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ALTERNATE FURROW IRRIGATION AND POTASSIUM FERTILIZER ON SEED YIELD, WATER USE EFFICIENCY AND FATTY ACIDS OF RAPESEED

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ABSTRACT

In order to study the effect of restricted irrigation systems and different potassium fertilizer on water use efficiency and yield of rapeseed (*Brassica napus* L.), an experiment was conducted in an arid area in Khuzestan, Iran in 2013. The main plots consisted of three irrigation methods: FI (full irrigation), alternate furrow irrigation (AFI) and fixed furrow irrigation (FFI). Each subplot received three rates of K fertiliser application: 0, 150 or 300 kg ha^{-1}. The results showed that the plots receiving the full irrigation resulted in significantly higher grain yields, 1000-kernel weight and grain number per pod than both alternate treatments. However, the highest WUE were obtained in alternate furrow irrigation and 300 kg K ha^{-1} and the lowest one was found in the FI treatment and 0 kg K ha^{-1}. Potassium application increased RWC in alternate furrow irrigation and fixed furrow irrigation than FI treatment. Maximum oil content was observed in those treatments where full irrigation was applied while minimum oil content was produced in FFI irrigated treatments. Potassium fertilizer also increased grain oil by 15 % than control. Deficit irrigation reduced oleic acid and erucic acid. However, oleic acid and linoleic acid increased with increasing of potassium.

Keywords: rapeseed, erucic acid, irrigation methods, linoleic acid, oil percent, oleic acid.

INTRODUCTION

Rape seed (*Brassica napus* L.) is an important oil crop, ranking third only to soybean and palm oil in global production (Muhammad *et al*., 2007). World area under rape seed crop was 33.78 million hectare with a grain production of 62.69 million tones and overall yield of 1856 kg per hectare during 2010-2011. In Iran rapeseed was grown on 165 thousand hectares with annual production of 345 thousand tones and average yield of 2090 kg per hectare (FAO, 2011).

Innovations for saving water in irrigated agriculture and thereby improving water use efficiency are of paramount importance in water-scarce regions. Conventional deficit irrigation (DI) is one of approach that can reduce water use without causing significant yield reduction (Kirda *et al*., 2005). Alternative furrow irrigation is a further development of DI. Alternative furrow irrigation is commonly applied as part of a deficit irrigation program because it does not require the application of more than 50-70% of the water used in a fully irrigated program (Marshal *et al*., 2008). Alternate furrow irrigation was proposed as a method to increase water use efficiency and decrease chemical leaching compared with every-furrow irrigation and with small yield losses for different crops compared with fixed furrow irrigation system (Shaheed *et al.*, 2008; Abedi and Pakniyat 2010). It seems that placing fertilizer in the non-irrigated furrow of an alternate furrow irrigation system or placing fertilizer in the row with either alternate or every furrow irrigation has the potential to decrease fertilizer leaching and nutrient elements poisoning without reducing crop productivity (Kassam *et al*., 2007). In maize alternative furrow irrigation reduced water consumption by 35% with a total biomass reduction of 6-11% as compared with fully watered plants (Bahrani *et al.*, 2012).

Iran faces a serious problem of water shortage for crop production. The water resources are becoming limiting and it has been estimated that water for irrigation purposes may be reduced up to 50% (Cakmak, 2005). Therefore, the objective of this study was to examine the effects of alternate furrow irrigation strategies and the role of potassium application on grain yield and water use efficiency of the rape seed crop under the Mediterranean climatic conditions in Southern Iran.

