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The effects of irrigation regimes and nitrogen rates on some agronomic traits of canola under a semiarid environment

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ABSTRACT

This study was aimed to investigate dual effects of irrigation regimes and N fertilizer rates on some agronomic traits (with emphasis on yield qualitative and quantitative characteristics) and finding optimized irrigation level and N application rate for two canola (*Brassic napus* L.) cultivars. For this purpose, two variety of canola (Zarfam and Modena), four irrigation regimes including 30%, 45%, 60% and 75% (I1–I4) of maximum allowable depletion (MAD) of available soil water (ASW) and four nitrogen rates (viz. 0, 90, 180 and 270 kg N ha^{-1} (N1–N4) were involved in Karaj, Iran for two successive years (2007–2008). Our results revealed special fertilizer threshold for each irrigation regime in respect to seed yield. Response rate to fertilizers was ceased in lower fertilizer rates by prolonging irrigation. The response rate showed a decrease of 15.4%, 17.2% and 30.7% in I2, I3 and I4 in comparison with I1, but I2 response to fertilizer ceased in higher N rate as $N_{critical}$ (189.8 kg N ha^{-1}). This implies that I2 improved response of canola cultivars to N fertilizer, which was accompanied by its higher WUE. Also, all estimated $N_{critical}$s for all irrigation levels were higher than the current recommendation of 130 kg N ha^{-1}. This show the capability of increasing canola cultivars yield in study region by reasonable increasing of fertilizer rate (decreasing gap between recommended N rate and estimated values) in advisable irrigation regime (I2). Cultivars tended to respond similarly to irrigation and nitrogen for seed yield in both years, but Zarfam was more efficient than Modena in respect to response to diverse treatments.

1. Introduction

Drought, one of the environmental stresses, is the most significant factor restricting plant growth and crop productivity in the majority of agricultural fields of the world (Abedi and Pakniyat, 2010). In crop production, instead of achieving maximum yield from a unit area by full irrigation, water productivity can be optimised within the concept of deficit irrigation (Istanbulluoglu et al., 2010).

Proper scheduling of irrigation to apply required quantities of water during the critical period, yet allowing moderate stress at vegetative and maturity stages is necessary for good growth and yield (Al-Barrak, 2006). Scarce water resources and growing competition for water will reduce its availability for irrigation. At the same time, rising costs of irrigation pumping, low commodity prices, inadequate irrigation system capacities and limited irrigation water supplies are among the reasons that prompt many irrigatiors to deliberately apply less water than is required to obtain maximum yield (Craciun and Craciun, 1999). The goal of effective management of irrigation water is to enhance economic returns with limited use of water and/or energy. Regulated deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on yield (Sidhu et al., 2008). Identifying growth stages of a particular cultivar under local conditions of climate and soil fertility allows irrigation scheduling to maximize crop yield and most efficient use of scarce water resources (Mahal and Sidhu, 2006).

Nitrogen (N) fertilizer plays a crucial role in enhancing canola yield. A high rate of N application increases leaf area development, improves leaf area duration (LAD) after flowering, number of branches per plant, the number of silique per plant and increases overall crop assimilation, thus contributing to increased seed yield (Rose et al., 2008; Ozer, 2003). Brassica oilseed crops respond to N fertilizer positively even when N fertilizer is applied at rates as high as 180 kg N ha^{-1} (Brandt et al., 2002). Amounts of N fertilizer

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Table 1
Result of some chemical and physical analysis of experimental soil.

Depth (cm)	Potassium (ppm)	Phosphor (ppm)	Nitrogen (%)	Organic matter (%)	EC (mmos/cm)	pH	FC (%)	PWP (%)
0–30	171	3.8	0.05	0.49	1.2	7.68	15.55	6.5
30–60	179	2.8	0.04	0.29	2.19	7.67	16.15	7.1

Table 2
Details of the irrigation events of canola under different schedule of irrigation for all the experiments.

Year	I1 amount (m^3)	I2 amount (m^3)	I3 amount (m^3)	I4 amount (m^3)
2006–2007	6.7	6.01	5.12	4.6
2007–2008	5.2	4.68	4.42	3.81

required for maximum yield of oilseed species vary, depending on environmental conditions (Gan et al., 2007).

The review of the previous works revealed that, either irrigation water or the nitrogen effects had been studied individually, on the response of canola. Thus, our primary aim was to study the effect of different schedules of irrigation and nitrogen rate on yield, yield components and seed oil content of canola under semiarid condition.

2. Material and methods

2.1. Experimental site

The study was conducted at Agricultural Research Station of Karaj, Tehran province, Iran (50°57′20′′E and 35°48′44′′N; 1321 m elevation) during the years of 2007 and 2008. The local climate is semi-arid with an average rainfall of 243 mm concentrated over the months of December–April. The average temperature for growing seasons was 21 °C and 19 °C in 2007 and 2008, respectively. The soil at the experimental site was sandy loam with physical and chemical properties as summarized in Table 1.

