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Different Irrigation and Nitrogen Fertilizer Treatments on Some Agro-Physiologic Traits in Rapeseed (*Brassica napus* L.)

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Abstract: In order to investigate the effect of irrigation and nitrogen fertilizer on agronomical and physiological traits of two winter rapeseed varieties, an experiment was established in a randomized complete block design as split-plot factorial arrangement with four replications in 2005-2006 at Agricultural Research Station of Khorramabad, Iran. Irrigation as main-plot factor consisted of four levels (I_{60}, I_{90}, I_{120} and I_{150}). Sub-plot factors included nitrogen in four levels (N_0, N_{70}, N_{140} and N_{210} kg N ha^{-1}) and two varieties (Zarfam and SLM046). Thousand-seed weight (TSW) in all irrigation and nitrogen levels was lower in the 2006 than that of the 2005. Seed oil percentage (SOP) was decreased with increasing water use only in second year. As nitrogen rate increased, SOP decreased and seed oil yield (SOY) increased in the 2006 significantly ($p<0.05$). With increasing water supply, SOY increased in first year. Zarfam variety had a higher TSW and SOP in both years. According to combined analysis results, seed and oil yield were not significantly affected by irrigation treatments and rapeseed varieties. Seed yield had not significant difference between 70 to 210 kg N ha^{-1} treatments. Both Water Use Efficiency (WUE) and dry matter remobilization efficiency (DMRE) were increased by decreasing water supply in I_{90} to I_{150} treatments. But N_0 and N_{210} resulted in the lowest WUE and DMRE, respectively. Considering all traits, the first year of experiment was better than second year. The irrigation × variety interaction had a significant ($p<0.01$) effect on seed yield and WUE. Generally, $I_{150}N_{70}V_1$ combination is recommended in the region of the study due to high performance in production of seed and oil yield.

Key words: Irrigation, nitrogen, rapeseed, variety, seed, oil yield

INTRODUCTION

Oilseed crops are important crop plants for human nutrition as well as livestock feeds. Rapeseed (*Brassica napus* L.) has some appropriate agricultural characteristics such as cultivation under different seasons, rotation with cereals and high oil quality (Starner *et al*., 1996). It is the second edible oil resource in the world (Raymer, 2002) and has not only 40-45% seed oil (Sovero, 1993) but also the lowest saturated fatty acids (5-8%) among all oilseed crops (Sovero, 1993; Starner *et al*., 1996). To increase the rapeseed yield, increasing the yield per unit area by using agricultural inputs (irrigation, fertilizers and certified seeds) are recommended and to achieve such a goal, proper agronomic management should be taken into account. For instance, water and fertilizer are major crop growth and yield limiting factors. Iran is located in arid and semiarid part of the world and therefore has limited water resources; since a huge amount of water resources are consumed in agriculture, conducting every measure to save water for agricultural sector will effectively help to increase the agricultural products. The soil of most regions in Iran is characterized by low organic matter. As results, nitrogen deficiency often occurs in plants. This deficiency can be solved by using nitrogen fertilizers. Nitrogen plays an important role in agricultural production. Although it is important to develop water saving strategies (increasing water use efficiency), efficient nitrogen use should be considered. Poma *et al*. (1999) reported that in both years of study, rapeseed yield was decreased from optimum soil moisture conditions to the stressed one. They also showed that in limited conditions, rapeseed limits its reproductive organs number of seeds/silique and number of siliques/plant with significant thousand-seed weight reduction. Banuelos *et al*. (2002) showed that leaf/shoot ratio and biomass were increased with increasing the amount of water used in irrigation and the maximum biomass was obtained with using 297 and 359 mm irrigation treatments.

Dadivar *et al*. (2003) in study including four irrigation regimes (50, 75, 100 and 125 mm) on okapi rapeseed variety reported that the highest yield was obtained with T_{50} which did not show any statistical difference with T_{75} treatment. Moreover, there were no significant difference(s) for oil percentage among different treatments. However, 46.98 and 45.91% oil percentage

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were obtained with T_{50} and T_{125} treatments, respectively. According to Goosheh *et al*. (2006) report, the best interval of rapeseed irrigation was 75 mm cumulative evaporation from class A evaporation pan, in south of Khouzestan Province, South of Iran. The average depth of irrigation water at every irrigation time was calculated 60 mm. They noted that water use of rapeseed was about 350 to 400 mm per 1.5-2 t ha^{-1} grain yields. Investigation of rapeseed variety and water stress interactions showed that with using 100 mm water based on evaporation pan and with two times irrigation including from beginning of rapid stem growth to seed maturation, the highest seed yield (SY) was obtained with Shiralli and Orieka varieties and these varieties showed a good adaptation to water deficit (Dehshiri *et al*., 2001). The results of morphological and physiological measurements by Gunasekera *et al*. (2004) showed that dry matter production of mustard (*Brassica juncea* L.) was higher than that of canola under sever water stress. These researches reported that this difference was related to superior osmotic adjustment and leaf water potential of mustard. In this trial, poor ability of mustard to convert its dry matter into seed yield (low harvest index) was related to the lower seed yield in mustard when compared with canola under post-flowering water stress.

