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SEED AND OIL YIELDS OF RAPESEED (*BRASSICA NAPUS* L.) CULTIVARS UNDER IRRIGATED AND NON-IRRIGATED CONDITIONS

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ABSTRACT

Drought is the major factor limiting plant growth and productivity in many regions of the world more than any other environmental factors. To determine the effect of water deficit on seed and oil yields in rapeseed (*Brassica napus* L.) cultivars, field experiments were conducted at the Seed and Plant Improvement Institute, Karaj, Iran, during 2007–2009. The experimental designs were randomized complete block with split-plot arrangement and three replicates. main plots were four levels of irrigation (control (irrigation after 80 mm evaporation from class “A” pan , IR_1), no irrigation after the start of stem elongation stage (IR_2), no irrigation after the start of flowering stage (IR_3), and no irrigation after the start of podding stage (IR_4)), and subplots were six rapeseed cultivars (Licord, SLM046, Okapi, Orient, Zarfam and Opera). Results showed that seed and oil yields, number of pods per plant, and number of seeds per pod were significantly affected by year, rapeseed cultivar and irrigation level. Moreover, the most average yield reduction due to drought conditions (IR_2) in comparison with control (IR_1) in first and second year was 30.44% (Licord) and 50.27% (Zarfam), respectively. In both two years, SLM046 cultivar has the least percentage of yield reduction and it was the best yielding in water stress conditions. Therefore, these experiments illustrated that rapeseed cultivars showed significantly different responses, depending on weather conditions, to different irrigation levels and SLM046 cultivar showed higher ability to capture soil moisture under severe competition and had the least reduction in seed yield compared to the other cultivars.

Keywords: *Brassica napus* L., oil yield, seed yield, water deficit, winter rapeseed cultivars.

INTRODUCTION

Environmental stress such as water limitation during growth and development of plants can affect seed quality and quantity (Younesi and Moradi, 2009). Drought stress often causes yield reduction, which is an important agricultural research subject (Zhang *et al*., 2008). Robertson and Holland (2004) reported that the effect of drought stress is a function of genotype, intensity and duration of stress, weather, growth and developmental stages of rapeseed (*Brassica napus* L.). The effects of water stress depend on timing, duration, and magnitude of water deficiency (Pandey *et al*., 2001). The occurrence time is more important than the water stress intensity (Abbasian and Shirani Rad, 2011). Most oilseed rape crops grown in Iran are established in autumn and usually drought is an important limiting factor. In certain tolerant-adaptable crop plants such as rapeseed, morphological and metabolic changes occur in response to drought, which contribute towards adaptation (Tohidi-Moghadam *et al*., 2009).

Breeding for drought resistance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes need to be evaluated efficiently (Akçura *et al*., 2011). Achieving a genetic increase in yield under these environments is a difficult challenge for plant breeders, while progress in yield grain has been much higher in favorable environments (Richards *et al.*, 2002).

Water limitation during seed development usually interrupts development and results in small seed size (Cruz-Aguado *et al*., 2000); this reduced size is primarily due to a shortening of the filling period rather than an inhibition of seed growth rate (Younesi and Moradi, 2009). Drought reduces biomass and seed yield, harvest index, number of silique and seeds, seed weight, and days to maturity (Abebe and Brick, 2003; Munoz-Perea *et al*., 2006; Padilla-Ramirez *et al*., 2005). Besides, drought increases cooking time and seed protein content (Frahm *et al*., 2004). According to Mir Mousavi *et al*. (2006), seed yield has a larger positive direct effect on oil yield and content. Harvest index has a large positive correlation with oil yield; Great positive correlation was due to its indirect effect via seed yield in each plant (Abbasian and Shirani Rad, 2011). Pazouki (2000) showed that shortening irrigation interval increased 1000-seed weight and vice versa. In an experiment with nine summer rapeseed, Chango and McVetty (2001) observed that total dry matter and harvest index had a significant correlation with grain yield. Under field conditions, early drought (occurring at green bud stage) could lead to a decrease in oil content of seeds, implying that allocation of assimilates to the ovule at the early stage of the megaspore could be related to the final oil concentration (Wright *et al*., 1995; Abbasian and Shirani Rad, 2011). Jensen *et al*. (1996) found that under low evaporative demands (2–4 mm d^{-1}) oil and seed yields were not influenced by soil drying. Under high evaporative demands (4–5 mm d^{-1}) oil and seed yields significantly decreased. Thus, it is very important to determine critical stages of oilseed rape crops against drought stress.

