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Effect of irrigation regimes and organic fertilizer on rapeseed performance in the semi-arid area

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Summary: Climate changes and the cost of irrigation water in semi-arid areas seriously reduce the availability of water for irrigation. The optimal allocation of water resources to irrigation and limit water overexploitation are necessary in these regions. A field trial aimed to evaluate irrigation regimes (60, 80, and 100% based on field capacity, abbreviated as FC_{60}, FC_{80} and FC_{100}) and organic fertilizer (0, 15, and 30 t ha^{-1} farmyard manure, abbreviated as FYM) on two rapeseed varieties (Hydromel and Nathalie) in the semi-arid region of Qazvin, Iran. The highest lateral growth (branch number) was observed in the Hydromel cultivar with the application of 15 and 30 t ha^{-1} farmyard manure (FYM_{30} and FYM_{15}) under FC_{100} and FC_{80} conditions. Comparison of lateral growth between the cultivars showed that Nathalie cultivar was less affected by FYM and irrigation. The chlorophyll content decreased under FC_{60}; however, no significant difference was observed between FC_{80} and FC_{100}. The maturity of Nathalie was earlier than that of Hydromel. However, the use of FYM significantly extended the days to maturity in Hydromel. Although the silique length of the Nathalie cultivar was 13% less than Hydromel, this component significantly decreased in Hydromel under water deficit conditions (FC_{80} and FC_{60}). The highest number of siliques was recorded in the Hydromel under FYM_{30}+FC_{100} and FYM_{30}+FC_{80}. The 60% irrigation regime caused a significant reduction in the number of siliques. Although the seed yield of Hydromel was higher than that of Nathalie, the stability of the seed yield in Nathalie was more evident under FC_{80} and FC_{60}. Overall, the obtained results showed that the Hydromel variety can produce an acceptable yield under FYM_{30}+FC_{80} and save 20% in water consumption. The results indicated that the 60% irrigation regime was a stressful deficit irrigation and cannot be recommended for this semi-arid region.
Keywords: chlorophyll content, days to maturity, deficit irrigation, field capacity, number of siliques, rapeseed

Introduction

Rapeseed or oilseed rape (*Brassica napus* L.) is related to the Brassica species and is one of the well-known oil crops of the cabbage family (Brassicaceae). This plant has special agronomic characteristics, including a wide range of adaptability to most types of climates and diverse weather conditions, and having spring and autumn types therefore has found a special position in crop rotations (Eskin & Przybylski, 2003). Rapeseed is the third producer of oil after palm and soybean (Chew, 2020). The harvested area of oilseed rape in the world is about 40 million hectares and the amount of seed production is estimated at 87.2 million tons (FAOSTAT, 2022). Its cultivated area in Iran is about 160,000 hectares and the amount of seed production is about 300,000 tons. However, studies indicate that less than 10% of the edible oil used in Iran is produced by the internal agriculture sector and the major part is supplied through imports. The low level of production in Iran is partly caused by the climatic conditions and the poor soil conditions of semi-arid areas that with the acceleration of climate change and significant decrease in rainfall (increase of dry spell), it is expected that these problems will be aggravated (Janmohammadi & Sabaghnia, 2023a). In the mentioned areas, rainfall is low and often irregular, and rapeseed production in Iran takes place under full irrigation conditions. However, it seems that all the volume of water used during the irrigation of rapeseed is not necessary and part of the applied water resources are wasted without function in plant and soil systems through evapotranspiration (Hergert et al., 2016). The most important ways to improve the production of rapeseed are the increase in seed yield per unit of area (high-yielding variety) and the increase of the production per inputs like water, fertilizer, and seed (Amiri et al., 2019). Although the rapeseed plant has a relatively deep root system, the genotypic response to irrigation methods and the quantities of utilized water are somewhat different. It seems that genotypes may show different efficiency of moisture absorption from deep soil layers (Chen et al., 2022), then the selection of drought-tolerant cultivars is very important in semi-arid areas.

Due to the scarce water resources for irrigation in semi-arid areas and the aggravation of this problem with the acceleration of climate change and global warming in recent decades, the optimal use of available water resources should be on the agenda (Morante-Carballo et al., 2022). On the other hand, due to the particular climatic conditions of Iran, the final stages of rapeseed growth are faced with dry hot spells, irrigation traffic, and water shortage. Lack of rational agricultural management leads to severe drought stress, reduction of leaf area, and accelerated aging of leaves, and through the reduction of photosynthetic area, the amount of net production of the plant and subsequently the partitioning of photoassimilates to seeds reduce the final seed yield (Farooq et al., 2012).