MATERIALS AND METHODS

A field experiment with the hybrid rape seed variety Hayola 401was conducted in an arid area in west of Iran, at the Islamic Azad University of Ramhormoz, Khuzestan, Iran (31°16´ N, 49°36´ E and 150.5 m above the sea level) during 2013-2014. Some metrological data in the experimental location was shown in Table-1. Split-plot experimental design was used, based on a complete randomised block design with three replications. The main plots consisted of three irrigation methods: FI (full irrigation) was the conventional way where every furrow was irrigated during each watering cycle with 100% of the water typically applied to the crop in Khuzestan according with crop requirements, AFI (alternate furrow irrigation) and FFI (fixed furrow irrigation). Each subplot received three rates of K (in the form of potassium sulphate) fertiliser application: 0, 150 or 300 kg/ha. Irrigation treatments were applied 30 days after planting. N and P fertilizer were applied according to recommendations of soil testing in forms of urea and superphosphates, respectively. Plots were sown on 3 November 2013 with a four rows planting machine, and were 8 m long and 4 m wide, with 8 rows 0.50 m apart. Plots were plowed and disked after winter wheat harvest in June. During the growth period, all plots were weeded manually. No serious

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incidence of insect or disease was observed and no pesticide or fungicide was applied. Drip irrigation system was used in the study. The soil water content measurements were done one day before irrigation until harvest in three replications for all treatments by gravimetric sampling in 0-0.30 m.

Water use efficiency (WUE): WUE was computed as the ratio of canola grain yield to seasonal water use.

In order to determine total dry matter above the ground level, five plants within 0.5-0.6 m of a row section in each plot were cut at the ground level at maturity stage. Plant samples were dried at 65°C until constant weight was achieved. Rape seed grain yields were determined by hand harvesting the 6 m sections of five center rows in each plot on April 21, 2014. Then, grain yield values were adjusted to 15.5% moisture content. In addition, 1000-kernel weight and harvest index values were also evaluated.

Relative water content: Leaf tissue was used for relative water content (RWC) determination, as follows: A composite four leaves of similar physiological maturity sample of leaf discs is taken and the fresh weight is determined, followed by flotation on water for up to 4 h under normal room light and temperature. The turgid weight is then recorded, and the leaf tissue is subsequently oven-dried to a constant weight at about 85 °C. RWC calculated according to Aliabadi *et al*., (2008).

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

Where, FW is fresh weight, DW dry weight and TW turgid weight.

Oil seed content: The oil concentration of a sample of whole seeds from each plot was determined by Near-Infrared Reflectance Spectroscopy as described by Bhatty (1991).

Fatty acids: Fatty acids were esterified as methyl esters (AOAC 1990) and analyzed by Agilent 6890 N GC equipped with a DB-23 capillary column (60 m x 0.25 μm) and a FID (Flame Ionization Detector) detector. The carrier gas was helium, at a flow rate of 1.2 mL/min. Both injector and detector temperatures were kept at 250ºC. Column temperature was initially kept at 165ºC for 15 min and then increased to 200ºC at a rate of 5ºC/min, where it was maintained for 15 min. Samples of 1 μl were injected by auto-sampler, in the split mode (1:50). The fatty acid identification was performed by retention time comparisons with corresponding fatty acid methyl ester standards. The standards were purchased from Sigma-Aldrich Ltd

Statistical analysis: Data were analysed by ANOVA using the general linear model (GLM) procedure provided by SAS (2004). When significant differences were found (p= 0.05), the Duncan's multiple range test (DMRT) was carried out.

Table-1. Metrological statistic in the experimental location during the experiment.

Months of experiment	**Average minimum temperature ºC**	**Average maximum temperature ºC**	**Average minimum relative humidity** (%)	**Average maximum relative humidity** (%)	**Evaporation from Class A pan** (mm)	**Rainfall** (mm)
November	15.0	29.7	16	42	70.9	14.0
December	9.8	24.1	22	53	67.8	10.0
January	10.1	20.5	48	77	64.6	44.2
February	12.2	22.6	38	72	54.3	30.0
March	15.5	29.0	25	56	113.4	12.6
April	20.2	33.4	20	52	136.1	36.1

