
B. napus (Hyola401)	77.26 a	0.27 a	26 a	-4.04 a	26 a	2924 a
B. juncea (Landres)	75.41 b	0.25 b	26 a	-4.14 a	21 b	2409 b
Irrigation Regime						
water depletion 50 %	86017 a	0.46 a	24 c	-6.09 c	26 a	3078 a
water depletion 70 %	75.22 b	0.18 b	26 b	-3.66 b	24 b	2682 b
water depletion 90 %	67.61 c	0.14 c	28 a	-2.51 a	20 c	2240 c
Potassium levels						
No application	72.56 c	0.21 c	27 a	-2.8 a	20 c	2351 c
150 Kg ha^{-1}	75.17 b	0.26 b	26 b	-4.23 b	24 b	2673 b
250 Kg ha^{-1}	80.28 a	0.30 a	25 c	-5.23 c	27 a	2975 a
			100% siliques formation stage			
Species						
B. napus (Hyola401)	69.89 b	0.17 a	32 a	-3.72 a	19 a	2924 a
B. juncea (Landres)	71.44 a	0.18 a	31 b	-4.71 a	16 b	2409 b
Irrigation Regime						
water depletion %50	78.22 a	0.26 a	29 c	-6.69 c	19 a	3078 a
water depletion %70	70.33 b	0.15 b	32 b	-3.88 b	17 b	2682 b
water depletion %90	63.44 c	0.13 c	31 a	-2.08 a	16 c	2240 c
Potassium levels						
No application	66.33 c	0.16 c	33 a	-3.3 a	14 c	2351 c
150 Kg ha^{-1}	70.67 b	0.18 b	32 b	-4.28 b	18 b	2673 b
250 Kg ha^{-1}	74.5 a	0.2 c	31 c	-5.06 c	20 a	2975 a

(g); Stomatal conductance; RWC; Relative Water Content; SPAD values; T_L; Leaf temperature; Δt ; (T_{canopy}-T_{air}); GY; Grain Yield.

Table 5. Interaction effects between species and irrigation regimes on grain yield and measured traits at 50% flowering stages.

Treatment	RWC (%)	g Cm s^{-1}	T_L (°c)	Δt (°c)	SPAD	G.Y Kg ha^{-1}
Species * Irrigation						
I 1 * 1 S	88 a	0.49 a	23 d	- 6.84 d	29 a	3228 a
I 2 * 1 S	75 a	0.19 c	26 b	-3.58 b	26 b	3111 b
I 3 * 1 S	68 a	0.13 d	28 a	-1.69 a	22 c	2232 d
I 1 * 2 S	84 a	0.43 b	25 c	-5.33 c	23 c	2728 c
I 2 * 2 S	75 a	0.18 c	26 b	-3.73 b	22 c	2253 d
I 3 * 2 S	67 a	0.14 d	27 b	-3.36 b	18 d	2247 d

Means followed by the same letters in each column are not significantly different at the 5%level, according to Duncan's Multiple Range Test.

Leaf Stomatal Conductance

Leaf stomatal conductance (g) consistently decreased under water stress in both species and sampling stages (Table 3). *Brassica napus* (Hyola 401 cultivar), showed higher stomatal conductance than *Brassica juncea* (landrace cultivar), but under sever stress condition, *Brassica juncea* (landrace cultivar) showed significant superiority (Table 4 and 5). It seems that bright green leaves in *Brassica juncea* (landrace cultivar), reflected higher radiation and inhibited from temperature rising in canopy, and consequently had cooler leaves. Similar findings have been reported by Kumar et al., (1987) and Singh et al., (1985) who reported close associations between osmotic adjustment and both stomatal conductance and canopy temperature in many Brassica species.

Kumar et al., (1998) reported that high osmotic adjustment genotypes maintained greater T_c-T_a and g. Osmotic adjustment could play an important role in maintaining cell turgor potential and turgor-related processes, such as the stomata opening, photosynthesis, shoot growth and roots extension in deeper soil layers. Under stress conditions mustard leaves have greater leaf turgor pressures than canola and leaf turgor is positively associated with leaf area duration and crop growth rate that reported by Wright et al., (1996). By increasing water stress in severe irrigation regime, g decreased very much (Table 4). In response to potassium application a Significant increases in g was observed under stress and non stress conditions that is due to improved turgor and stomatal opening (Table 3 and Figure 1b). Accumulation and release of potassium by stomatal guard cells lead to changes in their turgor, resulting in stomatal opening and closing (Fischer and Hsiao, 1968). Numerous studies have shown that the application of K fertilizer mitigates the adverse effects of drought on plant growth (Andersen et al., 1992 and Sangakkara et al., 2001). When plants are grown under low K supply, drought-stress induced ROS production which can be additionally enhanced, at least due to K^+ deficiency-induced disturbances in stomatal opening, water relations, and photosynthesis (Marschner, 1995). The more K^+ requirement of plants under different abiotic stresses appears to be related to the inhibitory role of K^+ against reactive oxygen species (ROS), production during photosynthesis and NADPH oxidase (Cakmak, 2005).