Deficit irrigation (DI) is one of the agronomic management methods to conserve water and increase the efficiency of water consumption, especially in areas with limited water resources (Teshome et al., 2023). In the DI methods, an attempt is made to reduce the amount of water consumption compared to full irrigation as much as possible without compromising on production quantity. DI may be applied in different ways, such as deficit irrigation in all developmental stages except for very susceptible reproductive stages, or sustained throughout plant development (Ibba et al., 2023). However, there is still not much information about the response of rapeseed to DI. The soils of semi-arid areas have very low organic matter so the use of organic fertilizers such as animal farmyard manure (FYM) can improve soil organic matter. Animal manure can maintain the nutritional balance in the rhizosphere by improving the chemical properties of the soil (Krouma 2023). FYM also can increase the water-holding capacity in the soil by improving the physical properties and increasing the micro pores of the soil (Mirzabaiki et al., 2020). The mentioned items are important under DI. The present experiment aimed to investigate different levels of DI and the application of various amounts of FYM on the agronomical characteristics in two oilseed rape hybrids in the Qazvin region of Iran.

Material and Methods

Climatic Characteristics of the Studied Site

A one-year field trail was conducted to evaluate the effects of farmyard manure and irrigation regimes on growth and morphophysiological response of rapeseed cultivars in a semi-arid region in Qazvin province in the northwest of Iran (Figure 1) during 2019-2020 growing season. The mentioned region is located at 36°15' N latitude and 50°03' E longitude with a cold and semi-arid climate and is located 1270 meters above sea level. The coldest month of the year at the meteorological station was recorded in January with an average temperature of -2.5 °C and the hottest month of the year is August with an average temperature of 34.4 °C. The annual mean temperature was 8.3 °C. The average number of frosty days during the year was 67 days and annual heating degree days (°C day) value was 2039. Average annual sunny hours were estimated to be 2954. Some meteorological data in the studied area are shown in Table 1.

Table 1. The meteorological data recorded in the experimental field during the rapeseed growing season

	Feb	Mar	Apr	May	Jun	July
Relative humidity (%)	69	63	61	52	42	36
Average of minimum temperature (˚C)	4.8	5.2	6.9	9.2	13.6	18.4
Average of maximum temperature (˚C)	9.8	12.9	12.1	21.6	28.7	32.5
Average of temperature (˚C)	7.3	9.05	12.85	15.4	21.1	25.4
Sunny hours per month	199.2	237.1	235.6	310.2	336.4	347.9
Total evapotranspiration (mm)	59.6	73.21	118.6	179.3	264.5	297.1
Total rainfall (mm)	45.7	29.8	49.0	32.4	4.1	2.4

Figure 1. Geographical location of the studied area - Qazvin in the northwest of Iran

Soil and FYM properties

Soil characteristics were: pH= 7.62, electrical conductivity (EC) =0.716 dsm^{-1}, organic matter= 1.69 g kg^{-1}, nitrogen (N) = 0.081%, available phosphorus = 8.21 mg kg^{-1} and available potassium (K) = 286 mg kg^{-1}. Farmyard manure contains 82.26% organic matter, 2.13% nitrogen, 0.76% phosphorus, 2.16% potassium, 1.56% calcium, 0.48% magnesium, 0.87% sulfur, 202 mg kg^{-1} zinc, 135 mg kg^{-1} iron, 73 mg kg^{-1} Mn, and its EC was 5.72 ds m^{-1} and pH=7.5. The proportions of sand, silt, and clay content in the experimental field soil showed that soil texture was clay loam.