RESULTS AND DISCUSSIONS

Yield and yield components: Variance analysis of the grain yield data indicated that irrigation treatments significantly affected the yields ($p < 0.05$). The plots receiving the full irrigation (FI) resulted in significantly higher grain yields than both irrigation treatments (Tables 2 and 3). Grain yields varied from 1478 to 1832 kg/ha among the treatments. The highest average grain yield was observed in FI treatment as 1832 kg/ha, and the lowest yields were found in fixed furrow irrigation treatment as 1478 t/ha, when irrigation was reduced by 50%. Alternate and fixed furrow irrigation treatments significantly ($p < 0.05$) resulted in lower grain yield (20 and 25 %, respectively), compared to FI treatment. Yield in fixed furrow irrigation treatment was 5% lower than alternate furrow irrigation treatment. Jianweil *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 K2O in compare to control, respectively.

The highest and lowest grains yield in consumption of 300 kg K/ha was 1760 kg/ha and in control 1150 kg/ha. Potassium fertilizer in comparison with control increased grains yield as rate 31 and 65%, respectively (Figure-1). Potassium fertilizer application in deficit irrigation treatments increased grain yield more than full irrigation treatment. In full irrigation treatment at the highest potassium fertilizer treatment grain yield increased 15%, however, at the same potassium level grain

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yield increase to 26% at alternate furrow irrigation treatment (Table-3). These results similar to those found by Fanaei *et al*., (2009) that with rising stress severely grain yield reduced, except K+ application awarded huge increase on rapeseed yield. It is clear that K+ Levels could improve negative effects of water stress on seed yield and physiological indicators and as a result improved them (Fanaei *et al*., 2009).

In the study, there was significant difference in 1000-kernel weight among different irrigation treatments. The highest 1000-kernel weight was observed in FI treatment as 3.36 g, and the lowest one was found in FFI treatment as 1.91 g. Deficit irrigation reduced 1000-kernel weight; however, there were not significant differences between AFI and FFI treatments. Deficit irrigation decreases the effective filling period of seed, but it does not affect the collection of dry material existing in the endosperm and the germ (Wasson *et al.*, 2002). Kamkar *et al*., (2011) observed a reduction in 1000 grain weight under drought stress conditions. Moreover, the reduction in the production and translocation of photosynthates to the developing seed might cause loss in grain weight.

Results showed that significant difference exist among different potassium fertilizer levels on 1000-kernel weight. The highest 1000-kernel weight was obtained with consumption rate of potassium 300 kg/ha and the lowest was in control. This indicates that 1000-kernel weight was increased with consumption of 300 kg/ha relative to control as 21% (Table-2). However, there were no significant difference between 150 and 300 kg K/ha.

Table-2. Mean values of the traits under three irrigation methods and potassium fertilizer.

Treatments	**1000-Kernel weight** (g)	**Grain yield Kg/ha**	**WUE ‡ Kg grain/m**	**Oil percent**	**Oleic acid**	**Linoleic acid**	**Erucic acid**
Irrigation							
FI	3.36a	1832 a	0.3 b	45.2 a	63.24a	20.24a	0.193 a
AFI*	2.95 a	1524 b	0.75a	39.8 b	65.31b	16.91b	0.327 b
FFI✧	1.91 b	1478 b	0.80a	38.6 b	66.42b	17.52b	0.426 b
Potassium fertilizer							
0	2.83 b	1150 b	0.45 c	36.6 b	59.11b	21.9b	0.320 a
150	3.17 a	1510 ab	0.86 b	41.9 a	61.52a	22.12a	0.304 b
300	3.30 a	1860 a	1.04 a	42.1 a	61.21a	22.19a	0.307 b

* Alternate furrow irrigation, ✧ Fixed furrow irrigation, ‡: Water use efficiency
Same letters in columns are not significantly different at $p \leq 0.05$.

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Table-3. Mean values of the traits as affected by irrigation and potassium fertilizer.

