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Yield and Yield Components of Rapeseed as Influenced by Water Stress at Different Growth Stages and Nitrogen Levels

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Abstract: Irrigated rapeseed (*Brassica napus* L.) cultivation is currently expanding in rotation with winter cereals in Iran where its reproductive growth is often exposed to water deficit in many parts, particularly in the south. A two growing seasons (2006-2008) field experiment was conducted at the Experimental Research Center, Shiraz University to study the effects of water stress at different growth stages [Normal irrigation at all growth stages (control), water stress at flowering, at pod development and at seed filling stages] and nitrogen (N) levels (0, 75, 150 and 225 kg ha^{-1}) on yield and yield components of rapeseed (Telayeh cultivar). The design was split plots arranged in randomized complete block with four replications. Full irrigation and the highest N level had the highest plant height, number of branches per plant, pods per plant, seed and oil yields. However, increased N levels decreased seed oil content and had no significant effect on 1000-seed weight. Flowering was the most sensitive stage for water stress damage resulting a drastic reduction in seed and oil yields by 29.5% and 31.7%, respectively. Pods per plants was the most sensitive yield components to water stress during reproductive growth in both year and it had the highest significant positive correlation with seed and biological yields. The seed and oil yields of the 1^{st} season were more than the 2^{nd} season due to favorable weather conditions for growth. Overall, supplying sufficient water to rapeseed crop, particularly at flowering and pod formation, in comparison with 225 kg ha^{-1} of N fertilizer are important to produce higher yields.

Key words: Water stress, Nitrogen rates, Branches per plant, Pods per plant, Seed yield

INTRODUCTION

Rapeseed is an important oilseed crop in the agricultural systems of many arid and semiarid areas where its yield is often restricted by water deficit and high temperatures during the reproductive growth. Seed yield can be primarily limited even by the relatively short period of soil moisture shortage during the reproductive development.

The effect of water stress on crop is a function of genotype, intensity and duration of stress, weather conditions and developmental stages of rapeseed [35]. The occurrence time is more important than the water stress intensity [22]. Seed yield potential of *Brassica* crops depends on the events occurring prior to and during the flowering stage, while the reproductive period is most susceptible to stress [27]. Severe stress decreases the duration of reproductive growth (Hall) [16] and stress during flowering or ripening stages results in large yield losses [41].

Water stress occurring at any time during reproductive growth can result a drastic change in seed yield. The worst time to experience water stress on many grain crops is during stem elongation and flowering. Gan *et al*. [14] found that canola stressed at earlier growth stages exhibited recovery, whereas stressed during pod development severely reduced most of the yield components. Masoud Sinaki *et al*. [25] found that the highest rapeseed yield reduction was obtained when water stress occurred at flowering and then at pod developmental stages. They reported that seed yield reduction by short term water stresses during stem elongation, flowering and pod development were mostly associated with the reduction of pods per plant. Rahnema and Bakhshande [33] reported that the highest seed yield reduction occurred when irrigation was only once applied in spring. Muhammad Tahir *et al*. [30] found that the highest seed yield was obtained with three times irrigation at early vegetative, flowering and seed formation. Henry and MacDonald [18] showed that severe drought decreased oil and increased protein contents of rapeseed.

Rapeseed has a high requirement for N [23]. Several studies have shown that N is a critical limiting

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nutrient in rapeseed production [15, 19, 39]. Nitrogen increases yield by influencing a variety of growth parameters such as branches per plant, buds per plant and by producing more vigorous growth as reflected by increase in stem length, number of flowering branches, total plant weight, seeds per pod [38], number and weight of pods and seeds per plant [3, 15, 43]. Jackson [19] found that the relationship between total plant yield and N reflects the tendency of canola to exhibit an indeterminate growth habit when nutrients and water were essentially unlimited. He obtained optimal oil yield in the same range as seed yield, even though a negative relationship exists between oil content and increased N levels. Starner *et al.* [40] reported the effects of N levels on canola oil yield were not significant but there was a trend towards increasing seed yield for N level up to 100 kg ha^{-1} N. Nitrogen applications usually decreases oil and increase protein contents of rapeseed [6, 11, 43].

Under dry land conditions, soil moisture often limits yield. Nitrogen only increase yield to the limits imposed by the moisture supply. Increased moisture supply increased the yield potential of the crop and increased the amount of N required for optimum yield [15]. Al-Jaloud *et al.* [1] reported application of 175 kg ha^{-1} N had significant effect on crop yield under well water treatment.