2.2. Field layout and experimental details

In this study, two canola cultivars, Zarfam and Modena, were used. As cultivar Zarfam is more drought-resistant than Modena (Daneshmand, 2006). The study (a randomized complete block design with four replicates) was conducted at two years and consisted of a factorial combination of two canola cultivars, four irrigation regimes and four nitrogen rates. The irrigation regimes consisted of irrigation scheduling based on maximum allowable depletion (MAD) of the total available soil water (ASW). Each irrigation regime was based on a predefined level of MAD, which was a fixed percent of the total ASW. Irrigation water was applied whenever the threshold value of MAD for the particular irrigation treatment was attained. The irrigation treatments signed by I1–I4 as 30%, 45%, 60% and 75% MAD of ASW.

The target plant density was 95 plants per m^2. The area of each plot was 1.8×5.3 m (9.6 m^2) consisting of 6 rows, 5.3 m long and 30 cm apart, Maintaining a buffer of 2m between adjacent plots.

Irrigation scheduling was based on the depletion percentage of available soil water in the root zone. The available soil water was taken as the difference between root zone water storage at field capacity and permanent wilting point. For estimating soil water storage, the effective root zone of canola crop was considered as 0–60 cm (Daneshmand, 2006). Soil moisture was measured by gravimetric measurement, also these instruments were used such as Auger, Shovel, Sampling metal container, Oven (Memmert, UNB-100-500). The amount of water applied after the attainment of predefined MAD was calculated (Panda et al., 2004) as Eq. (1).

$$V_d = \frac{\text{MAD}(\%)(\text{FC} - \text{WP})R_z A}{100} \quad (1)$$

where V_d is the volume of irrigation water, R_z the effective rooting depth, A the surface area of the plot and FC and WP are root zone water storage in the limits of field capacity and wilting point, respectively. The total quantity of water applied during each irrigation event is given in Table 2 for the two experiments. More much water was applied in the first year compared with the second year because of different rainfall of 230 mm versus 260 mm.

Nitrogen (urea) was splited as half with sowing (incorporated) and the remaining half at the beginning of stem elongation (hand broadcasted) (N45 + 45, N90 + 90, and N135 + 135). All plots received phosphorus at 60 kg ha^{-1} as triple super phosphate and 50 kg K_2O ha^{-1} from potassium sulphate at sowing in both years.

The dry matter was determined after drying the plant material at 65 °C and constant weight during three consecutive days. Measurements of canola LAI were taken from 50 cm length of one row of each plot. Plant samples were taken approximately every 20 days in both of years. Sampling started from day 60 after emergence and involved 10 plants from the selected sampling area. Leaf area was estimated by measuring the green leaf area of all leaves with a leaf area meter (Model LI-3000, LI-ORInc., Lincoln, NE).

Plots were harvested on 27–31 May in 2007 and 2008 when approximately 40% of seed was brown. All above-ground plant material was cut from 4 random quadrates of 0.5 m^2 (1 m × 0.5 m) in each plot for harvest yield, components of yield, N and Oil analyses. Days to maturity also was recorded on 10 tagged plants. At harvest maturity, lodging scores were also determined (0.0, all plants uprighted; 5.0, all plants prostrated). Seed oil content was determined by the Soxhlet apparatus (Behro test, In-Line Extraction units) and seed N concentration was determined by micro-Kjeldahl method (Page et al., 1982). Water use efficiency was considered as the proportion of seed yield)kg(/total water use (m^3) during crop growth period (FAO, 2000).

The relationship between irrigation regimes and N fertilizer rates was investigated by regressing seed yield against N fertilizer rates using a segmented linear-plateau model (Soltani et al., 2006; Kamkar et al., 2011) as Eq. (2).

$$\begin{aligned} y &= a + b\text{N if N} < \text{N}_{\text{critical}} \text{ (linear part)} \\ y &= a + b\,\text{N}_{\text{critical}} \text{ if N} \geq \text{N}_{\text{critical}} \text{ (plateau part)} \end{aligned} \quad (2)$$

where y is the yield (kg ha^{-1}), N is fertilizer rates (kg N ha^{-1}), $N_{critical}$ is the critical point or the N fertilizer rate at which the plateau begins, a and b are model coefficients. The plateau of the regression estimated the maximum yield, and the critical point of the regression estimated the N fertilizer rate at which the maximum seed yield was achieved. These nonlinear regression coefficients were estimated using iterative optimization method by the Solver Add-ins tool of Microsoft Excel (2003).