Nitrogen is a very important factor to achieve optimum yield in rapeseed and high rates of nitrogen doses regarded as a nitrogen-demanding crop (Kimber and McGregor, 1995). High yield and low NO_3 leaching are compatible goals and can be achieved by appropriate irrigation and fertilizer management (Pang *et al*., 1997). Application of nitrogen fertilizer at rates higher than the optimum requirement for crop production may cause an increase in nitrate accumulation below the root zone and pose a rise of nitrate leaching (Kage *et al*., 2003). Field irrigation is not only essential for plant water supply, but it influences soil fertility. When soil moisture is sufficient (and plant is not stressed), utilization of inorganic fertilizers to provide soil nutrient elements can increase the yield. Many factors influence the crop plants nutrition needs such as water, variety type and interactions of factors. One of these important factors is the amount of water. Under low irrigation of a crop and during growth season, plant is stressed at different intensities. Such stress, changes the plant response to utilization of inorganic fertilizers. Some studies evaluated the effect of water and nitrogen on rapeseed yield (Abdel Gawad *et al*., 1990; Shekari, 2000; Ozer, 2003; Gunasekera, 2004). But little studies have been considered interaction of water and nitrogen on agronomical and physiological traits in different rapeseed varieties (Poma *et al*., 1999; Daneshmand *et al*., 2007). Nitrogen is one of the most important nutrients for rapeseed growth (Bybordi and Malakouti, 2002). Ozer (2003) reported that nitrogen application 160 kg ha^{-1} was sufficient for fertilizer requirement in rapeseed crop. Jackson (2000) and Bybordi and Malakouti (2002) showed that with increasing amount of nitrogen, rapeseed seed yield increased, but seed oil percentage was decreased. Thus, application of 200 kg ha^{-1} of nitrogen for the highest seed oil yield was recommended. Daneshmand *et al*. (2007) reported that in drought stress conditions, those rapeseed varieties were able to maintain their relative water content at high levels, had higher leaf area index and seed yield. This study was aimed at evaluating effects of different rates of water and nitrogen (60, 90, 120 and 150 mm accumulative evaporation from the evaporation pan) and nitrogen (0, 70, 140 and 210 kg N ha^{-1}) and their interactions on some agronomical and physiological characters of two rapeseed varieties (Zarfam and SLM046) in Khorramabad Conditions, Iran.

MATERIALS AND METHODS

This experiment was conducted at the Agricultural Research Station of Khorramabad (48° 21' E 33° 29' N, asl 1170 m) in a randomized complete block design as split-plot factorial arrangement with four replications during the 2005 and 2006, Khorramabad Iran. Annual mean temperature is 17.3°C at experimental region (Anonymous, 2006). The climate of region of studied is semi-arid that has relatively hot and dry summers, according to the Koppen Climate Classification System. Total precipitation in the 2005 and 2006 growing seasons was 456.6 and 658.4 mm, respectively. This range was 56.4 and 145.4 mm lower than long-term average of precipitation for experimental region (513 mm), respectively. In the 2005, total water use (irrigation plus effective rainfall) over 240 days of rapeseed growth period, for treatments I_{60}, I_{90}, I_{120} and I_{150} was 581.2, 517.3, 434.7 and 346.8 mm and in the 2006 it was 610.7, 560.3, 493.2 and 451.6 mm, respectively. Total evaporation from Class A evaporation pan was 1770.0 and 1608.2 mm in the 2005 and 2006, respectively. Soil samples were collected at various soil depths (0 to 60 cm) and were sent to soil test laboratories for soil phsico-chemical analysis. Results of soil analysis are shown in Table 1.

Treatments included three factors: irrigation, nitrogen and variety. Irrigation as main-plot factor consisted of four levels, (I_{60} (control), I_{90}, I_{120} and I_{150}) mm accumulative evaporation from the evaporation pan. Sub-plot factors included nitrogen fertilizer and rapeseed varieties. Nitrogen fertilizer treatments were applied as 0, 70, 140 and 210 kg N ha^{-1} (as N_0, N_{70}, N_{140} and N_{210}). Experimental

Table 1: Results of the soil analysis

Years and soil properties	EC (dS m^{-1})	pH	Organic carbon (%)	Total N (%)	P (mg kg^{-1})	K (mg kg^{-1})
2005	0.69	7.7	1.05	0.098	7.2	360
2006	0.57	7.9	1.04	0.1	9.0	280

materials are the Zarfam (V_1) and the SLM046 (V_2) cultivars. At each fertilizer treatment, 1/3 of total rate (applied as Urea, 46% N) was applied at sowing time (as starter fertilizer) and the rest was applied at the end of rosette stage and at the beginning of flower bud formation. Phosphorus was applied based on soil analysis and recommended rate for rapeseed (Khademi *et al.*, 1999). Land preparation, fertilizer application and weed control operations (with Trifluralin at 1.5 L ha^{-1} pre plant incorporated) all were conducted during early August and rapeseed was sown on 2nd October. Plots were 6×2.4 m and included 8 planting rows. Row spacing was 30 cm and seeds were sown on depth of 2 cm. Soil samples were collected from the 60 cm depth and their weight moisture was measured in laboratory. Water use at each irrigation interval (d in cm) was determined based on pre-irrigation soil moisture (θ_i) and depth of root expansion (D in cm) according to the following equation (Cuenca, 1989).