Crop Management and Experimental Design

This research was conducted as a split-split plot arrangement based on a randomized block design with three replications. The main factor included the application of three different levels of farmyard manure (zero, 15, and 30 t ha^{-1} abbreviated as FYM_0, FYM_{15}, and FYM_{30} respectively). Sub-plots were assigned to two rapeseed cultivars (Hydromel and Nathalie). Sub-sub plots allocated to three irrigation regimes (full irrigation: supply an adequate amount of water that 30 cm soil layer reaches100% field capacity, and deficit irrigation: irrigated until the soil water content of the 30 cm soil layer reaches 80% and 60% field capacity abbreviated as FC_{100}, FC_{80}, and FC_{60} respectively). Rapeseed seeds were obtained from the Agricultural Research Station of Qazvin province. After doing the initial plowing with a one-way moldboard plow field divided to the 9 experimental main plots (24 × 4 m) in late September 2019. Well-rotted farmyard manure was applied in the three determined quantities and integrated with a mini rotavator with a depth of 15 cm. Then the main plots were divided into two sub plots with size 12 × 4. After secondary tillage and formation of ridges and furrows, the seeds of cultivars were planted manually in sub-plots at a depth of 2 cm on October 5, 2019. The distance between the ridges was 30 cm and the ridge height was around 15 cm. The intra-row spacing was 3 cm. Immediately after planting all plots were fully irrigated uniformly up to the field capacity (FC_{100}). All treatments were irrigated initially with the same amount of water for three weeks to achieve uniform initial water content and to reach FC. Also, to establish the seedling, the second full irrigation was done on October 31. Irrigation regimes were applied after the end of the winter rains and at the initiation of stem elongation. For applying the irrigation regimes, each sub-plot was divided into 3 equal plots as a sub-sub-plot. Each experimental plot with an area of 16 m^2 (4 × 4 m) had 14 planting rows.

Irrigation Treatments

Soil water content was determined by a Time Domain Reflectometry sensor (TDR 200, Campbell Scientific, Inc. USA) in three-day intervals. To calculate the moisture content at the field capacity point (θ_{FC}), the field was irrigated to reach the saturated soil conditions and after hourly and consecutively monitoring the soil moisture status, when the gravity drainage water was removed from the soil and in two or more samples the moisture condition of the soil showed a relatively stable trend, the soil moisture content was determined using TDR (Cassel & Nielsen, 1986). The amount of moisture at permanent wilting point (θ_{pwp}) was measured in the part of the field 14 days after irrigation at a depth of 30 cm (Hillel, 1980). The following equation (Bahreininejad et al., 2013) was used to calculate the volume of water required for irrigation

$$\text{Required water} = [(\theta_{FC}-\theta_{pwp})\times SD\times PDI\times 100]/IE,$$

where SD is the depth of the investigated soil, which was considered 30 cm for this product. PDI is the desired percentage of deficit irrigation in the experiment, which was considered according to the experimental plots of 1.0, 0.8, and 0.6. Surface irrigation in the ridge and furrow system was applied, and IE refers to the irrigation efficiency, which was considered 65% in this experiment. The precise amount of water needed by the experimental plots to reach the desired soil moisture content was added through polyethylene pipes equipped with volumetric meters. The total water consumption in FC_{100}, FC_{80} and FC_{60} irrigation regime was 4142, 3357 and 2638 m^3 ha^{-1}, respectively. The trend of soil moisture content changes during the growing season is shown in Figure 2. The deficit irrigation treatments started at the end of February with the reduction of winter rains and initiation of stem elongation. The irrigation was performed when 50% of available water was depleted from the 100% treatment.

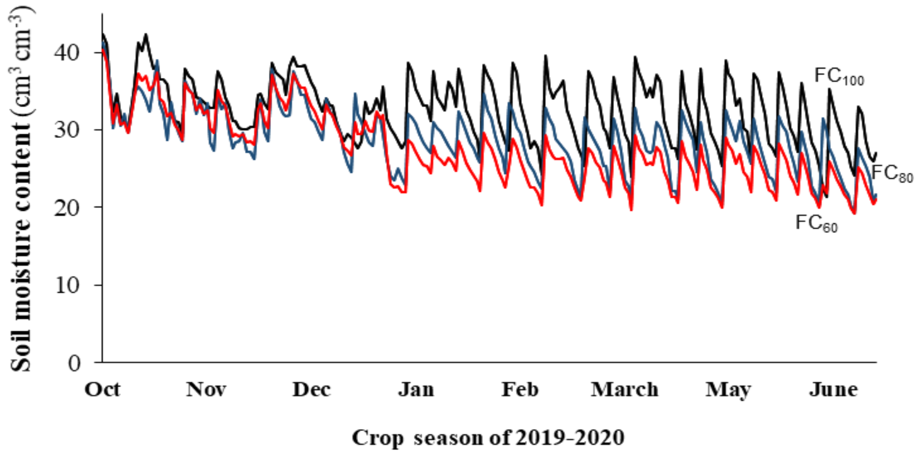

Figure 2. Soil moisture content during the growing season (2019-2020) in the investigated research field in the Qazvin region under well-watered condition