Rapeseed is a new oilseed crop in Iran and its hectarages has been currently expanding. The reproductive growth of the crop is exposed to water stress in many parts of the country, particularly in the south. The objective of this experiment was to determine the influences of water stress at different growth stages and N levels on yield and yield components of rapeseed in northern Shiraz, a main rapeseed growing area in southern Iran. There is a high potential for expansion of rapeseed cultivation in these regions as a promising alternative crop for diversification and economical use of land and water resources.

MATERIALS AND METHODS

A two growing seasons (2006-2008) experiment was conducted at the Experimental Research Center (Badjgah), Shiraz University (52° 46′E, 29° 50′ N and 1810m). Mean monthly temperatures and rainfall rate for two years of study and 30-years means of the region and some properties of soil are shown in Tables 1 and 2. The experiment was conducted as split plots arranged in randomized complete block design with four replications and comprised four irrigation treatments viz., normal irrigation at all growth stages (I_1) (control), water stress at flowering (I_2), at pod development (I_3) and at seed filling (I_4) stages as main plots and four N levels (0, 75, 150 and 225 kg ha^{-1}) as sub plots. The codes of plant growth stages for water deficit treatments were considered as when 50% of all buds on raceme are flowered, when 50% of potential buds on raceme were more than 2 cm long (pod formation) and when most seeds were brown [42]. The amount of water applied was to restore the water to field capacity. Field capacity and permanent wilting point were previously measured by pressure plate. Fertilizer application included 150 kg ha^{-1} of superphosphate before planting and urea which equally applied at both stem elongation and before flowering time.

Table 1: Mean air temperature and rainfall values during the years of experiment and 30-year means at Agricultural Research Center (Badjgah), Shiraz. Iran[a].

	Rainfall (mm)			Temperature(°C)		
	2006-2007	2007-2008	1975-2005	2006-2007	2007-2008	1975-2005
Sep-Oct	0.00	0.00	1.80	16.70	15.70	15.30
Oct-Nov	0.00	0.00	25.90	12.30	11.30	9.90
Nov-Dec.	82.00	18.00	82.00	2.60	6.60	5.80
Dec-Jan.	50.50	76.00	98.30	0.38	1.40	3.40
Jan-Feb	82.50	29.50	87.50	4.50	3.70	3.50
Feb- Mar	35.00	0.00	66.70	7.40	8.90	6.90
Mar-Apr	138.50	3.50	43.90	11.50	14.00	10.90
Apr-May	3.00	0.00	13.60	17.30	17.90	15.70
May-Jun	0.00	0.00	0.80	22.00	22.40	20.20
Jun- Jul	2.50	0.00	0.30	25.10	25.80	23.76
Jul-Aug	0.00	0.00	0.50	24.10	24.70	23.72
Aug-Sep	0.00	0.00	0.40	21.20	21.00	20.40
Total	394.00	127.00	421.70	-	-	-

[a]Unpublished report, Irrigation Department, College of Agriculture, Shiraz University, Shiraz, Iran

Table 2: Some chemical and physical properties of soil of the experimental location

Organic matter (%)	0.7
Nitrogen (%)	0.11
Phosphorus (mg kg^{-1})	23.01
Potassium (mg kg^{-1})	264
EC (ds m^{-1})	0.43
pH	8.3
Soil texture & group	Silty clayloam (fine, mixed, mesic, Calcixerollic Xerochrepts)

The rapeseed (Telayeh cultivar) seeds were manually planted on October 8, 2006 and September 24, 2007 in 2 × 5 m plots and irrigated in the same day by siphons. The experimental sites were under wheat (*Triticum aestivum* L.) cultivation the year before starting the experiment in both growing seasons. Weeds were controlled both mechanically and by Trifluralin (2.5 l ha^{-1}) as preplant and incorporated.

All plots were harvested during the 2^{nd} week of June in each year and number of branches and pods per plant, seeds per pod, 1000-seed weight, seed and oil yields were determined. Seed oil contents were determined by Soxhlet methods [4]. The data were statistically analyzed for each season and then combined for both years by (SAS [37]) and M STAT C systems and the means were compared by Duncan˝' s Multiple Range Test.