$$d = (\theta_{FC} - \theta_i)/100.\rho b.D$$

In this equation, θ_{FC} and ρb represent for soil moisture percentage by weight at field capacity (25.3% for sampled soil) and soil bulk density in g cm^{-3} (1.4 g cm^{-3} for sampled soil), respectively. Then, volume of irrigation water (m^3 ha^{-1}) was calculated by the equation, V = (d/100)10000 m^2. Determined irrigation volumes with this method, were delivered to the plots by irrigation counter and pump. Seed yield (SY) was calculated from 4.8 m^2 area in each plot. Yield components and number of secondary branches were also determined. Dry matter remobilization efficiency (DMRE) was determined by the method of Blum *et al.* (1989). Shoot dry matter was determined after oven drying at 70°C for 48 h (Kramer and Boyer, 1995). Seed oil percentage (SOP) was determined by using Inframatic 8620 instrument, which functions based on infrared spectrometry (Ludwiga *et al.*, 2006). Results of first and second years including three heterogeneous variables (thousand-seed weight (Bartlett's test), oil percentage (Bartlett's test) and seed oil yield (Bartlett's test) are discussed at Table 2-5. All statistical analyses were done using the SAS software version 8.02 (SAS Institute Inc., 1996). Combined analysis of variance was conducted after Bartlett's test for homogeneity of variance. Combined analysis of variance was conducted for seed yield, number of secondary branches per plant, water use efficiency and dry matter remobilization efficiency. Duncan's Multiple Range Test was used for mean separation with a significance level of 5% (Gomes and Gomes, 1984).

RESULTS AND DISCUSSION

Interactions of the factors were found significant for the thousand-seed weight and oil yield in the 2006, but not in the 2005 (Table 2). Therefore, we have discussed main effects for the 2005 and the interactions for the 2006. Moreover, interaction of irrigation×nitrogen×variety had a significant effect on seed oil in the 2005 and the 2006 (Table 2).

Thousand-seed weight (TSW)(g): Effect of irrigation on TSW was significant in the 2006 ($p<0.05$), but not in the 2005 (Table 2). TSW in all irrigation and nitrogen levels was lower in the 2006 than that in the 2005. Moreover, number of pods and number of seeds per pod were lower in the 2006 than that of 2005 (data not shown). Water and nutrients stresses, hamper flowering or reduce probability of developing flower to pod and occurring during pod formation will result in pod abortion (Kimber and McGregor, 1995). Generally, in present study there was a compensatory relationship between yield components in both years. This compensatory mechanism between rapeseed yield components has been reported by others (Mingeau, 1974; Kimber and McGregor, 1995). Nitrogen had a significant effect on TSW in the 2005 ($p<0.05$), but not in 2006 (Table 2). The lowest TSW was obtained in 210 kg N ha^{-1}. TSW decreased significantly as nitrogen rate increased from 140 to 210 kg ha^{-1} (law of diminishing return) (Table 3). It seems that rapeseed could not absorb this rate of nitrogen efficiently, so its nitrogen absorption efficiency was lower (Kimber and McGregor, 1995). Variety had a significant effect on TSW in the 2005 ($p<0.01$), but not in the 2006 (Table 2). Zarfam had higher TSW than SLM046 and produced heavier grains (Table 3). Irrigation×variety interaction had a significant ($p<0.05$) effect TSW in the 2006 (Table 4). Moreover, at both I_{60} and I_{120} irrigation treatments, Zarfam variety showed a significant performance in comparison to SLM046. Besides, there was no significant difference between two varieties at the two irrigation levels. $I_{120}V_1$ and $I_{150}V_2$ showed the highest (3.78 g) and the lowest (2.90 g) TSW, respectively (Table 4).

Table 2: Analysis of variance for TSW, SOP and SOY characters of varieties in the 2005 and 2006

		2005 Mean square			2006 Mean square		
Source of variation	df	TSW	SOP	SOY	TSW	SOP	SOY
Replication (R)	3	0.0590ns	8.5900ns	195674.33ns	0.2304ns	3.3834ns	71595.6328ns
Irrigation (I)	3	0.0472ns	7.6484ns	40598.04*	1.2520*	6.6409*	50176.2505ns
Error (R×I)	9	0.2473	3.6763	86167.50	0.3364	1.5251	87143.3963
Nitrogen (N)	3	0.2368*	8.8419**	123786.74ns	0.1097ns	4.0900**	55743.4303ns
Variety (V)	1	3.5510**	129.0019**	864908.40**	5.9297**	10.0689**	399450.3926**
I×N	9	0.0969ns	2.2553*	58984.29ns	0.1520ns	0.6220ns	81345.2765*
I×V	3	0.0045ns	5.7429**	112025.78ns	0.5645*	0.4367ns	185869.4613**
N×V	3	0.0429ns	1.3519ns	13703.69ns	0.1304ns	1.8100*	51260.3928ns
I×N×V	9	0.1039ns	2.3843*	39526.98ns	0.1690ns	1.9904**	39957.3996ns
Experimental error	84	0.0730	0.9624	55124.28	0.2028	0.5649	34310.157

*,**Significant at 5 and 1%, respectively, ns: Not significant

Table 3: Mean comparison (main effects) of irrigation, nitrogen and variety on TSW and SOY in the 2005

	2005	
Treatments	TSW (g)	SOY (kg ha^{-1})
Irrigation		
I_{60}	3.69a	1426.24a
I_{90}	3.63a	1473.57a
I_{120}	3.47a	1347.30ab
I_{150}	3.44a	1223.43b
Nitrogen		
N_0	3.64a	1366.41ab
N_{70}	3.50ab	1402.53ab
N_{140}	3.62a	1457.77a
N_{210}	3.46b	1309.77b
Variety		
Zarfam	3.7a	1466.32a
SLM046	3.4b	1301.92b