The objective of this study was to evaluate the response of rapeseed cultivars to water deficit occurring at either vegetative or reproductive stages in order to achieve the optimum use of resources.

MATERIALS AND METHODS

Set up of the experiment: This study was carried out at the Seed and Plant Improvement Institute, Karaj, Iran (35° 55′ N, 50°54′ E, 1313 m altitude), during 2007–2009. This region has a semi-arid climate (354 mm annual rainfall). The soil texture of the experimental site is a clay loam, with montmorillionite clay mineral, low in nitrogen (0.06-0.07 %), low in organic matter (0.56-0.60 %), and alkaline in reaction, with a pH of 7.9 and Ec= 0.66 dS m^{-1}(using an Electrical Conductivity Meter).

Experimental design and crop management: The experimental designs were randomized complete block with split-plot arrangement and three replications. main plots were four levels of irrigation (control (irrigation after 80 mm evaporation from class “A” pan, IR_1), no irrigation after the start of stem elongation stage (IR_2), no irrigation after the start of flowering stage (IR_3) and no irrigation after the start of podding stage (IR_4)), and subplots were six rapeseed cultivars (Licord, SLM046, Okapi, Orient, Zarfam and Opera). Individual plot consisted of 6 rows, 6 m long and spaced 30 cm apart using a seeding rate of 7 kg ha^{-1}. The experimental fields and seedbed preparation consisted of two passes with a tandem disk. Seeds were planted 1 to 1.5 cm deep at a rate of 100 seeds m^{-1} on 10 October 2007 and 2008. For all treatments, N: P: K fertilizers applied at the rates of 150:60:50 kg, respectively. All of P, K fertilizer and one-third of N were added and incorporated to soil at presowing stage. Other two-third of N fertilizer was split equally at the beginning of the stem elongation and the flowering stages. Weeds were controlled by application of haloxyfop- R-methyl ester (Gallant Super. 10 % EC) at 0.6 L ha^{-1}. Broadleaf weeds were also hand weeded during the season. Final harvests were carried out at the 16 June 2008 and 28 June 2009.

Sampling: At maturity stage, ten plants from each plot were randomly selected for the measurement of yield components: number of pods per plant, number of seeds per pod, 1000-seed weight. To determine the seed yields per unit area, seeds and straw were collected and dried at 70°C for 48 h. Harvested area was 2m × 4m in each plot. Seed yield of rapeseed was adjusted to 9% moisture content. Oil content was determined by Nuclear Magnetic Resonance (NMR) with a Bruker equipment (DMX 500 MHz) (Bruker, Germany) using deuterated chloroform as solvent. Oil yield was calculated by multiplying seed yield by oil content.

Statistical analysis: Because of achieved data for two years were different and in second year we have a bad climate conditions, we separated and analyzed information for every year. The experimental data were statistically analyzed by using of SAS system (SAS Institute, 2002). Mean separation was obtained using fisher's protected LSD at the 0.05 probability level.

RESULTS AND DISCUSSION

Analysis of variance showed that rapeseed cultivars and water stress had significant effects on all traits except oil content, 1000-seed weight and harvest index (Table 1). Moreover, the interactions between rapeseed cultivars and irrigation level were significant for seed and oil yields, number of pods per plant, and number of seeds per pod. Rapeseed cultivars showed significantly different responses to different irrigation levels. Because of bad climate conditions in the second year as well as great difference between the amount of seed yield and oil yield in these two years, we have measured these data separately. Also, in the second year, we had higher reduction in percentage yield compared with the first year. Means comparison for the effect of drought stress on yield and its components of rapeseed cultivars are shown in Table 2 and 3. Seed yield and yield components were reduced significantly when drought stress imposed either during vegetative or during reproductive growth stage of rapeseed. In full irrigation (control), Okapi cultivar produced the highest and Opera cultivar given the least seed yield (Table 2) in the first year. In the second year, Opera cultivar produced the highest seed yield, followed by Licord and Okapi (Table 3).