Measurement of Growth and Morphophysiological Traits

The chlorophyll measurement of the leaves was determined through a manual chlorophyll meter (SPAD 502, Konica Minolta, USA) at the yellow bud stage. After the application of deficit irrigation treatments, other agricultural management methods such as weed control and pest control were carried out uniformly in all plots if it was necessary. The number of days to maturity was estimated through regular daily monitoring of the field. In early summer and during July when 15-20% of the seeds in the main branches turned brown and the moisture content of the seeds was about 12%, by eliminating the marginal effects in the plots, the plants were harvested in the middle 6 rows and characteristic such as length of silique, the number of siliques per plant, and the weight of 1000 seeds were measured. The height of the plant in the maturity stage was determined from the ground level to the uppermost part of the plant. The estimation of biological yield was done by plants harvesting from 2 m^2 of the central part of plots and drying the plants in an eclectic oven at 70 °C for 24 h and then weighing them on a digital scale. By separating silique and seeds and weighing them, seed yield was estimated.

Statistical Analysis of Data

The gathered data were subjected to analysis of variance with SAS software and the comparison Correlation and decomposition into main components were done with Minitab software. Comparison of average data was done using LSD test at 5% level. Box plots were prepared through Statistica software.

Results

Chlorophyll content

Investigation of the chlorophyll content of leaves showed that the main effects of cultivar (C), irrigation (I), and farmyard manure (FYM) on this trait were significant. Also, I×F interaction effects were significant at the 0.05 level (Table 2). Chlorophyll content in cv. Hydromel was 13% higher than cv. Nathalie. The application of mild deficit irrigation (FC_{80}) and FC_{60} reduced the chlorophyll content by 4% and 27%, respectively, compared to full irrigation conditions (FC_{100}). On the other hand, application of FYM_{15} and FYM_{30} increased chlorophyll content by 11% and 18%

compared to FYM_0. The highest chlorophyll content was recorded under FC_{100}- FYM_{30} (59.50) and the lowest content was recorded in the condition of FC_{60}- FYM_0 (36.5).

Plant Height

Analysis of variance for the height of the plant indicated the significant mutual effects of I×F at the 5% level (Table 2). The tallest plants were recorded under FC_{100}-FYM_{30} conditions, which were 45% higher compared to FC_{60}-FYM_0 (shortest plants). Plants grown under FC_{80}-FYM_{15} were next in rank. The treatments FC_{80} and FC_{60} reduced plant height by 5% and 17% compared to full irrigation conditions.

Phenological Traits

The evaluation of the plant phenological traits showed that the number of days to maturity (DM) was intensely influenced by the investigated treatments. The three interaction effects of I×FYM×C were significant. Application of FYM and irrigation significantly affected the DM and the maximum DM was recorded for cv. Hydromel grown under FC_{100}-FYM_{30}. Intriguingly the use of FYM_{30} under full irrigation conditions reduced the DM to 6 days in cv. Nathalie. However, on average, the application of FYM_{15} and FYM_{30} delayed the maturity by 8-10 days. On the other hand, irrigation regime FC_{60} accelerated the maturity up to 10 days, while FC_{80} only accelerated plant maturity by three days (Table 2).

Siliques Number and Length

Examining the number of siliques per plant indicated the main and mutual effects of evaluated factors were significant on this important component of seed yield. The highest number of siliques per plant was recorded in the Hydromel cultivar under full irrigation or mild deficit irrigation along with using FYM_{30} (307, 294). The response of this trait in cv. Hydromel to application of organic fertilizer and irrigation levels was more obvious than cv. Nathalie, and the number of siliques increased significantly with the increase in FYM application. However, the number of siliques in the cv. Hydromel under FC_{60} showed a sharper decrease compared to the cv. Nathalie. Nevertheless, the number of siliques in the cv. Hydromel (200.2) was higher than the cv. Nathalie (162.8). The effect of FYM application on cv. Hydromel was more noticeable than cv. Nathalie, so that with FYM application, the number of siliques increased by 21% in cv. Hydromel (Figure 3).