In each column means followed by the same letter(s) are not significantly different, based on Duncan's test at p≤0.05

Table 4: Interaction of irrigation×variety on SOP (in the 2005), TSW and SOY (in the 2006)

	2005	2006	
Irrig. ×Var. interaction	SOP (%)	TSW (g)	SOY (kg ha^{-1})
$I_{60}V_1$	46.00a	3.30bc	853.70d
$I_{60}V_2$	43.84c	2.95d	1181.00a
$I_{90}V_1$	45.09b	3.62ab	1043.56abc
$I_{90}V_2$	43.45c	3.41bc	1142.35ab
$I_{120}V_1$	44.60b	3.78a	986.68c
$I_{120}V_2$	43.48c	2.95d	1032.65bc
$I_{150}V_1$	45.33ab	3.26cd	1077.51abc
$I_{150}V_2$	42.22d	2.90d	1052.35abc

In each column means followed by the same letter(s) are not significantly different, based on Duncan's test at p≤0.05

Seed oil percentage (SOP) (%): Three way interaction (irrigation×nitrogen×variety) had a significant effect on SOP in both 2005 ($p<0.05$) and 2006 ($p<0.01$) years (Table 2). $I_{60}N_0V_1$ with 46.80 in the 2005 and $I_{90}N_0V_1$ with 43.20 in the 2006 had maximum SOP. $I_{150}N_{210}V_2$ with 41.12 in the 2005 and $I_{60}N_{210}V_2$ with 39.70 in the 2006 had the minimum SOP (Table 5). The result of irrigation×nitrogen×variety interaction on SOP showed that in both Zarfam and SLM046 varieties in all irrigation levels, the highest SOP was obtained from no nitrogen application and SOP decreased with nitrogen application (Table 5). These result are similar to the result of Smith *et al.* (1988), Kimber and McGregor (1995), Jackson (2000) and Bybordi and Malakouti (2002). Results of seed SOP as effected by three way interaction (irrigation×nitrogen×variety) in the 2006 showed that SOP was increased due to the increasing irrigation intervals (from I_{60} to I_{150}) (Table 5), which was similar to result of Thompson (1978). But, Smith *et al.* (1988) reported that SOP increased with increasing soil water content and decreased with increasing nitrogen level. In most combinations of irrigation and nitrogen in the 2005 and

Table 5: Interaction of irrigation, nitrogen and variety on SOP in the 2005 and 2006

Interaction of Irrig.×Nitro.×Var.	2005 SOP (%)	2006 SOP (%)
$I_{60}N_0V_1$	46.80a	41.40bcde
$I_{60}N_0V_2$	44.92bcdef	40.80cdefg
$I_{60}N_{70}V_1$	45.77abc	40.30defg
$I_{60}N_{70}V_2$	44.60bcdefg	39.85fg
$I_{60}N_{140}V_1$	45.95abc	39.72g
$I_{60}N_{140}V_2$	42.32ijk	40.17efg
$I_{60}N_{210}V_1$	45.50abc	41.42bcde
$I_{60}N_{210}V_2$	43.50fghi	39.70g
$I_{90}N_0V_1$	45.62abc	43.20a
$I_{90}N_0V_2$	44.27cdefgh	40.70cdefg
$I_{90}N_{70}V_1$	45.02bcdef	41.80bc
$I_{90}N_{70}V_2$	43.67efghi	41.55bcd
$I_{90}N_{140}V_1$	45.22abcde	40.97cdefg
$I_{90}N_{140}V_2$	43.65efghi	42.37ab
$I_{90}N_{210}V_1$	44.47cdefg	40.62cdefg
$I_{90}N_{210}V_2$	42.22ijk	41.07cdef
$I_{120}N_0V_1$	45.00bcdef	41.87bc
$I_{120}N_0V_2$	43.00ghij	41.15bcde
$I_{120}N_{70}V_1$	44.90bcdef	40.95cdefg
$I_{120}N_{70}V_2$	43.00ghij	40.77cdefg
$I_{120}N_{140}V_1$	44.75bcdef	41.30bcde
$I_{120}N_{140}V_2$	42.82ijk	40.17efg
$I_{120}N_{210}V_1$	43.77defghi	41.22bcde
$I_{120}N_{210}V_2$	45.10bcdef	40.45defg
$I_{150}N_0V_1$	46.22ab	41.92bc
$I_{150}N_0V_2$	43.80defghi	41.10cdef
$I_{150}N_{70}V_1$	45.40abcd	40.95cdefg
$I_{150}N_{70}V_2$	42.47ijk	40.80cdefg
$I_{150}N_{140}V_1$	44.80bcdef	41.37bcde
$I_{150}N_{140}V_2$	41.50jk	40.20efg
$I_{150}N_{210}V_1$	44.90bcdef	41.22bcde
$I_{150}N_{210}V_2$	41.12k	40.42defg

In each column means followed by the same letter(s) are not significantly different, based on Duncan's test at p≤0.05