The difference between the highest and lowest yielding cultivars was about 767 and 505.7 kg ha^{-1} in 2007–2008 and 618.1 and 585.5 kg ha^{-1} in 2008–2009 in non-stress and stress conditions, respectively (Tables 2 and 3). The most average yield reduction due to drought conditions (IR_2) in comparison with control (IR_1) in first and second year was 30.44% (Licord) and 50.27% (Zarfam), respectively. SLM046 cultivar has the least percentage of yield reduction and it was the best yielding in water stress conditions (Table 2 and 3).

Table 1: Variance analysis of variables in winter rapeseed cultivars between 2007 and 2009.

SOV	df	Number of pods per plant	Number of seeds per pod	1000-seed weight (g)	Seed yield (kg ha^{-1})	Harvest index	Oil content (%)	Oil yield (kg ha^{-1})
Year	1	1048.14**	583.6***	26.89***	119772412***	323.6**	98.43***	20762737***
Rep. (Year)	4	321.94	10.01	0.7	344776.7	21.5	4.66	69174.1
Irrigation	3	7943.89***	42.7***	0.08 ns	3442479.1***	74.74ns	3.42ns	742948.1***
Irrigation×Year	3	1143.4***	62.58***	0.14 ns	165269.6 ns	44.21ns	3.9ns	51454.1ns
Error	12	82.8	2.17	0.26	153797.6	74.96	3.12	28038.1
Variety	5	470.8**	10.8**	0.17 ns	495652.8**	40.89ns	3.88ns	94214.3**
Variety×Year	5	367.2**	3.21ns	0.4*	485164.5**	25.48ns	1.93ns	94499.3**
Variety×Irrigation	15	418.05***	6.09**	0.13 ns	432337.9**	57.21*	1.55ns	76665.5**
Variety×Irrigation×Year	15	801.7***	8.22***	0.12 ns	257859.8*	41.37ns	3.33ns	42091.4ns
Error	80	87.1	2.16	0.14ns	122565.1	30.1	2.13	27242.5
CV %		11.79	6.65	8.89	11.03	22.68	3.27	11.74

ns: nonsignificant; * $p \le 0.10$; ** $p \le 0.05$; *** $p \le 0.01$.

In control treatment, Okapi and Zarfam produced the greatest and least oil yields in the first year, respectively. In contrast, Licord and Zarfam produced the greatest and least oil yields in the second year, respectively. Zarfam cultivar, however, has least oil yield in normal irrigation but this cultivar had smallest degree of oil yield reduction in the severe water stress (0.44% in first year and 15.83% in second year). Grain yield under irrigated condition was adversely correlated with rain-fed condition suggesting that a high potential yield under optimum condition does not necessarily result in improved yield under stress condition. Thus, indirect selection for a drought-prone environment based on the results of optimum condition will not be efficient (Sio-Se Mardeh *et al*., 2006). The number of pods per plant, and number of seeds per pod reduced significantly when water deficit stress occurring at either vegetative or reproductive stages, leading to a reduction in seed yield (Table 2 and 3). The highest pods per plant were recorded for Opera and Orient cultivars in full irrigation regime, while the lowest ones were recorded for Okapi and Zarfam cultivars (Table 2 and 3). Number of pods per plant was the most sensitive yield components to water stress occurring at reproductive growth stage (Diepenbrock, (2000). Seed yield of rapeseed depended on density, number of pods per plant, number of seeds per pod and seed weight (Angadi *et al*., 2003).