Evaluation of lateral growth and number of branches per plant indicated that the main effects and interaction effects of I×FYM and I×C were significant for this trait (Table 2). The highest number of branches was recorded in cv. Hydromel under FC_{100} (9.52) and the lowest number of branches was related to cv. Nathalie under FC_{60} (6.93). The number of branches in cv. Hydromel even moderate deficit irrigation (8.60) was higher than cv. Nathalie under full irrigation (7.95). ANOVA results for silique length showed that in addition to the main effects of evaluated factors, the interaction effects of two factors (I×FYM, C×FYM, and C×I) were significant on this trait. Comparisons of the average impacts of C×I showed that the longest silique was recorded in cv. Hydromel under full irrigation (5.82 cm). The smallest siliques were observed in cv. Nathalie under FC_{60} (4.35 cm). Even the silique length in cv. Hydromel under FC_{80} was higher than silique length in cv. Nathalie under full irrigation (5.05 cm). Mean comparisons for C×FYM combined treatments showed that the highest silique length was obtained with the use of FYM_{30} and FYM_{15}, and the shortest was observed in cv. Nathalie e under the conditions without fertilizer use (4.44 cm). The comparisons of this trait in I×FYM levels indicated that with the increase of irrigation water and the organic fertilizers supply, the length of the silique increased and the shortest silique was recorded under the conditions of FC_{60}-FYM_0 (Table 2).

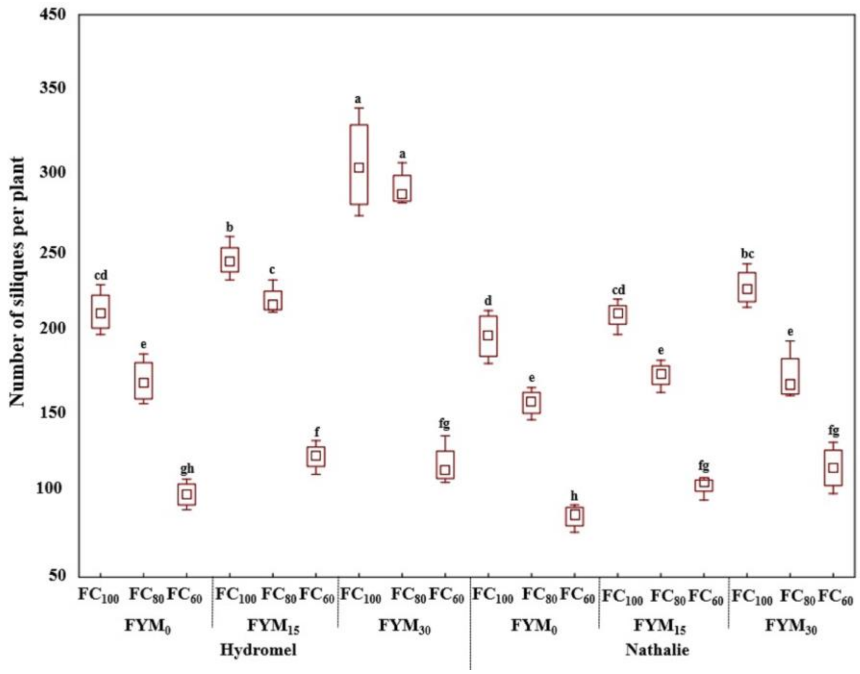

Figure 3. The effect of applying different levels of animal manure and deficit irrigation on the number of siliques in rapeseed cultivars (Hydromel and Nathalie) grown in the Qazvin region. FC_{100}, FC_{80} and FC_{60}: irrigation up to 100%, 80%, and 60% field capacity, FYM_0, FYM_{15} and FYM_{30}: application of 0, 15, and 30 t ha^{-1} farmyard manure. Boxes with common letters have no statistically significant difference at the 5% level.

Principal component analysis showed that the first component was able to separate effective FYM levels and also levels of irrigation from other combined treatments. Application of FYM_{30}+FC_{100} resulted in the best growth and yield performance when compared with deficit irrigation and no fertilizer application conditions. On the other hand, the second component was able to distinguish the cultivars according to the investigated characteristics, and cv. Hydromel which showed better performance in most of the traits, was separated from cv. Nathalie (Figure 4).

Thousand Seed Weight

Seed weight showed a significant response to the studied factors; interestingly, the highest thousand seed weight was recorded in cv. Hydromel with the application of FYM_{15} (3.49 g) and was about 10% higher than seed weight in plants grown under FYM_{30} condition (Table 2). The lowest thousand seed weight was observed in cv. Nathalie with the application of FYM_{15} (2.77 g). The highest thousand seed weight was achieved in FC_{80}-FYM_{15} (3.30 g), FC_{100}-FYM_{30} (3.28 g) and FC_{100}-FYM_{15} (3.15 g) conditions, and the lightest seeds were obtained under FC_{60}-FYM_0 and FC_{60}-FYM_{30} conditions.