Table 6: Combined analysis of variance for SY, NSB, WUE and DMRE

		Mean square			
Source of variation	df	SY	NSB	WUE	DMRE
Year (Y)	1	19002897.07**	497.568**	324.901**	4316.490**
Error I	6	1192437.44ns	18.884	5.333	284.669ns
Irrigation (I)	3	695516.74ns	2.136ns	52.874**	364.921ns
I×Y	3	389988.05ns	5.001*	12.269**	547.846ns
Error II	18	431629.27	1.449	1.415	275.375
Nitrogen (N)	3	397476.72ns	2.223ns	1.972ns	280.712ns
Variety (V)	1	6226.20ns	11.433**	0.289ns	791.718*
I×N	9	352909.90ns	1.136ns	1.557ns	187.902ns
I×V	3	1488026.32**	1.962ns	4.639**	494.404ns
N×V	3	209611.03ns	0.664ns	1.217ns	87.981ns
N×Y	3	422307.81ns	0.279ns	1.547ns	396.118ns
V×Y	1	6623706.49**	26.45**	27.040**	1880.306**
I×N×V	9	175678.31ns	1.254ns	6.443ns	242.845ns
I×N×Y	9	442111.42*	0.533ns	0.716ns	512.327**
I×V×Y	3	149527.93ns	1.459ns	1.355ns	321.198ns
N×V×Y	7	114967.67ns	1.642ns	0.614ns	164.899ns
I×N×V×Y	12	188357.91ns	0.435ns	0.277ns	583.521**
Experimental error	161	209520.24	1.081	0.874	186.587

* and ** Significant at 5 and 1%, respectively and ns not significant

Table 7: Mean comparisons of the years on measured characters

Year	SY (kg ha^{-1})	SOP (%)	SOY (kg ha^{-1})	NSB	WUE (kg grain mm^{-1} H_2o)	DMRE (%)
2005	3103.3a	44.25a	1384.12a	7.56a	7.01a	43.06a
2006	2558.4b	40.99b	1046.22b6	4.77b	4.76b	34.85b

In each column means followed by the same letter(s) are not significantly different, based on Duncan's test at $p \le 0.05$

2006, Zarfam showed higher SOP than SLM046. SOP of two varieties was significantly different in both years, which was higher in Zarfam. Also, oil percentage was less in 2006 than that in the 2005 (Table 7).

Seed oil yield (SOY) (kg ha^{-1}): Effect of irrigation on SOY was significant in the 2005 ($p<0.05$), but not in the 2006 (Table 2). Results of mean comparison showed that with increasing water use, SOY increased (Table 3). Kajdi (1994) and Shekari (2000) reported that with increasing water supply, rapeseed SOY increased. The highest SOY in the 2005 was obtained from I_{60} and I_{90} irrigation treatments, which were significantly different from I_{150} (severe water-limited level) (Table 3). Although nitrogen had no a significant effect on SOY in both years (Table 2), but mean comparison showed that the lowest SOY was obtained when no nitrogen fertilizer (N_0) was added to the soil and SOY was increased by increasing nitrogen application in the 2006 (data not shown). Nitrogen application to N_{140} level increased SOY, but increasing nitrogen rate from 140 to 210 kg ha^{-1} decreased SOY significantly in the 2005 (Table 3). According to the significant correlation between SOY and SY (0.89**), it can be concluded that lower SOY in N_{210} treatment is due to the decreasing SY in this nitrogen level.

Irrigation and nitrogen interaction on SOY was significant in the 2006 ($p<0.05$) (Fig. 1). Multiple Duncan's range test showed that every I_{60} and I_{120} level had significant effect on SOY in some all nitrogen levels. In contrast, every I_{90} and I_{150} level had no significant effect on SOY in all nitrogen levels. The final results showed that the highest (1199.74 kg ha^{-1}) and the lowest (872.21 kg ha^{-1}) SOY was obtained from $I_{160}N_{210}$ and $I_{120}N_0$, respectively (Fig. 1).

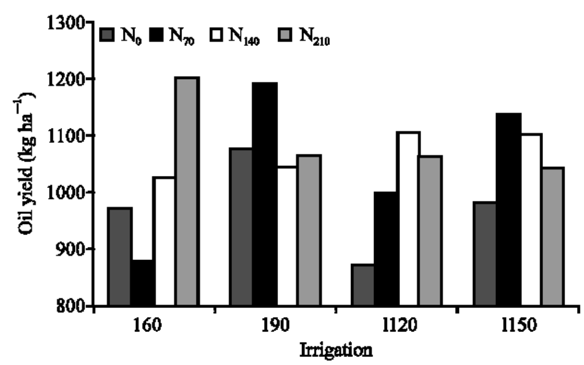

Fig. 1: Interaction of irrigation and nitrogen on oil yield in the 2006

Variety had a significant effect on SOY in both years ($p<0.01$) (Table 2). Zarfam showed higher SOY than SLM046 (Table 3), but not in the 2006. It seems that SOY variations among varieties were due to the effects of environmental variables, genotype and genotype and environment interaction on SY and SOP over the growing season. Irrigation and variety interaction had a significant effect on SOY in the 2006 ($p<0.01$) (Table 2). Mean analysis results revealed that two varieties had no significant difference between water deficit treatments (I_{90}-I_{150}) on SOY. While two varieties at I_{60} level showed a significant difference (Table 4). Also, the highest and the lowest SOY were belonged to $I_{60}V_2$ and $I_{60}V_1$, respectively.