It seems that water stress caused yield reduction probably by inducing pod abortion via limiting photosynthesis. Under drought stress, stomata become blocked or half-blocked, leading to a decrease in absorbing CO_2. At the same time, the plants tended to consume a lot of energy to absorb water, causing a reduction in producing photosynthetic assimilates (Moaveni *et al*., 2010). It appears that water stress hampered flowering and reduced the probability of developing flower to pod and its occurrence during flowering and pod formation resulted in pod abortion (Shirani Rad, 2012). Mendham and Salisbury (1995) reported that competition for assimilates among new branches and extra pod formation at the time when seed numbers are set was responsible for decreasing seeds per pod as well. Clarke and Simpson (1978) suggested that increased number of pods per plant in irrigation treatments were primarily due to lengthening of the flowering period. Due to the reduction in the area of photosynthesis, a drop in producing chlorophyll was happened and also, the rise of the energy consumed by the plant in order to take in water caused the increasing the density of the protoplasm, changing respiratory paths and, the activation of the path of phosphate pentose, or the reduction of the root spread, which could finally reduce plant height (Moaveni *et al*., 2010). The interaction between rapeseed cultivar and irrigation level was significant for harvest index at 0.05 probability level (Table 1). The lower harvest index for Okapi under severe drought stress (IR_2) indicates lower partitioning of dry matter towards the seed. Reduction in the length, width and area of the leaf, and reduction in the plant height and tiller number, all contribute to the reduction of plant's evaporation area and photosynthesis and consequently, dry matter decreases (Moaveni *et al*., 2010). Daneshmand *et al*. (2007) suggested that at water stressed conditions, those rapeseed cultivars which were able to maintain their relative water content at high levels, also had higher seed yield.

Table 2. Effects of irrigation level (IR) and cultivar (V) on yield components, seed yield, biological yield, harvest index, oil content and yield of rapeseed during 2007-2008.

Oil yield (kg ha^{-1})	Oil content (%)	Harvest index	Seed yield (kg ha^{-1})	1000-seed weight(g)	Number of seeds per pod	Number of pods per plant	Treatment
Interaction (I irrigation × V variety)							
2088.04ab	42.89ab	30.44a	4858ab	4.89abcd	24a	111.833b	IR1 * V1
1949.47bcd	44.09ab	27.35bcdef	4678abc	4.33cde	22.3abc	97c	IR1 * V2
2211.05a	44.76a	29.57ab	4941a	5.06ab	21.3bcd	110.333b	IR1 * V3
1984.21bc	43.24ab	26.1cdefg	4594.3bcd	4.79abcde	23ab	130.667a	IR1 * V4
1665.56fghij	44.67a	24.73g	4272.3ef	5.02ab	23.3a	95c	IR1 * V5
1779.9defgh	42.87ab	25.93defg	4174efg	4.93abcd	23.7a	97c	IR1 * V6
1493.29j	44.16ab	24.82fg	3379l	4.77abcde	19.2efgh	64jklm	IR2 *V1
1835.17vdef	44.49a	29.14ab	3884.7ghij	4.44bcde	17.3ijk	63.3jklm	IR2 *V2
1590.84ij	43.25ab	21.85hi	3680.7jkl	4.56bcde	16.3k	60.3klm	IR2 *V3
1753.95efghi	42.92ab	25.6efg	3882ghij	4.71abcde	18hijk	56m	IR2 *V4
1658.26ghij	44.96a	24.29gh	3547.7kl	4.7abcde	17jk	55.3m	IR2 *V5
1741.51efghi	42.97ab	27.95abcde	3444.7l	4.56bcde	17jk	58.7lm	IR2 *V6
1662.26fghij	44.04ab	20.46i	3772.3ijk	4.28de	21.3bcd	70.3hijk	IR3 * V1
2038.02ab	43.56ab	28.02abcde	4170.7efg	4.16e	20defg	75.67fghi	IR3 * V2
1797.34defgh	41.77b	19.82i	4162.7fgh	5.28a	18.7fghij	82defg	IR3 * V3
1790.01defgh	44.29ab	26.16cdefg	4039.3fghi	4.69abcde	19efghi	71.3ghij	IR3 * V4
1851.29cde	43.91ab	20.62i	3674jkl	5.13ab	18.7fghij	67.67ijkl	IR3 * V5
1530.85j	44.45a	28.41abcd	3817.7ijk	4.54bcde	18.3ghij	88cde	IR3 * V6
1828.63cdefg	43.2ab	21.96hi	4241.7ef	4.64abcde	22.3abc	90.3cd	IR4 * V1
1753.06efghi	44.08ab	28.46abc	4475cde	4.64abcde	21cd	80.3defgh	IR4 * V2
1805.41defgh	43.35ab	23.99gh	4301def	4.53bcde	20defg	91cd	IR4 * V3
1797.88defgh	43.74ab	29.9a	4136.7fgh	4.76abcde	20.3def	78.3efghi	IR4 * V4
1583.92ij	44.68a	24.11gh	3863.3hij	4.89abcd	20.7cde	86.3cdef	IR4 * V5
1644.53jhi	43.06ab	25.67efg	4036.7fghi	4.47bcde	19.7defgh	83.3def	IR4 * V6
175.38	2.66	2.53	306.37	0.71	1.83	10.78	LSD