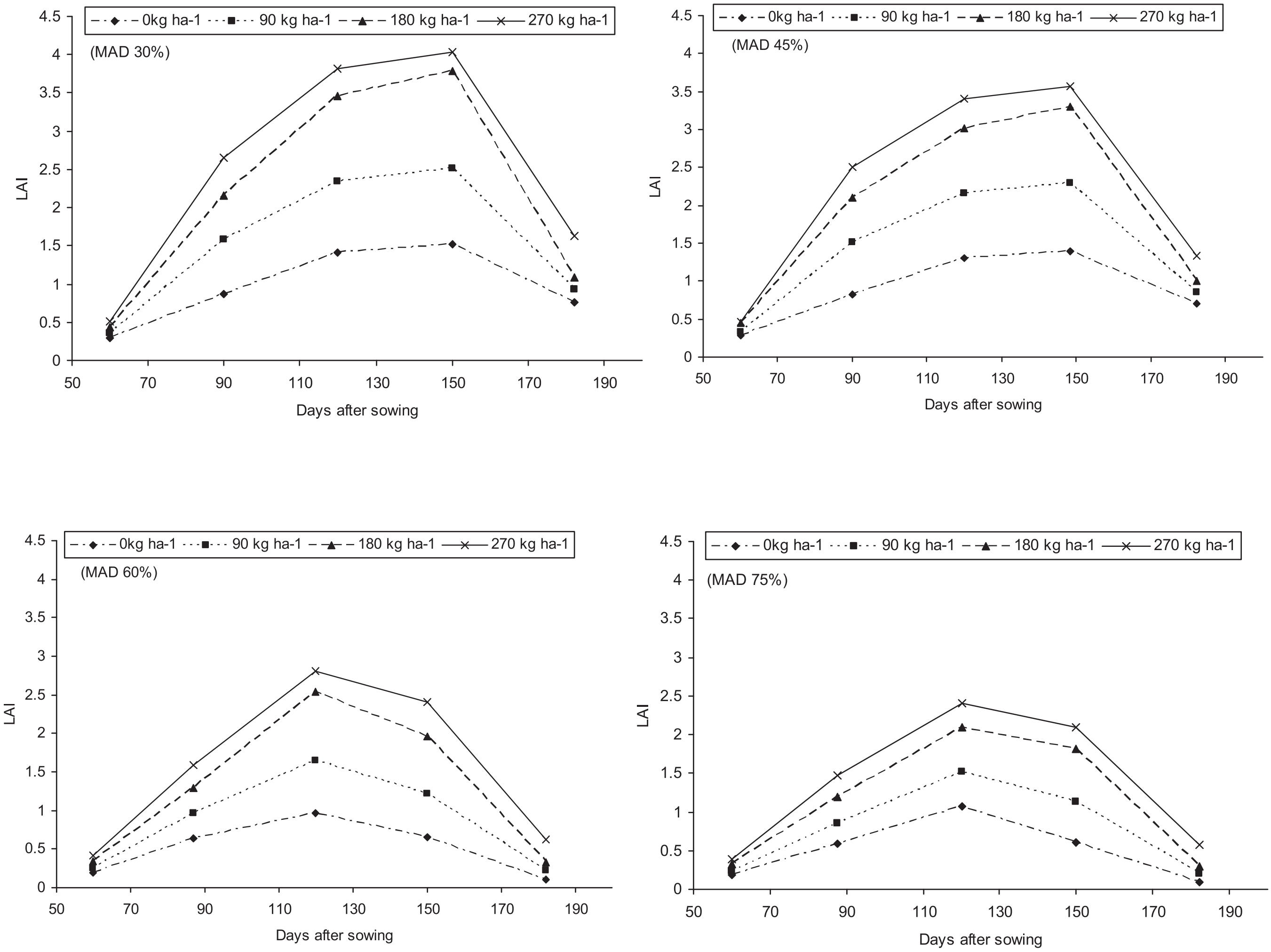

Fig. 1. Leaf area index of canola as influenced by irrigation and nitrogen application treatments, average data for two experiments.

3. Results and discussion

3.1. Leaf area index

The reduction of leaf area index was insignificant from I1 to I2, due to marginal effect of variation in soil moisture (Fig. 1). However, a little more reduction in the leaf area index was noticed when irrigation was scheduled at MAD of more than 45% MAD that is at 60% (I3) to 75% (I4) MAD. It was also observed that at a particular irrigation treatment, LAI was significantly greater in N4, followed by N3, N2 and N1. However, maximum LAI belonged to I1–N4. The combination of more irrigation and nitrogen application (N4 and N3) significantly influenced LAI probably by improving more of the basic infrastructural frame and the photosynthetic production efficiency of leaves (Mandal et al., 2006). The combined effect of irrigation and nitrogen was prominent in leaf area duration also.

3.2. Dry matter production

In all nitrogen treatments, increase in water applied at I1 and I2 increased the DM production of the crop (Fig. 2). Among the nitrogen treatments, N4 maintained significantly greater DM throughout the growing period, followed by N3, N2 and N1 under all irrigation levels (Fig. 2).

In the combined treatment of N4 with I1 (high water and fertilizer supply), the crop produced greater DM (Fig. 2). This may be due to synthesizing more food in the leaves with better water relation in plants (Majid and Simpson, 1997).

Seed yield of canola was affected by rainfall and temperature during growing season, as suggested by the significant effect of year (Y) in the combined ANOVA (Table 3), therefore each year data was analyzed separately.

Averaged over the all treatments, the plants grown in 2007 had 11 days shorter maturity than those in 2008. Irrigation regimes, cultivar, and nitrogen rates influenced the time to maturity and crop height significantly (Tables 3 and 4). In general, short height and fewer days to maturity were more prominent beyond the depletion level of 45% MAD that was seen for the treatments I3 and I4 (Table 4). This could be due to the fact that the greater soil moisture depletion level than 45% MAD was sufficient enough to limit extraction of water by the roots and led to more rapid development of the crop. Faraji et al. (2009) reported that irrigation supplementary result delayed maturity in rapeseed.