RESULTS AND DISCUSSION

Water stress treatments significantly decreased branches per plant, pods per plant and 1000-seed weight leading to lower seed yield (Table 3). Pods per plants was the most sensitive yield components to water stress during reproductive growth in both year as shown by Diepenbrock [12]. It seems that water stress caused yield reduction probably by inducing pod abortion via limiting photosynthesis. Clarke and Simpson [9] suggested that increased pods per plant in irrigation treatment were primarily due to lengthening of the flowering period. Halvorson *et al*. [17] found that the number of branches per plant was closely correlated with soil moisture regime during growing season, while Clarke and Simpson [9] showed that it was scarcely affected by irrigation.

Irrigation increased seed number through its effects on pod surface which in turn can result a greater assimilate supply. 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 [21]. Flowering was the most sensitive stage to water stress, probably due to susceptibility of pollen development, anthesis and fertilization leading to lower seed yield [8, 13, 25]. Mendham and Salisbury [27] reported that competition for assimilates among new branches and extra pod formation

Table 3: Effect of irrigation treatments and N levels on yield and yield components of rapeseed for two years

	Plant height (cm)	Branches per plant	Pods per plant	Seeds per Pods	1000-seed weight(g)	Seed yield (kg ha^{-1})	Oil yield (kg ha^{-1})
Irrigation treatments*							
I_1	132.1a	7.1a	128.3a	22.2a	3.4a	2988.4a	1264.0a
I_2	112.4c	5.2d	89.4d	17.8d	3.5a	1888.4d	700.5d
I_3	124.7b	6.5c	105.5c	21.3c	3.2b	2392.1c	916.1c
I_4	128.1a	6.8b	124.8b	21.9a	3.1c	2678.6b	1025.9b
N (kg ha^{-1})							
0	111.9d	5.1d	73.5d	17.8d	3.2b	1470.3d	661.2d
75	121.2c	5.8c	92.1c	21.4c	3.2b	2366.8c	970.5c
150	128.5b	7.0b	130.6b	22.6b	3.4a	2858.8b	1109.2b
225	135.6a	7.8a	151.9a	23.1a	3.4a	3251.6a	1235.0a
Year							
2006-2007	125.4a	6.4a	113.3a	21.3a	3.3a	2506.2a	982.4a
2007-2008	123.3a	6.3a	110.7b	21.1a	3.2a	2467.5b	952.4b

Mean of each group in each column and in each treatment with similar letters are not significantly different (Duncan 5%). *I_1, Normal irrigation at all growth stages; I_2, Water stress at flowering; I_3, Water stress at pod development; and I_4, Water stress at seed filling

Table 4: Correlation coefficients between yield and yield components of rapeseed

Characteristics	Plant height	Branches per plant	Pods per plant	Seeds per pods	1000-seed weight	Seed yield
Plant height						
Branches per plant	0.289					
Pods per plant	0.582*	0.692**				
Seeds per pods	0.221	0.252	0.015			
1000-seed weight	0.881**	-0.327	-0.052	-0.921**		
Seed yield	0.827**	0.413	0.845**	0.581**	0.649**	
Oil yield	0.831**	0.213	0.088	0.611**	0.685**	0.985**
Biological yield	0.575**	0.645**	0.841**	-0.15	-0.3	0.715**

*,** significant at 0.05 and 0.01 level, respectively

at the time when seed numbers are set was responsible for decreasing in seeds per pod as well. Abiotic stress at the later stages of reproductive growth can result in source limitation for seed yield by inducing leaves shedding and hastening maturity [14].

In general, crop is susceptible to water stress during the flowering period, but cultivars differ in their sensitivity [34]. The seed yield reduction at pod formation was also associated with the reduction of the pods per plant. Krogman and Hobbs [20] indicated that both leaves and pods are important in photosynthesis and seed yield increases with adequate soil moisture. Since water stress during the seed filling period did not affect sink capacity (seeds per plant) and it decreased source capacity leading to the reduction of seed weight (Table 3), thus it seems that water stress during this period reduced seed yield via reduction of seed weight. Champolivier and Merrin [8] found yield and yield components of rapeseed were mainly affected by water shortage occurring from flowering to the end of seed set. Stresses imposed at a later stage of development reduce sink size (Mendham and Salisbury [26]), shorten the duration of seed filling (Hall [16]) and decrease the opportunity of crop to recover [28]. Irrigation had more influence on seeds per pod than other yield components and water deficit influenced flowering to maturity stages more than other growth stages [25]. Daneshmand *et al*. [10] suggested that at water stressed conditions, those rapeseed cultivars which were able to maintain their relative water content at high levels had higher seed yield.