Means with different letter in each column are not significantly different (LSD=5%).
Control (IR1), no irrigation after the start of stem elongation stage (IR2), no irrigation after the start of flowering stage (IR3) and no irrigation after the start of podding stage (IR4).
Licord (V1), SLM046 (V2), Okapi (V3), Orient (V4), Zarfam (V5) and Opera (V6)

Table 3. Effects of irrigation level (IR) and cultivar (V) on yield components, seed yield, biological yield, harvest index, oil content and yield of rapeseed during 2008-2009.

Treatment	Number of pods per plant	Number of seeds per pod	1000-seed weight(g)	Seed yield (kg ha^{-1})	Harvest index	Oil content (%)	Oil yield (kg ha^{-1})
Interaction (I irrigation × V variety)							
IR1 * V1	70.37efgh	25.33abcd	3.89abc	3013.9ab	21.94abcd	47.47a	1430.6ª
IR1 * V2	98.83bc	26.33ab	4.05ab	2773.2abc	26.51abc	46.43abcd	1165.2abcd
IR1 * V3	66.73efgh	25.1bcd	3.83abc	2956ab	30.09a	45.39abcdef	1340.1ab
IR1 * V4	68.73efgh	25.67abcd	3.4c	2736.1abcd	23.09abcd	47.24ab	1173.6abcd
IR1 * V5	77.83def	24.33bcde	3.81abc	2601.8bcd	28.61ab	44.84cdef	1123.7abcde
IR1 * V6	126.87a	19.67g	3.86abc	3219.9a	24.99abcd	43.94ef	1414.2ª
IR2 *V1	75.6def	28a	3.67abc	1669ijkl	18.75abcd	44.99bcdef	921.8cdefg
IR2 *V2	36.37i	25.33abcd	4.1a	1719hijkl	22.13abcd	45.04bcdef	810.9efg
IR2 *V3	59.9fgh	23.57bcde	3.97abc	1620.4jkl	17.08bcd3	44.84cdef	726.6fg
IR2 *V4	56.23gh	24.33bcde	3.92abc	1435.2kl	14.37d	44.77cdef	839.8defg
IR2 *V5	54.13hi	21.67efg	3.5bc	1294l	16.2cd	45bcdef	945.8cdef
IR2 *V6	91.33bcd	25.9abc	3.68abc	1879.5ghijk	19.21abcd	43.27f	991cdef