Addition of N fertilizer delayed canola maturity and increased height in 2007 and 2008 (Tables 3 and 4). Ozer (2003) also observed delayed maturity in spring-sown oilseed rape due to high N levels.

Differences between cultivars were observed for plant height (Table 3). Zarfam produced significantly taller plants than Modena (Table 4). The variation in plant height can be partly explained by difference observed in days to maturity. As days to maturity, the height at the first year was also less than the second year, because total rainfall during the growth stages of canola in the second year

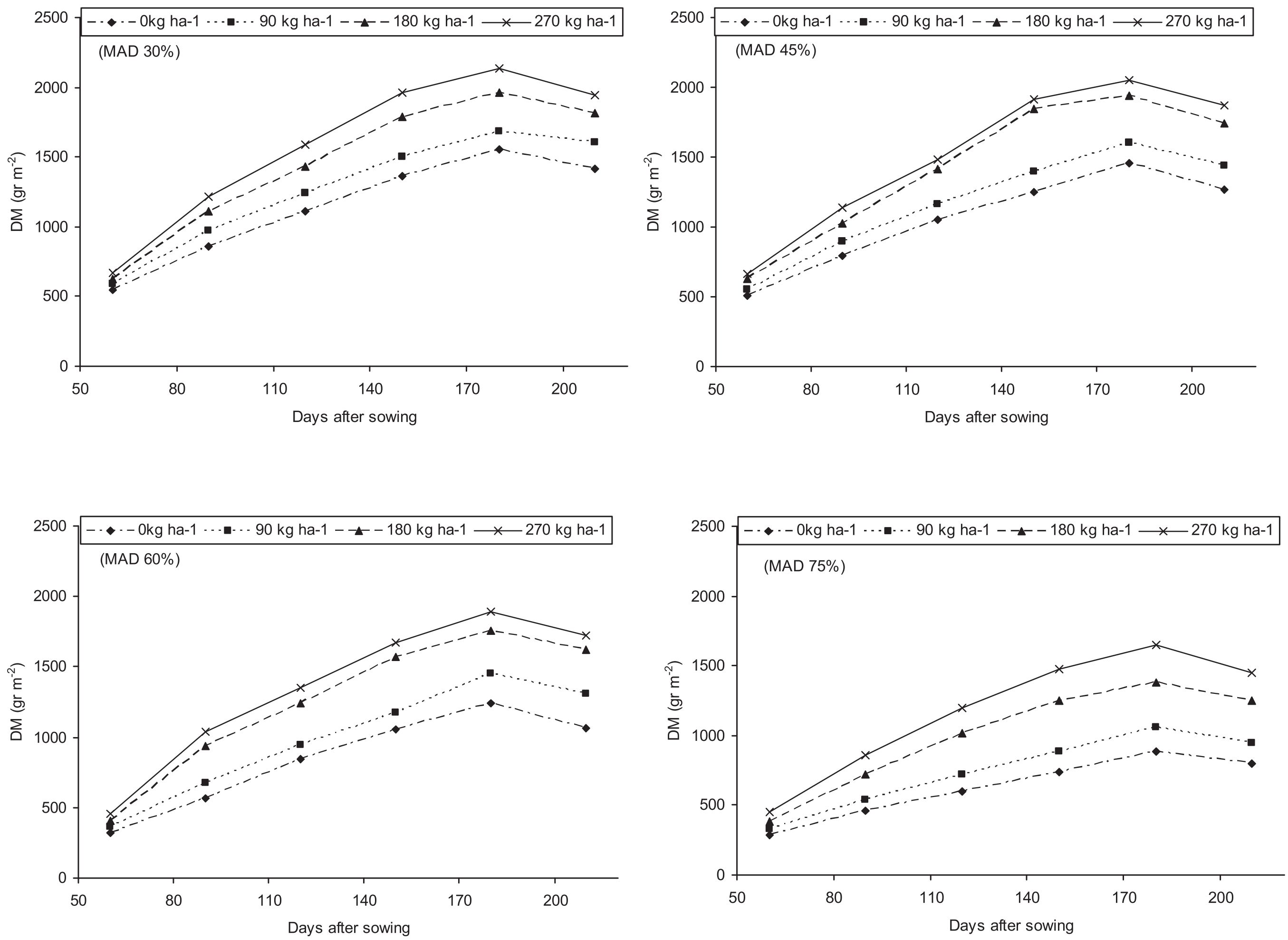

Fig. 2. Dry matter production of canola as influenced by irrigation and nitrogen application treatments, average data for two experiments.

Table 3
Analysis of variance for some agronomic traits of canola in the combined ANOVA.