Nitrogen application significantly increased number of branches per plant and the highest number was obtained with 225 kg N ha^{-1} (Table 3) which can be attributed to increase in absorption and translocation of assimilates and stimulating apical and lateral meristems to grow [45]. Increase N application significantly increased seed yield, mainly due to an increase the number of pods per plant and seeds per pod [7, 12] and the highest seed yield was obtained when irrigation was applied at all growth stages and 225 kg N ha^{-1}(Table 3). Allen and Morgan [3] reported that the highest seed yield which was obtained with higher N levels was due to a greater production of seeds by a larger number of pods carrying seeds. The lowest seed yield was obtained when water stress occurred at flowering stage without N application which was associated with the reduction of pods per plant and the seeds per pod.

The lowest 1000-seed weight was obtained when water stress occurred at seed filling stage without N fertilizer (Table 3) which can be attributed to deficiency of resources (photosynthesis from lower number of leaves and pods) to support pod filling [5]. McGregor [26] and Olsson [32] found that 1000-seed weight was not strongly or little influenced by environmental conditions, respectively. However, Krogman and Hobbs [20] concluded that 1000-seed weight was increased with irrigation and N levels.

Increased irrigation and N application levels significantly increased plant height as mentioned by Al-Jaloud *et al* [1] and Taylor *et al* [43] and the highest plant height was obtained when normal irrigation was applied at all growth stages (control) and 225 kg ha^{-1} N with no significant difference with the treatment in which the water stress occurred at seed filling stage (Table 3). It appears that plants have obtained their final height at seed filling stage and water stress did not significantly affect height.

The interaction between N levels and water stress treatments showed that full irrigation and 225 kg ha^{-1} N application had the highest seed yield, pods per plant and 1000-seed weight. Biological yield was increased with N application and the highest yield was obtained when normal irrigation was applied at all growth stages and 225 N kg ha^{-1}. Diepenbrock [12] suggested that duration of growth is crucial for enhancing biomass and seed yield. Seed oil content was increased with irrigation and decreased with N application [19], while the highest seed oil content was obtained when normal irrigation was applied at all growth stages in combination with 75 kg ha^{-1} of N application. Champolivier and Merrin [8] reported a marked reduction in oil concentration was noticed when water deficit occurred from anthesis to maturity.

There was a significant difference between the number of pods per plants, oil and seed yields during the two growing seasons (Table 3). The seed (2506.2 kg ha^{-1}) and oil (982.4 kg ha^{-1}) yields of 1st season were more than in the 2nd season due to favorable weather conditions, higher and better rainfall distribution during crop growth seasons (Tables 1 and 3). Al-Kaisi *et al*. [2] reported that the interaction between irrigation and N on seed yield was significant and varied by year and also seed yield response to N levels was affected by irrigation and year. Nuttall *et al*. [31] found that the interaction effect of year and N was significant, indicating a wide range of response to applied N among years, because of temperature, precipitation and soil nutrient effects. They mentioned that temperature and precipitation at the later stages of growth were most important factors affecting canola seed yield. Similar negative effects on seed yield have been observed with water stress during flowering and seed filling stages [41].

Correlation coefficients between yield and yield components in both growing seasons showed that the seed yield had significant correlation (r= 0.845) with pods per plants as shown by Al-Kaisi and Yin [2], Buttar *et al*. [7] and Diepenbrock [12] (Table 4). Seed yield had positive and negative correlations with plant height and 1000-seed weight, respectively as well. Sadaqat *et al*. [35] found that seed yield had significant positive correlations with plant height, pods per plant and branches per plant under drought conditions. There was a positive correlation between seed yield and branches per plant as mentioned by Tunturk and Ciftci [44].

In summary, it is concluded that water stress during rapeseed reproductive growth stages, particularly flowering and pod formation was a critical period that the reduction led to decreased seed and oil yields mainly by the reduction of pods per plant. Flowering was the most sensitive stage for water stress damage resulting in a drastic reduction in yields. The crop had a high requirement for N fertilizer and 225 kg N ha^{-1} produced the highest seed and oil yields. Thus, providing sufficient water during reproductive growth stages and N fertilizer are important to produce higher rapeseed yield in the region. Further refinement of these findings will require additional work to address responses of different rapeseed cultivars to water stress and N application.

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