IR3 * V1	74.13defg	25bcd	3.65abc	2280.1cdefg	23.99abcd	44.79cdef	890.1cdefg
IR3 * V2	60.93fgh	26abc	3.82abc	2043.2efghij	19.59abcd	44.23def	1096.7abcde
IR3 * V3	72.43efgh	24.1bcde	3.74abc	1995.4fghij	21.95abcd	46.56abc	933.3cdef
IR3 * V4	78.13def	23def	3.84abc	2199defghi	27.57abc	44.05ef	1140.3abcde
IR3 * V5	81.1cde	24bcde	3.86abc	1627.3jkl	19.83abcd	45.57abcde	588g
IR3 * V6	77.93def	23.33cde	3.9abc	2411.2cdefg	27.36abc	45.04bcdef	1001.5bcdef
IR4 * V1	92.87bcd	20.33fg	3.71abc	2500bcdef	21.8abcd	46.06abcde	1104.8abcde
IR4 * V2	98.37bc	25bcd	4.11	2328.7cdefg	20.65abcd	45.59abcde	955.2cdef
IR4 * V3	102.7b	23def	3.98abc	2578.7bcde	23.86abcd	45.66abcde	1182.8abc
IR4 * V4	75.7def	24.9bcd	3.64abc	2409.7cdefg	20.17abcd	47.38a	869.7cdefg
IR4 * V5	71.73efgh	21.9efg	4.06ab	2226.1defgh	23.39abcd	46.15abcde	844.3cdefg
IR4 * V6	65.7efgh	23.33cde	4.01ab	2733.8abcd	24.31abcd	44.81cdef	1118.3abcde
LSD	18.745	2.89	0.6	537.49	11.56	2.26	342.02

Control (IR_1), no irrigation after the start of stem elongation stage (IR_2), no irrigation after the start of flowering stage (IR_3) and no irrigation after the start of podding stage (IR_4).
Licord (V1), SLM046 (V2), Okapi (V3), Orient (V4), Zarfam (V5) and Opera (V6)
Means with different letter in each column are not significantly different (LSD=5%).

The correlation coefficients among the measurements are shown in Table 4. All the characters except oil content and 1000-seed weight were positively correlated with seed yield in two years. In both years, oil yield showed the highest correlation value with seed yield in comparison to the others ($r = 0.7^{**}$ and 0.71^{**}). Sadaqat *et al*. (2003) found that seed yield had significant positive correlation with pods per plant and branches per plant under drought conditions. Among yield components, number of seed per pod and number of pods per plant had greatest influence on seed yield. Our results were similar to the findings of Biabani *et al*. (2008), Singh (2007) and Aliabadi *et al*. (2009).

Table 4. Correlation Coefficients between characters calculated from six rapeseed cultivars in 2007-2008 (above diagonal) and 2008-2009 (below diagonal).

Characters	Number of pods per plant	Number of seeds per pod	1000-seed weight	Seed yield	Harvest index	Oil content	Oil yield
Number of pods per plant	1	0.72^{**}	0.18ns	0.64^{**}	0.23ns	-0.03ns	0.46^{**}
Number of seeds per pod	-0.1ns	1	0.18ns	0.61^{**}	0.12ns	0.06ns	0.32^{**}
1000-seed weight	0.08ns	-0.27^{*}	1	0.1ns	-0.1ns	-0.1ns	0.04ns
Seed yield	0.46^{**}	-0.08ns	0.03ns	1	0.47^{**}	-0.07ns	0.7^{**}
Harvest index	0.19ns	-0.1ns	0.14ns	0.5^{**}	1	0.06ns	0.38^{**}
Oil content	-0.07ns	0.09ns	0.04ns	0.24^{*}	-0.01ns	1	0.17ns
Oil yield	0.29^{*}	-0.01ns	-0.09ns	0.71^{**}	0.37^{**}	0.09ns	1

ns, *, ** and ***: non significant, significant at the 5%, 1% and 0.1 % levels of probability, respectively.

Conclusions: In this study, our results demonstrated that seed yield and yield components were significantly reduced by drought stress occurring at either vegetative or reproductive growth stage of rapeseed cultivars. The differential response of cultivars to imposed water stress condition indicates the drought tolerance ability of rapeseed cultivars. SLM046 cultivar showed higher ability to capture soil moisture under severe competition and had the least reduction in seed yield compared to the other cultivars. SLM046 cultivar has the least percentage of yield reduction and it was the best yielding in water stress conditions.

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