Seed and Biological Yield

The main effects of factors and interaction effects of two factors on seed yield were significant. The highest seed yield was obtained from cv. Hydromel under full irrigation along with application of FYM_{30} (1803 kg ha^{-1}). Utilization of mild deficit irrigation in cv. Hydromel under the FYM_{30} applied condition caused a 5% decrease in seed yield. The treatment FC_{60} reduced the seed yield in almost all fertilizer conditions and cultivars, but the reduction rate was more significant in cv. Hydromel under no application of organic fertilizer. However, the average seed yield of cv. Hydromel was 17% higher than cv. Nathalie and even under FC_{60} and without using organic fertilizer, it could show a better performance. It is interesting to note that the applying irrigation regime FC_{80}, did not result in a noticeable and significant seed yield reduction in the cv. Hydromel, and this variety had acceptable yield stability under mild deficit irrigation conditions (Figure 5).

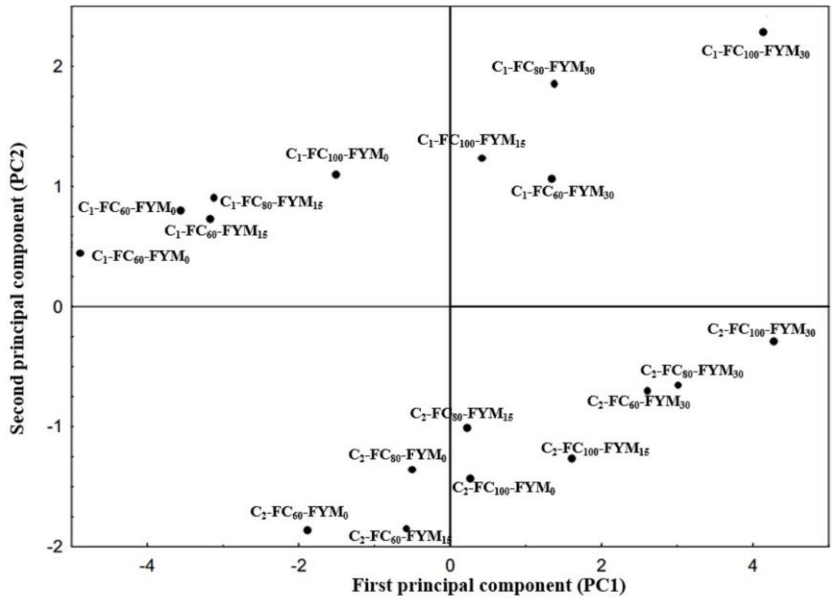

Figure 4. PCA model standardized scores plot for the effects of different farmyard manure levels and irrigation regimes on agronomic traits of rapeseed cultivars. FC_{100}, FC_{80} and FC_{60}: irrigation up to 100%, 80%, and 60% field capacity, FYM_0, FYM_{15} and FYM_{30}: application of 0, 15, and 30 t ha^{-1} cow farmyard waste. G1: Hydromel cultivar, G2: Nathalie cultivar.