Source of variation	*Df*	Days to maturity	Plant height	Lodging score	Silique number (no. plant^{-1})	Seed number (no. silique^{-1})	1000-Seed weight	Seed yield	Seed oil concentration	Seed N concentration	Water use efficiency
Year (Y)	1	**	**	**	**	*	*	*	*	*	*
Irrigation (I)	3	**	**	**	**	**	*	**	*	*	**
Cultivar (C)	1	**	**	*	*	*	**	**	*	*	**
Nitrogen (N)	3	**	**	**	**	**	*	**	*	**	**
Y × I	3	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Y × N	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × C	1	NS	NS	*	*	*	NS	NS	NS	NS	NS
C × N	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × I	3	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
N × I	9	NS	NS	NS	NS	NS	NS	*	NS	NS	NS
C × N × Y	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × I × Y	3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × I × Y	9	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × N × I	9	*	NS	NS	NS	NS	NS	NS	NS	NS	NS
C × N × I × Y	9	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V. (%)		0.54	4.9	30.2	11.44	7.32	7.74	15.89	6.86	17.31	12.5

NS, non significant, * and **, significant at the 0.05 and 0.01 level of probability, respectively, C.V., coefficient of variation.

was more than that in the first year. Similar observation was made by Al-Barrak (2006).

The analysis of variance revealed significant differences in lodging scores between the cultivars in 2007 with a different in the 2008 growing season, probably because of different rainfall. The effect of irrigation regimes on lodging was significant for both years (Table 3). In both years, (I1) 30% MAD canola tended to lodge more than other irrigation regimes, because of the taller plants and excessive silique weight (pod plus grain weight) with (I1) 30% MAD (Table 4). As expected, N applications up to 270 kg N ha^{-1} increased lodging each year (Table 4). This obviously is an indirect effect, since high N rates promote the formation of more silique and seeds but also decrease of stem strength.

Table 4
Mean comparison some agronomic traits of canola under irrigation regimes, cultivars, and nitrogen rates.

	Days to maturity (*d*)	Plant height (cm)	Lodging score	Silique number (no. plant^{-1})	Seed number (no. silique^{-1})	1000-Seed weight(g)	Seed yield (kg ha^{-1})	Seed oil concentration (%)	Seed N concentration (%)	Water use efficiency (kg m^{-3})
Y1										
I1	230 a*	192 a	1.44 a	191 a	25 a	3.7 a	3872 a	40.81 a	20.11a	0.54 b
I2	229 a	189.7 b	1.41 a	188 a	24 a	3.6 a	3850 a	40.40 b	18.94 b	0.61 a
I3	225 b	180 c	0.97 b	119 b	20 b	3.21 b	3135 b	39.8 c	16.6 c	0.53 b
I4	220 c	173.8 d	0.78 c	83 c	18 c	3.2 b	2654 c	37 d	16.5 d	0.47 c
N1	227 c	194 d	0.0 d	73 d	20 c	3.26 c	2312 c	41.9 a	16.01 d	0.37 c
N2	229 b	196 c	0.84 c	105 c	22 b	3.33 b	3124 b	39.6 b	18.07 c	0.41 b
N3	229 b	199 b	1.69 b	170 b	25 a	3.44 a	3800 a	39 c	19.73 b	0.51 a
N4	230 a	201 a	2.38 a	190 a	25 a	3.5 a	3700 a	37.74 d	21.44 a	0.5 a
Zarfam	229 a	189	1.33 a	130 a	23 a	3.51a	3250 a	40.2 a	19.37 a	0.56 a
Modena	228 b	187	1.12 b	128 b	20 b	3.2 b	3157 b	39. b	18.38 b	0.5 b
Y2										
I1	241 a	199 a	1.81 a	210 a	28 a	3.74a	4190 a	44.9 a	21.13	0.63 b
I2	240 a	197 b	1.5 b	207 a	27 a	3.65 a	4134 a	44.7 a	21.1	0.79 a
I3	234 b	189.3 c	1.12 c	131 b	24 b	3.5 b	3264 b	43.8 b	20.95	0.56 c
I4	233 b	185.9 d	0.94 d	91 c	23 b	3.47 b	2740 c	41.73 b	20.9	0.5 d
N1	C 237	201.8 b	0.03 d	80.3 d	22 d	3.53 b	2464 d	46.17 a	17.62 d	0.4 d
N2	C 238	203 b	0.97 c	115 c	24 c	3.59 b	3231 c	43.58 b	19.68 c	0.63 c
N3	B 240	206 a	1.84 b	196 b	26 b	3.76 a	3830 b	42.7 c	21.47 b	0.73 b
N4	A 242	207 a	2.22 a	210 a	27 a	3.75 a	3991 a	41.52 d	23.55 a	0.88 a
Zarfam	240 b	196.6 a	1.28 a	144 a	26 a	3.8 a	3499 a	43.74 a	21.1 a	0.6 a
Modena	238 a	191.5 b	1.25 a	141 b	24 b	3.75 b	3389 b	43.2 b	20 b	5.5 b

* Mean values on the same columns with the same letters are not significantly different ($P<0.05$) according to the LSD.

3.3. Yield components

Irrigation regimes had significant influences on silique number, seed number and 1000 seed weight (yield components) of canola cultivars (Table 3). The results (Table 4) revealed the trend of variation in yield components from I1 to I2 was found to be almost similar during all experiments. The reduction in 1000-seed weight from I1 to I2 was inconsiderable due to marginal effect of different moisture level between I1 to I2. However, the decline in 1000-seed weight was more prominent beyond the depletion level of 45% MAD. The reduction in the yield components of the I3 and I4 could be attributed to increased temperature (Taiz and Zeiger, 2002) and consequently leaf area decreasing (Fig. 1), which is considered as an important factor affecting silique and seed growth and development of canola. This effect varied with the study years (Table 3). In 2008, the cultivars consistently gave more silique, seed number and 1000 seed weight due to the crop experienced no stress during the critical stages of the second year due to timely occurrence of rainfall (Table 4).