SPAD Values

SPAD is a non-destructive assessment of leaf chlorophyll (Duru, 2002; Tsialtas and Maslaris, 2007). The results showed that *Brassica napus* (Hyola 401cultivar), had higher SPAD values (16 %), than *Brassica juncea* (Landrace cultivar). Interaction between species and irrigation regime was significant on Leaf SPAD values (Table 5). Differences between rapeseed species were attributed to genotypic variation. SPAD values declined significantly under water stress (Table 4). Leaf SPAD values decreased, especially in severe stress treatment compared with control. It seems that, with advancement of plant age, the shadow of siliques on leaves and severe water stress, causes acceleration of leaf senescence and reduction of leaf chlorophyll content. Hassibi et al., (2007) also found that under cold stress condition SPAD value reduced as compared with normal condition. Potassium application affected leaf SPAD values in both cultivars irrespective of sampling stages (Table 3). Under water stress conditions, potassium application increased SPAD values (Figure 1C). Under proper water supply, potassium application in 250 kg/ha level increased leaf green area (32 %), over the zero potassium treatment. It seems that, higher potassium rates could maintain green foliage for a longer period during irrigation and non irrigation and thus yield losses could be restricted. Increase in leaf SPAD values by potassium enriched plant is confirmed with the knowledge of nutrients that increases activity of nitrate reductase enzyme. Dobermann, (2004) reported that potassium application promoted the activity of nitrate reductase enzyme and thus nitrate assimilation by the plant, thereby increasing leaf chlorophyll content. Tsialtas and Maslaris, (2008) reported that SPAD reading 38 was optimal for maximum yield, also it related with petiole NO_3-N concentration and α-amino N in roots.

Leaf Temperature (T_L), Δt (T_c-T_a)

Measurement of canopy temperature has precedence for assessed plant water status (Kluitenberg and Biggar, 1992). *Brassica juncea* (Landrace cultivar), was characterized by the smallest increase in T_L and more increase in Δt compared with *Brassica napus* (Hola401 cultivar), under severe stress, But under non water stress conditions Brassica napus (Hola401 cultivar), was outstanding (Table 5). Water stress increased T_L and decreased the difference between canopy and air temperature (Table 3). Similar results reported by Pasban-Eslam et al., (2000) and kumar and Singh (1998) that approved these results. Application of potassium decreased the T_L whereas, (T_c-T_a) increased in both species and sampling stages, irrespective to stress levels (Table 4).

In severe water stress Δt was less than the other two treatments, but potassium application increased Δt. These results indicated that, at such conditions the plant has balanced its heat charge and reduced canopy temperature. Azizi et al., (2000) also reported that increase consumption of potassium had moderated effect on canopy temperature and Δt.

The correlation coefficients between some morphological and physiological properties under water stress at 50% flowering stage are presented in Table 6. In general, grain yield showed a positive significant association with RWC, g, and SPAD values, and a negative significant correlation with T_L and Δt under watering regimes. Among different indices of plant moisture stress, RWC and SPAD values showed higher correlation ($r = 0.751^{**}$, $r = 0.774^{**}$) with grain yield. Increase of RWC, lead to increasing g and hence continue plant stay green and increase the difference between canopy and air temperature Δt, in two growth stages. Since, RWC, g, SPAD values, and Δt, were decreased and T_L were increased significantly by water stress in both sampling stages (Table 4), it seems that these traits could appeared stress effects occurred from mid-flowering stage to end of podding on the rapeseed crop.

Brassica juncea (Landrace cultivar), had lower RWC, g and Δt in non stress conditions but under water-stress conditions represent better performance than *Brassica napus* (Hyola 401 cultivar). However, under both water stress and normal conditions Hyola 401 showed higher yield. Relationship between RWC and k_l revealed that cultivars with higher RWC rather maintained stomata opening and higher stomatal conductance consequently increasing photosynthetic activity in plant that this may have contributed to the maintenance of higher k_l. Kumar and Singh (1998) and Pasban-Eslam et al., (2000) have also reported significant correlation of grain yield with g, RWC, T_L and Δt.