Treatments		1000-Kernel weight (g)	Grain yield Kg/ha	WUE ‡ Kg grain/m	Oil percent	Oleic acid	Linoleic acid	Erucic acid
Irrigation	**Potassium fertilizer**							
	0	3.09	1491	40.9	61.17	21.07	0.256	22
FI	150	3.26	1632	43.5	62.38	21.18	0.248	24
	300	3.33	1710	43.6	62.22	21.21	0.250	25
	0	2.89	1337	38.2	62.21	19.40	0.323	21
AFI*	150	3.06	1517	40.8	63.41	19.51	0.315	22
	300	3.12	1692	40.9	63.26	19.55	0.317	24
	0	2.37	1314	37.6	62.76	19.71	0.373	22
FFI✧	150	2.54	1494	40.2	63.97	19.82	0.365	23
	300	2.60	1669	40.3	63.81	19.85	0.366	25
LSD (0.05)		0.7	356	2.23	5.1	4.2	0.02	7.5
S.O.V								
	Irrigation (I)	*	*	*	*	**	**	*
	Potassium fertilizer (P)	*	*	*	*	*	*	*
	I × P	*	*	*	ns	ns	ns	ns
	CV (%)	5.59	19.45	21.22	18.71	18.71	18.71	17.36

* Alternate furrow irrigation, ✧ Fixed furrow irrigation, ‡: Water use efficiency.* , ** Significant at 0.05 and 0.01 probability levels, respectively. Same letters in columns are not significantly different at $p \leq 0.05$.

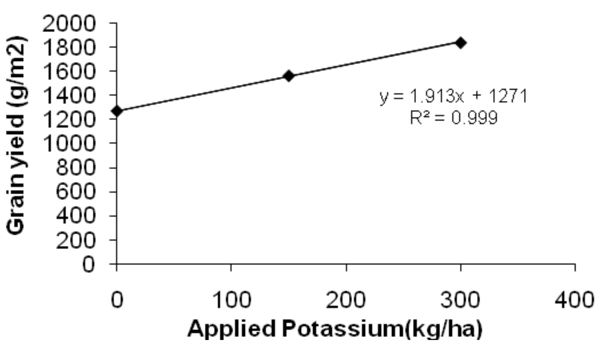

Figure-1. Mean grain yield response of canola to potassium fertilizer.

Water use efficiency: The highest water use efficiency (WUE) averaging0.8 kg/m^{3}was obtained in AFI treatment, followed by AFI with 0.75kg/m^{3}and the lowest one was found in the FI treatment as 0.3kg/m^3 (Table-2). Kang and Zhang (2004) reported that water use as percent of fully irrigated treatment is decreased and irrigation water use efficiency (IWUE) is increased essentially by alternate furrow irrigation as reported in a number of species, e.g. cotton, tomato, pear, grapevine and hot pepper. The highest water use efficiency averaging 1.04 kg/m^3 obtained in 300 kg K ha^{-1} and the lowest ones was found in the 0 kg K/ha treatment as 0.45kg/m^3 (Table-2 and 3). Potassium regulate stoma closure and prevent water wasting and regulating osmosis, increase water use efficiency and improved growth condition in corn (Wiebold and Scharf, 2006). While potassium consumption lead to accelerate canopy formation and cause to more available water use by plant and even plant early maturating (Cakmak, 2005). Soil nutrients like as potassium ions affect water transport in whole plant, maintain cell pressure and regulate the opening and closing of stomata (Wortmann *et al*., 2009; Parsons *et al*., 2007).

Relative water content (RWC): RWC was significantly lower in water-stressed plants than in plants grown under normal conditions. Application of K improved RWC under both moisture levels with the maximum effect figuring at K300.The highest K application increased RWC by 10% under normal conditions, and by 12% and 16% under FFI and AFI (Figure-2), respectively. Mengel and Kirkby (2001) observed that due to low K concentration, ROS production was induced during water deficit which caused disturbance in stomatal opening. Fusheng (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.