COMBINED ANALYSIS

Seed yield (SY) (kg ha^{-1}): Effect of irrigation was not significant on SY (Table 6). The relative superiority of SY in I_{90} irrigation interval over I_{60} irrigation interval can be related to its higher TSW and harvest index. Moreover, the last irrigation in treatment I_{60} apparently had little influence on yield, as synchronizing with the final stages of seed development and exposure to high temperatures and dry weather. Less water use efficiency in this treatment, also confirm this conclusion (Table 8). Nielsen (1997) also emphasized that drought stress during the final growth period has no important influence on rapeseed yield. SY is dependent on yield components. Considering significant effect of irrigation on TSW and, but not on number of pods and seed number per pod in this study (data not shown), it can be found that just seed weight is an important factor in adjusting SY and the two other components had little influence on SY. Reported by others, irrigation has more influence on number of seeds per pod than other yield components and water deficit will influence flowering to maturity stage more than the other growth stages (Mailer and Cornish, 1987; Mailer and Wratten, 1987). However, present results agree with those of Nielsen (1997) who reported that there were no significant differences among water stress treatments with regard to yield components in rapeseed. Results of SY showed that the lowest SY was obtained when no nitrogen fertilizer was applied and with nitrogen application increased yield (Table 8). However, there was no significant difference among treatments 70, 140 and 210 kg N ha^{-1}. Therefore, 70 kg ha^{-1} nitrogen treatment is recommended from economical and bioenvironmental point of view for rapeseed in the region of the study.

Although interaction of irrigation×nitrogen×variety (due to combined analysis) was not significant on SY and SOY characters, according to Duncan's multiple range test, there was a significant difference ($p<0.05$) among different combinations of these characters. On the basis of above mentioned results, SY of $I_{150}N_{70}V_1$ (3037.3 kg ha^{-1}) and $I_{150}N_{70}V_2$ (2781.3 kg ha^{-1}) combinations were the same and located in one statistical group. Although SOY was not different between both above mentioned combinations and they were in one statistical group (1298.4 and 1156.7 kg ha^{-1}, respectively), but $I_{150}N_{70}V_1$ combination also was located in a superior statistical group. Therefore, according to oil production importance in rapeseed and also rate of yield, $I_{150}N_{70}V_1$ combination is recommended in the region of the study. SY of two studied varieties was not significantly different (Table 8). The interaction effect of variety and year was significant ($p<0.01$) (Table 6), as Zarfam variety having higher SY (3259.2 kg ha^{-1}) in 2005, while its yield (2392.6 kg ha^{-1}) was lower than SLM046 variety in the 2006. Due to changing weather, genotype, year interaction was found highly significant. As a result, genotypes lost their stability for grain yield and two cultivars changed their rank grain yield. When genotypic stability is low, genotype can not bear environmental variation. In such a circumstance, seed yield differs yearly. The interaction effect of irrigation and variety was significant on SY ($p<0.01$) (Table 6), as the highest (3014.4 kg ha^{-1}) and the lowest SY (2594.0 kg ha^{-1}) were obtained from $I_{60}V_2$ and $I_{150}V_2$ treatments, respectively (Table 9). It can be concluded than that of the SLM046 (V_2) variety reacted more quickly to soil moisture variations than Zarfam (V_1) and apparently has low tolerance to drought condition. In contrast, Zarfam variety had a slow reaction to soil moisture variations and seems to have higher tolerance to drought condition. Therefore, as having higher SY in drought stress levels, especially in I_{150} level (Table 9) as well as relative early maturity, it seems Zarfam can be introduced as a suitable variety for cultivation in water-

Table 8: Mean comparison (main effects) of rapeseed studied traits from combined analysis

Treatments	SY (kg ha^{-1})	NSB	WUE (kg grain mm^{-1} H_2O)	DMRE (%)
Irrigation				
I_{60}	2804.20ab	5.98a	4.74c	35.00b
I_{90}	2985.00a	6.05a	5.58b	40.06a
I_{120}	2768.00ab	6.26a	6.47a	41.52a
I_{150}	2728.50a	6.37a	6.74a	39.04a
Nitrogen				
N_0	2666.25b	6.00b	5.64b	40.88a
N_{70}	2875.92a	6.02b	5.97ab	39.22a
N_{140}	2894.40a	6.20ab	6.04a	39.73a
N_{210}	2834.17ab	6.42a	5.88ab	35.63b
Variety				
Zarfam	2825.88a	5.95b	5.92a	40.72a
SLM046	2835.75a	6.38a	5.85a	37.20b

In each column means followed by the same letter(s) are not significantly different, based on Duncan's test at $p\leq 0.05$

Table 9: Combined analysis of interaction of irrigation×variety on SY and WUE

Irrig.×Var. interaction	SY (kg ha^{-1})	WUE (kg grain mm×^{1} H_2O)
$I_{60}V_1$	2613.7b	4.42c
$I_{60}V_2$	3014.4a	5.06d
$I_{90}V_1$	3012.0a	5.64c
$I_{90}V_2$	2957.9a	5.51cd
$I_{120}V_1$	2773.6ab	6.53b
$I_{120}V_2$	2762.4ab	6.41b
$I_{150}V_1$	2923.9a	7.08a
$I_{150}V_2$	2594.0b	6.41b

In each column means followed by the same letter(s) are not significantly different, based on Duncan's test at $p\leq 0.05$

limited conditions. In this study, year had a significant effect on SY ($p<0.01$) (Table 6). Rapeseed mean SY was 3103.3 and 2558.4 kg ha^{-1} in the 2005 and 2006, respectively. Also, mean SOY was 1384.12 and 1046.22 kg ha^{-1} in the 2005 and 2006, respectively. SY and SOY were 17.5 and 24.4% higher in the 2005 than that in the 2006, respectively (Table 7). In spite of higher precipitation and its better distribution in year the 2006, probably decreasing SY and SOY in this year can be related to weather variations over the growth season (low temperature during flowering, 11.5 and 14.5°C in the April 2006 and 2005, respectively); cloudy and rainy weather in most days during April (therefore inadequate honeybee activity and less flower fertilization) and soil and nitrogen leaching due to higher precipitation in the 2006. Moreover, this yield difference can be explained by later planting date in 2006 than that in the 2005 (about 7 days).