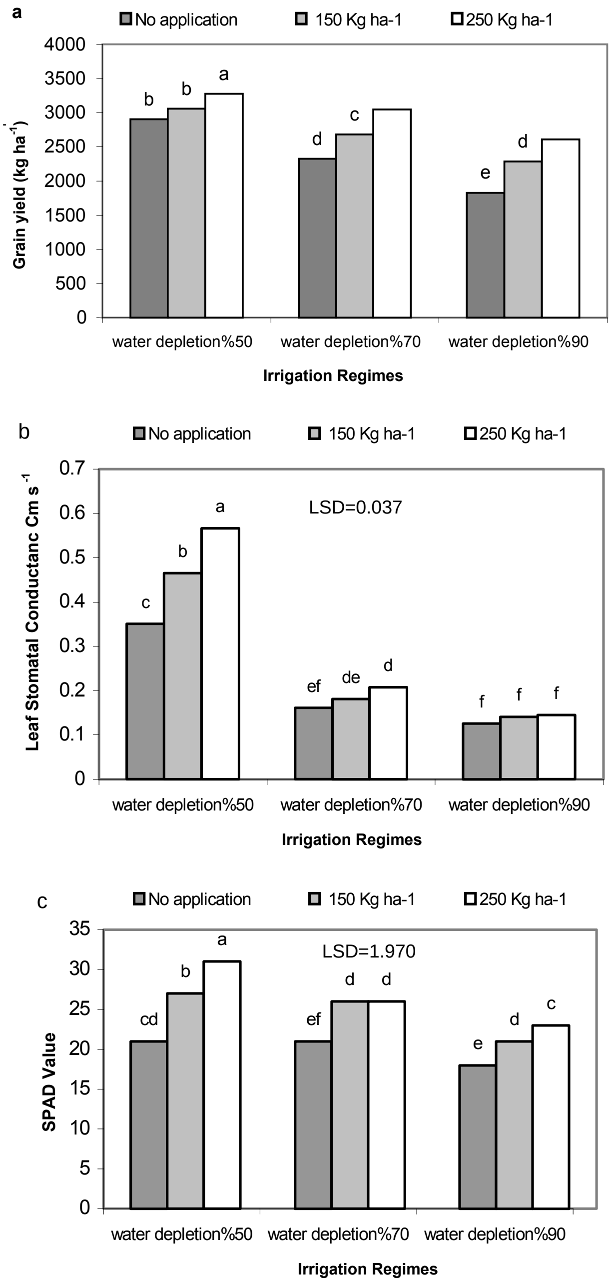

Figure 1. Interaction effect of irrigation regimes and potassium fertilizer application on grain yield (a) Stomatal conductance (b), SPAD values (c) at 50% flowering stage.

Table 6. Correlation coefficients among some morphological and physiological parameters (average of two rapeseed species) under irrigation regimes and potassium fertilizer application at 50% flowering stage*

Treatment	g	RWC	SPAD	TL	Δt	G.Y
g	1					
RWC	0.86 **	1				
SPAD	0.628 **	0.687 **	1			
TL	- 0.822 **	-0.781 **	-0.609 **	1		
Δt	- 0.815 **	-0.778 **	-0.604 **	0.999 **	1	
G.Y	0.635 **	0.751 **	0.774 **	-0.701 **	-0.696 **	1

g, Stomatal conductance; RWC, relative water content; SPAD values; T_L, Leaf temperature; Δt,(T_{canopy}-T_{air}); and G.Y, Grain yield;

*, ** Significant at 0.05 and 0.01 probability levels, respectively

* Note, Correlation coefficient among the traits measured on rapeseed species in 50% flowering and 100 % siliques formation stages not was different, therefore data relate to 100% siliques formation stage was not showed in text.

Conclusion

This study suggesting that application of potassium under water stress affects on grain yield and physiological properties of rapeseed. Drought adversely affected yield and physiological properties in contrast with increasing potassium consumption, negative effect of water stress on grain yield and physiological properties modified and consequently improved them. Although, increasing the supply of nutrients to the growth medium under water deficit can alleviate the adverse effects of stress on plant growth, it is generally accepted that such increases will not improve plant growth when the nutrient is already present in the soil in sufficient amounts and the drought is severe. Result showed that stability and less yield decrease under severe stress condition in *Brassica juncea* species is related to physiological traits such as higher stomatal conductance and less Leaf temperature at critical stages of crop growth that this in dry regions is important, although potentioal yield it is low. Furthermore, g, RWC, SPAD, T_L and Δt showed significant correlation with grain yield in both sampling stages. Screening the Brassica genotypes by these indices may promote to higher yields under water stress conditions. Since, g, SPAD values and T_L are easy to measure; they could be suitable plant characters for screening the large numbers of genotypes, in a short time at critical stages of crop growth, with the aim of selecting drought tolerant cultivars. The results also could be interesting and useful for farmers for irrigation scheduling with applying a precision technique for water management.

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