The results also revealed that number of silique, seed number and 1000 seed weight increased with an increase in applied N fertilizer (Table 4). These results agree with the findings by Cheema et al. (2001) who found that the number of silique and seed number per plant increased with increasing rates of N. This can be explained by increased leaf growth with higher N rates (Gan et al., 2008). Zarfam tended to be higher in seed weight than Modena (Table 4). This is a cultivar-dependent characteristic.

3.4. Seed yield

Zarfam had higher seed yield than Modena (Table 4). The variation in seed yield from I1 to I2 was found to be almost similar during two crop experiments (Table 4). The reduction in seed yield from I1 to I2 was little due to marginal effect of moisture level variation between I1 and I2, which is 30–45% MAD. However, the decline in seed yield was more prominent beyond the depletion level of 45% MAD (I3 and I4). Similar trends were observed during the two experiments. As rainfall during the growth stages in the first year was less than that in the second year; the seed yield was less in the first year than that in the second year. The crop experienced no stress during the critical stages of the first year due to timely occurrence of rainfall.

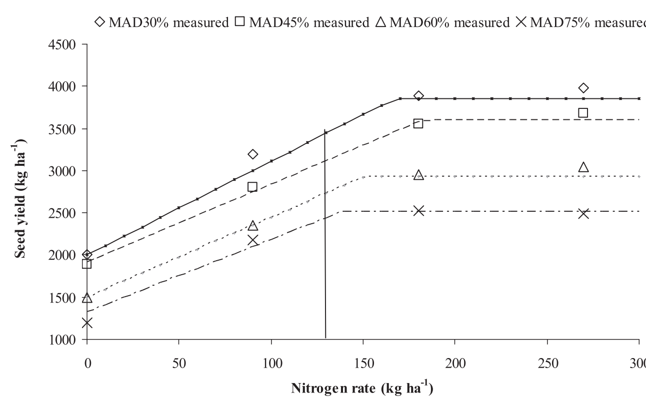

Fig. 3. Nonlinear regression output for seed yield produced under different irrigation regimes, averaged data for two experiments, the vertical solid line indicates the recommended rate of N fertilizer (130 kg N ha^{-1}) for canola production under normal growing conditions.

The yield reductions in canola at I3 and I4 MAD of ASW can be explained by fewer silique per plant and lower 1000-seed weight (Table 4). The water stress usually causes a decline in growth, leaf area, and a hasten maturation (Sinaki et al., 2007), thus decreasing seed yield.

Seed yield responded to N fertilizer rates in a curvilinear manner, and the responses were consistent among the irrigation regimes and cultivars (Fig. 3). The segmented linear-plateau model revealed that seed yield increased sharply with increasing N fertilizer rates up to $N_{critical}$ (Fig. 3 and Table 5). Beyond $N_{critical}$, the yield response to N fertilizer rates was generally leveled off or the rate of increase in yield declined. The rate of $N_{critical}$ was greater than the current recommendation of 130 kg N ha^{-1} (the vertical solid line in Fig. 3; Roodi et al., 2004). The intercept of the regressed line indicated the minimum yield, which in most cases occurred when no N fertilizer was applied. The critical point of the segmented lines estimated the N fertilizer rate at which the maximum seed yield was achieved, while the plateau of the regression estimated the

Table 5
Summary of the nonlinear regression coefficients (*a*, intercept; *b*, linear slope coefficient; critical point, N fertilizer rate at which the plateau begins) for seed yield. Average data for two experiments (Eq. (2)).

Irrigation regimes	R^2	*a*	*b*	$N_{critical}$
I1	0.97	1999	11.11	166.5
I2	0.97	1850	9.4	189.8
I3	0.97	1500	9.2	150
I4	0.98	1200	7.7	147

maximum yield. The I1 and I2 were the most responsive irrigation levels to added N fertilizer (highest b value) in terms of seed yield. The critical point for seed yield was the lowest for I4 and highest for the I2. Nitrogen rate recommendations are site-specific and affected by environmental conditions. Therefore, knowledge of the residual soil N, rate, and amount of N mineralized from soil organic sources, and individual crop needs are all required to optimize N fertilizer recommendations.

3.5. Seed oil concentration

Increased oil concentration in the second year (Table 4) may have been related to wetter weather conditions. In both years, oil concentration generally reduced as irrigation was delayed (Table 4). These results are consistent with those reported by Sinaki et al. (2007), who reported that high oil contents were correlated with high water availability. It is likely that increased temperature and water stress during seed filling was a major cause of reduced oil concentration (Hocking and Stapper, 2001). In both years, higher N rates usually reduced seed oil concentration (Table 4). Oil concentration was inversely related to the N concentration in the seed ($P < 0.05$; Table 4), which is in agreement with Cheema et al. (2001). Although N fertilizer decreased oil concentration, but increased oil yield.