The significance of effect of year on measured characters in the present study showed that the changes of weather from one year to another have significant effect on these characters (Table 7). Interaction of variety and year ($p<0.01$) and irrigation, nitrogen and year ($p<0.05$) were significant on SY (Table 6). Although Zarfam had a higher SY of 3259.2 kg ha^{-1} in the 2005, its SY in the 2006 was lower (2392.6 kg ha^{-1}). The highest yield (3498.8 kg ha^{-1}) was obtained from $I_{90}N_{210}Y_1$ and the lowest yield (2113.7 kg ha^{-1}) obtained from $I_{120}N_0Y_2$, which was 1385.1 kg ha^{-1} lower than the first one. Present results are supported by the studies of Faraji (2004) who observed that effect of the year; variety and interaction between year and variety was significant on seed yield. Also, he noted the interaction was significant because of different temperature in two years of the experiment. Faraji and Soltani (2007) also showed that effect the year was significant on seed and oil yield. They reported that existence of good climatic condition, greater sunshine during flowering and seed formation periods resulted in seed and oil yield enhancement. Haefele *et al.* (2003) observed across all genotypes tested and in comparison with the irrigated control, rainfall conditions reduced grain yield of treatment without N application by 69% in 2004 and by 59% in 2005. Lewis and Thurling (1994) reported further increase in seed yield of oilseed Brassicas in experimental environment should be possible if higher postanthesis water use could be combined with lower soil evaporation and improved WUE. Al-Kaisi *et al.* (2003) reported that irrigation×nitrogen interaction on grain yield was significant and varied by year and also grain yield response to N rate was affected by irrigation and year. This finding agrees to present results.

Number of secondary branches per plant (NSB): Effect of irrigation and nitrogen treatments was not significant on NSB, while effect of variety and year was significant ($p<0.01$) (Table 6). With increasing nitrogen application, NSB increased (Table 8), as the highest (6.42) and the lowest mean NSB (6.00) obtained from 210 kg N ha^{-1} and no N fertilizer treatments, respectively. This result agrees with that of Abedl Gawad *et al.* (1990), who reported that increasing nitrogen rate in rapeseed resulted in higher NSB. Increasing nitrogen rate will increase NSB due to increasing absorption and translocation of assimilates and stimulating apical and lateral meristems to grow. The SLMO46 variety produced more NSB and there was a significant difference between two varieties (Table 8). However, producing more NSB in this variety didn't result in higher seed yield and oil content (Table 8) (data of oil yield not shown). Despite the fact of the SLM046 had more NSB than Zarfam, their grain and oil yield was the same approximately. Moreover, considering negative significant correlation between NSB and SOP (-0.38*) and TSW (-0.55**), it seems that high NSB is not a suitable factor in rapeseed. Moreover, plant lodging occurred due to high NSB and its heavy weight during seed maturity period. In support of present study, Khan *et al.* (2008) reported that the relationship of branches $plant^{-1}$ with seed yield was highly significant but negative. They also showed branches $plant^{-1}$ had negative but non-significant association with 100 grain weight and oil content. Ali *et al.* (2003) observed branches $plant^{-1}$ had negative but highly significant correlations with seeds pod^{-1}. Kimber and McGregor (1995) surveyed that producing fewer basal branches and more pods on main stem and upper branches is considered to be one of the rapeseed ideotype characteristics. Present results are opposite to that of Diepenbrock (2000) who found that the number of pods per plant is decisive for seed yield. He showed that this trait is ultimately determined by the survival of branches $plant^{-1}$, buds, flowers and young pods. Tunturk and Ciftci (2007) also noted were statistically positive correlation between seed yield with NSB. Effect of year ($p<0.01$), irrigation and year ($p<0.05$) and variety and year ($p<0.01$) was significant for NSB (Table 6). This number was higher in the 2005 than that in the 2006 (Table 7). Interaction of irrigation and year showed that the highest and fewest NSB was obtained in $I_{90}Y_1$ and $I_{120}Y_2$ treatments, respectively. Interaction of variety and year showed that SLM046 variety produced more and fewer NSB than Zarfam in the 2005 and 2006, respectively. Halvorson *et al.* (2001) showed that bearing branches in unit area is functional plant density, power of production of bearing branches and their survival. They also found that NSB in rapeseed closely correlated with soil moisture regime during growing season. Brassica rapa in compare to *B. napus* produced more NSB (Kimber and Mc-Gregor, 1995).