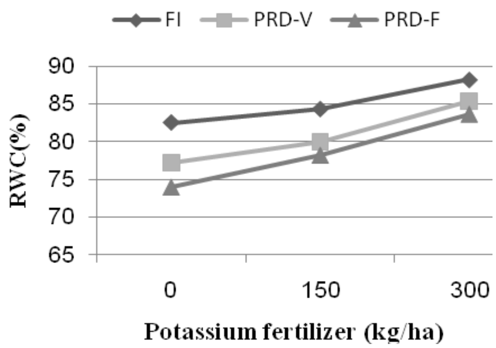

Figure-2. Relative water content (RWC) of leaf as afected by potassium fertilizer and irrigation methods.

Oil content: Both irrigation methods and potassium fertilizer had significant effect of grain oil percent (Tables 2 and 3). Irrigation methods had a strong significant ($P<0.05$) effect on oil content of rapeseed. The data revealed that maximum oil content of 45.2% was observed in those treatments where full irrigation was applied while minimum oil content (38.6%) was produced in FFI irrigated treatments. According to Bouchereau *et al*., (1996) decrease in oil concentration in rapeseed grain exposed to water deficit is justified by changes in availability of precursors to fulfill the grain, as reproductive organs and grains are built of resources either recently achieved or previously amassed in the vegetative part.

Potassium fertilizer also increased grain oil by 15 % than control. However, there were no significant difference between 150 and 300 kg K/ha.

Fatty acids: There were significant differences in irrigation methods in these traits (Table-2). The lowest oleic acid and erucic acid was observed in FI treatment as 63.24 and 0.193, and the highest one was found in FFI treatment as 66.42 % and 0.426 %. Deficit irrigation reduced oleic acid and erucic acid; however, there were not significant differences between AFI and FFI treatments. Inversely, the highest linoleic acid was found in FI treatment as 20.24% and the lowest one in FFI as 17.52%.

Mean comparison also showed oleic acid and linoleic acid increased with increasing of potassium, and at the rate of 150 kg/ha produced the highest contents. Application of potassium more than 150 kg/ha decreased these two traits. However, erucic acid decreased with increasing potassium application.

The results of correlation coefficients between traits showed that grain yield had a positive and significant correlation with oil yield and biological yield at 1% probability levels, oil yield also had positive correlation to oil percent. Negative correlation also was observed between number of pod per seed and 1000-kernel weight (Table-4).

Table-4. Simple correlation coefficients between traits.

Factor	1	2	3	4	5	6	7
1-Number of pod per plant							
2-Number of seeds per pod	-0.023						
3-1000-kernel weight	-0.05	-0.746**					
4-Biological Yield	0.477	0.078	0.172				
5-Grain yield	0.581	0.203	0.082	0.81**			
6- Oil Percent	-0.064	-0.087	0.084	0.164	0.102		
7-Harvest Index	0.521	0.01	0.079	0.015	0.58	-0.073	
8-Oil Yield	0.484	0.171	0.19	0.238	0.884**	0.637*	0.029

CONCLUSIONS

Deficit irrigation techniques (AFI and FFI) reduced rapeseed yields by20 and 25% compared to FI irrigation. Both irrigation strategies, the AFI and FFI, were equally effective in saving irrigation water. Alternate furrow irrigation practice for rapeseed provide water use efficiency benefit as compared to full irrigation (FI).The value of benefits from water saving should be balanced with value of yield reductions and cost of implementing alternative irrigation system compared with conventional systems.

Potassium fertilizer application in deficit irrigation treatments increased grain yield more than full irrigation treatment.1000-kernel weight and biologic yield were increased with consumption of 300 kg K/ha relative to control. However, there were no significant difference between 150 and 300 kg K/ha. Potassium fertilizer improved RWC under three moisture levels with the maximum effect at K300.

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