3.6. Seed N concentration

Seed N concentration was not influenced significantly by irrigation regimes in 2008 (Tables 3 and 4). But was affected significantly by cultivars and nitrogen rates (Tables 3 and 4). Seed N concentration responses to N application were similar in both years. Increasing N rates resulted in significantly higher seed N concentration in canola. These observations supported Ogunlela et al. (1990), who reported that nitrogen concentration in seeds of canola increased with N supply. This was probably due to increased seed N uptake with increasing N fertilizer rate and also the N uptake seed was closely associated with yield and seed N concentration (Gan et al., 2008).

3.7. Water use efficiency

Water use efficiency was influenced by the treatments (Table 3). Zarfam had higher WUE than Modena (Table 4). The results shown

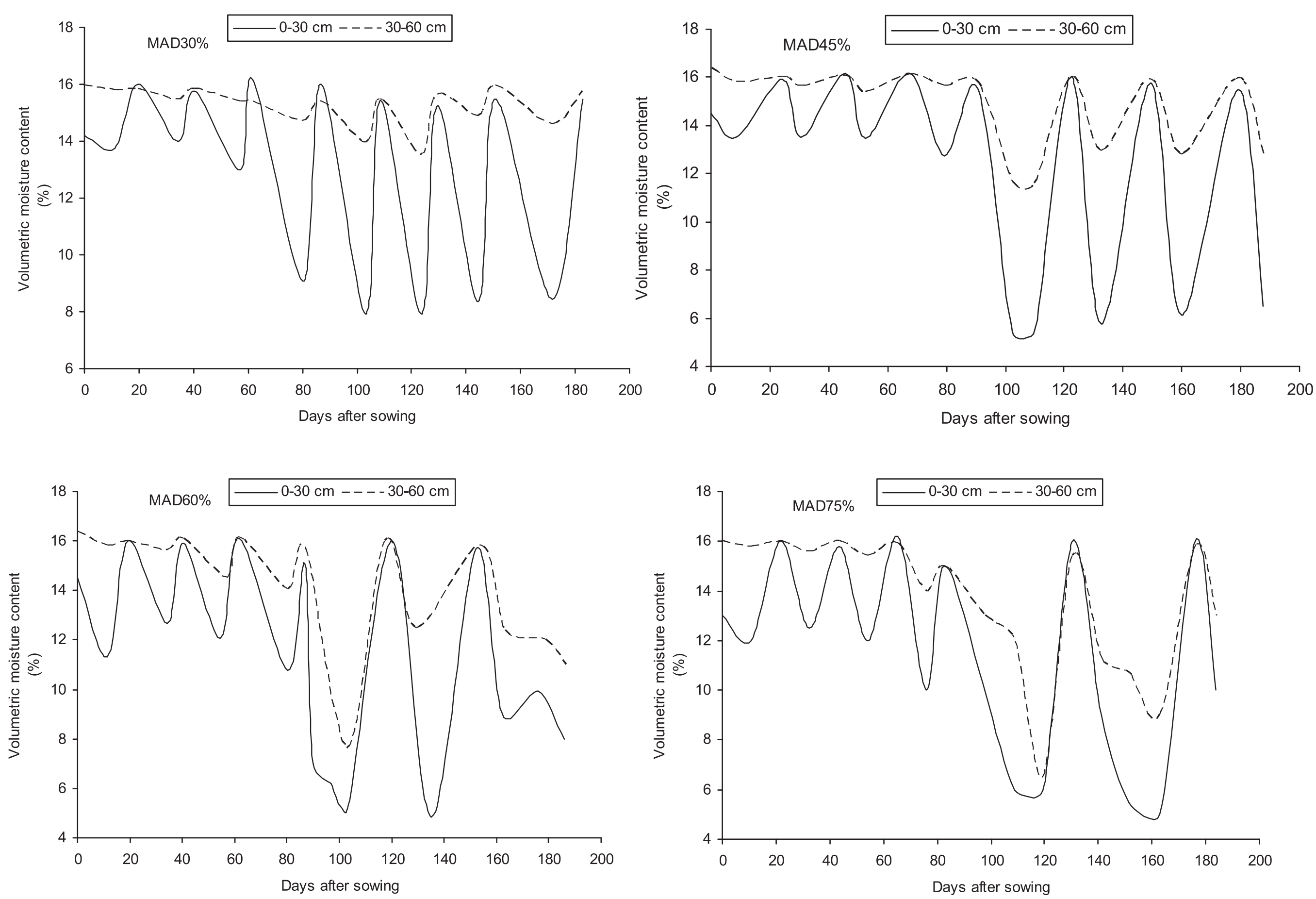

Fig. 4. . Temporal variation of soil moisture in the root zone of canola at: different MAD of available soil water during Experiment 1.

in Table 4, revealed that the highest field water use efficiency was attained when irrigation was scheduled at 45% MAD (I2). Water use efficiency increased from I1 to I2. It decreased for I3 and I4 as irrigation was delayed (Table 4).