Water use efficiency (WUE) (kg grain mm^{-1} H_2O): Irrigation significantly influenced WUE ($p<0.01$) (Table 6). WUE increased in water deficit treatments (I_{90} to I_{150}), while increasing water use in control (I_{60}) resulted in lower WUE (Table 8). Maximum rapeseed WUE values obtained in treatment which received no spring irrigation and its WUE values were decreased as increasing water use (Anonymous, 2003). Regarding WUE, Irrigation treatments I_{120} and I_{150} were in the same statistical group and each treatment I_{60} and I_{90} were placed in different statistical groups. Water use efficiency is considered to be a key indicator of plant production potential in water deficit conditions. Results of this study show that rapeseed can have high the WUE when irrigation is limited. Also, it was increased significantly as a result of nitrogen application (Table 8). Norton (1989) reported that nitrogen application increased the WUE of the rapeseed from 3 to 6 kg ha^{-1} mm^{-1}. WUE of two varieties was not significantly different (Table 6). Genetic and management factors influence the crop WUE. In this experiment, genetic factor alone had no influence on WUE. Effect of irrigation and variety was significant for WUE ($p<0.01$) (Table 6). Results showed that the lowest WUE was belonged to Zarfam variety in I_{60} moisture level (the highest water use). The highest WUE also obtained in this variety, but in I_{150} moisture level (the lowest water use) (Table 9). So it was observed that the WUE of rapeseed increased as the drought period lengthened and vise versa. Nielsen (1997) reported that rapeseed exhibited a linear response of seed yield to water use with approximately 186 kg ha^{-1} of seed produced for every mm of water used. In this experiment, Zarfam variety showed another aspect of drought resistance by saving water in severe moisture level. Effect of year, irrigation×year and variety×year was significant on WUE ($p<0.01$) (Table 6). WUE was higher in 2005 than that in 2006 (Table 7). This difference among years can be related to their difference in regard to evapotranspiration potential and atmospheric evaporative demand. $I_{150}Y_1$ and $I_{60}Y_2$ combinations showed the highest (8.31 kg grain mm$\times^1$ H_2O) and the lowest (4.10) WUE, respectively. Zarfam in first year and the second year had the highest (7.37) and the lowest (4.46) WUE, respectively.

Dry matter remobilization efficiency (DMRE): Combined analysis of data revealed that generally, the DMRE increased in water limited conditions (I_{90} to I_{150} levels) as compared to I_{60} (no water limitation). The DMRE in three water deficit levels (I_{90} to I_{150}) averaged 40.2%, which were 5.2 units higher than that in I_{60} level (Table 8). Increasing nitrogen availability before flowering stage and water during grain filling, decreased the DMRE in I_{60} level. The results are in line with those of Papakosta and Gagianas (1991) and Blum (1998), who reported that proportion of remobilized dry matter increased during drought stress conditions, as compared to optimal moisture conditions. These results agree with those Ehdaie *et al.* (2002) who observed that the amount of current assimilates and stem reserves contributed to grain yield was reduced, respectively, by 54 and 11% under drought. Hocking *et al.* (1997) also showed on basis averaged over all N treatments, about 20% of the dry matter and 60-65% of the N was apparently mobilized from the stem and leaves, after flowering. In contrast, Ercoli *et al.* (2008) noted although remobilization of dry matter and N was less affected by water stress than accumulation, it was not able to counter balance the reduction of assimilation and consequently it was not able to stabilize grain yield under drought.

Results of remobilization efficiency showed that increasing nitrogen application (210 kg ha^{-1}), apparently resulted in increasing green parts of plant and their duration, so increasing current photosynthesis. Therefore, it was not needed for plant to consume its reservoirs, so remobilization had been decreased in this fertilizer level (Table 8). Overall, in present study, variety had a significant effect on DMRE ($p<0.05$) (Table 6). Zarfam had higher DMRE than the SLM046 (Table 8). It was previously reported that there is a distinct difference among different genotypes in regard to the rate of translocated materials to seed (Blum, 1998). Effect of year, irrigation×nitrogen×year were significant on the DMRE ($p<0.01$) (Table 6). As the DMRE was 19% higher in the 2005 than that in the 2006 (Table 7). This difference between two years can be explained by mainly weather variations. $I_{150}N_0Y_1$ and $I_{60}N_{210}Y_2$ treatments had the highest and the lowest DMRE, respectively. Correlation between DMRE and TSW (0.35*) showed that the DMRE can play a role as a source in grain filling. Genotypic differences reported by Kumar *et al.* (2006) and Ehdaie *et al.* (2008) in percent contribution of stem reserves to grain yield were significant in well-watered and in drought-field conditions. But, Clark *et al.* (1984) reported that not observed correlation between stress tolerance index and amount of remobilization. Blum *et al.* (1989) and Clark *et al.* (1984) noted that DMRE had correlated to the crops genetic characteristic.

CONCLUSION

Under weather conditions at the time of experiments conducting, combined analysis results revealed that water-limited had not significant reduction on rapeseed grain yield as well as oil content in comparison to the control plants. Since limited irrigation treatments (I_{90} to I_{150}) resulted in a higher and significant WUE values to the control plants, they can be considered to save water rapeseed production. Furthermore, the DMRE was significantly higher in comparison to the control plants. Therefore, it can be concluded that applying some controlled and purposeful drought stress during grain filling (as plant could restore its water during the night), will increase remobilization efficiency of rapeseed as a result of more translocation of stored materials from vegetative parts to seeds. But further studies are required to address this issue. Considering interaction of irrigation and variety, it seems that Zarfam had better adaptation to water-limited conditions than the SLMO46, because of the higher SY and WUE under sever water-Limited treatment (I_{150}) and matured earlier than the SLM046.

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