The lower WUE of 30% MAD compared with the I2 Irrigation regime apparently relates to increase in amount of irrigation water which increased evapotranspiration (ET), but decreased the WUE. The lower WUE associated with higher amount of irrigation water could be due to a greater loss of water by ET than the corresponding increase in seed yield. Zhang et al. (2004) have reported WUE values that are higher under deficit than adequate irrigation, especially when irrigation is applied to critical stages of plant development. Lower WUE with increasing irrigation interval more than 45% MAD could be due to the decrease in seed yield with increasing the drought period.

At a particular level of irrigation, the greater evapotranspiration in fertilized plots was principally related to the stimulation of crop growth and increase in LAI and DM production with more interception of solar radiation (Mandal and Sinha, 2004) and also the increase in root biomass, length and volume. Thus, nutrient application positively influenced the WUE. The greater increase in seed yield in N2, N3 and N4 over N1 and relatively less increase of the corresponding ET have evidently resulted in significantly higher WUE with the treatment of 45% MAD, particularly in the case of application the highest N rate (270 kg N ha^{-1}).

3.8. Depth and time course of soil moisture

The results of only the first experiment conducted in 2007 have been presented here. Results obtained from second experiment followed almost similar pattern. Temporal variation of soil moisture observed in experimental plots at 30% MAD is presented in (Fig. 4). The amplitude of cyclic variation of soil water was high only in the 0–30 cm soil layer and low in other layer (30–60 cm), indicating that most of the water required by the plant was extracted from the top layer under this schedule (Fig. 4). The results also revealed that during the later stages of growth, when roots were full developed, the plant also extracted some water from the lower layer i.e. 30–60 cm (Fig. 4). Under the irrigation schedule with 45% MAD (I2), soil water was extracted from all the layers of the root zone; but most of the extraction was from 0 cm to 30 cm soil layers (Fig. 4). The schedule I2 being a dryer regime as compared to I1, the magnitude of cyclic variation was higher in 0–30 cm soil layer as compared to similar layers in I1. The frequency of irrigation was lower and the volume of water applied was higher under this irrigation schedule than that of I1. High amplitude of cyclic variation was noted under the irrigation schedule with 60% MAD (I3) in 0–30 cm soil layer of the root zone and low variation was noted in 30–60 cm soil layer (Fig. 4). The frequency of irrigation was lower and the volume of water applied each time was comparatively higher than that of I2. In this irrigation schedule, the plant roots penetrated deeper to explore the water. Considerable soil moisture fluctuation was observed under 60% MAD (I3) schedule. High amplitude of cyclic variation was noted in 0–30 cm soil layer of the root zone and little variation was seen in case of 30–60 cm soil layer (Fig. 4). Under this schedule, large volume of water was applied during each irrigation event. The fluctuation of soil water was quite high under 75% MAD (I4) schedule (Fig. 4). The 0–30 cm soil layer exhibited higher cyclic variation as compared to that of the 30–60 cm soil layer. The water was lost through upper most soil layer at a faster rate because of the evaporation from soil surface and transpiration from the grown up plants. The time span of cyclic variation was found to be higher during I4 as compared to other treatments.

4. Conclusions

Seed yield increased sharply with increasing N fertilizer rates up to $N_{critical}$. The magnitude of the responses to N rates (as *b* coefficient) and $N_{critical}$ varied among the irrigation levels (Table 5). The highest response was seen in I1 (11.11 kg kg^{-1} N ha^{-1} applied), while the highest $N_{critical}$ was achieved in I2 (189.8 kg N ha^{-1}). Therefore, more N fertilizer was required to maximize seed yield in I2 relative to I1 which show I2 has resulted in improving response range of canola to N fertilizer.Our results revealed a dual-threshold effect of fertilize and irrigation regimes on quantitative and qualitative traits of canola cultivars. Response rate to fertilizers was ceased in lower fertilizer rates by prolonged irrigation. The response rate showed a decrease of 15.4%, 17.2% and 30.7% in I2, I3 and I4 in comparison with I1, but I2 had the highest $N_{critical}$. This implies that I2 improved response of canola cultivars to N fertilizer, which was accompanied by its higher WUE. Also, all estimated $N_{critical}$s for all irrigation levels were higher than the current recommendation of 130 kg N ha^{-1}(Roodi et al., 2004). This can show that to fulfill potential capabilities of canola cultivars in different irrigation levels the gap between recommended N fertilizer values and estimated values as $N_{critical}$ should be filled. These results confirm Mandal and Sinha (2004) whom stated that optimal canola seed yield could be harvested if sufficient water is accompanied by nitrogen fertilization. Also, decreasing seed oil and N concentration by increasing fertilizer rates and prolonging irrigation regimes emphasis on this point that irrigation regimes and N fertilizer rates should be optimized to achieve more seed and oil yield finally. These results in parallel with other analysis on different influencing factors on seed yield (alike phenological events, LAI value, maturity time etc.), which in turn, are affected by irrigation regimes and fertilizer rates showed that overall I2 is more advisable irrigation level if recommended fertilizer increase to $N_{critical}$ for this irrigation level. Cultivars tended to respond similarly to irrigation and nitrogen for seed yield in both years, but Zarfam was more efficient than Modena in respect to response to diverse environments make the best adapted cultivar to the drier areas of the Tehran province.

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