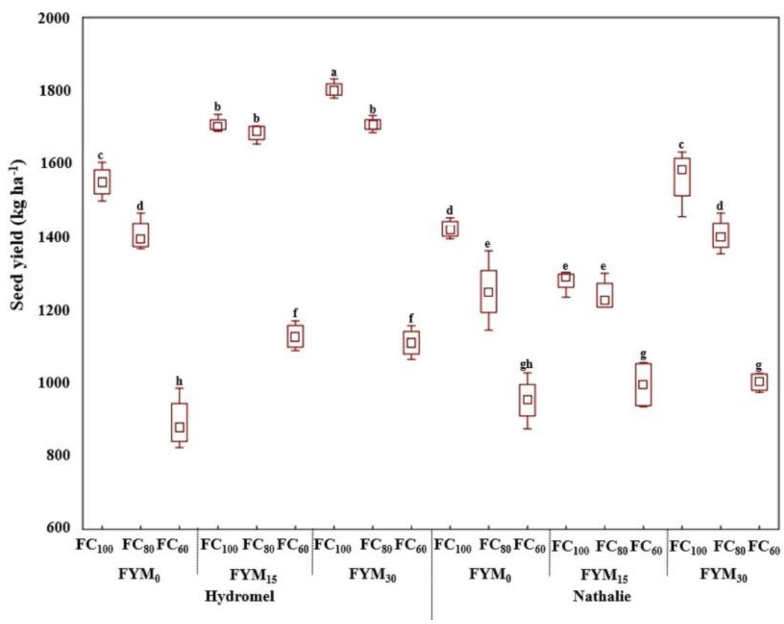

Figure 5. Comparison of the seed yield of rapeseed cultivars (Hydromel and Nathalie) grown under various farm yard manure levels and irrigation regimes at the Qazvin region. FC_{100}, FC_{80} and FC_{60}: irrigation up to 100%, 80%, and 60% field capacity, FYM_0, FYM_{15} and FYM_{30}: application of 0, 15, and 30 t ha^{-1} farmyard manure. Boxes with common letters have no statistically significant difference at the 5% level.

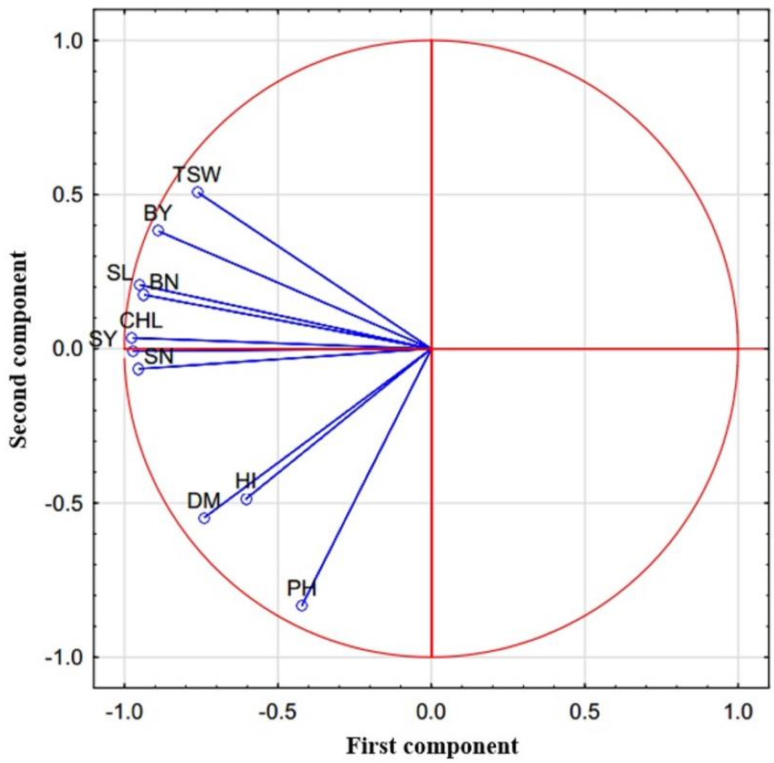

Figure 6. Principal component analysis (PCA) biplot for vector dispersion and investigating the correlation between agronomic traits in rapeseed. Smaller angles between traits indicate a positive and significant correlation between them. SY: seed yield, BY: biological yield, PH: plant height, CHL: chlorophyll content in upper leaves, HI: harvest index, SN: silique number per plant, BN: branch number, SL: length of silique, TSW: Thousand seed weight.

The application of moderate and high levels of FYM and FC_{100} caused a significant increase in vegetative growth and biological yield, and this increase was slightly higher compared to seed yield. Therefore, under FC_{100} and fertilizer-applied conditions, the harvest index did not show a significant increase. The highest harvest index was recorded in cv. Nathalie cultivar with FC_{100}-FYM_0 application and the lowest harvest index was observed in cv. Hydromel under FC_{60}-FYM_0 (Table 2). Assessment of the eigenvalues of the correlation matrix symbolized as a vector by PCA (angular correlation between traits) showed that there was a positive and significant correlation between seed yield silique number, leaf chlorophyll content, and silique length. Considering the 90°-angle between plant height and seed yield, no correlation was observed between them, and it seems that the increase in height is only caused by increasing vegetative growth which can result in a decreased harvest index. A positive correlation was observed between DM and the harvest index, and the conditions that led to an increase in the number of days to maturity increased the harvest index (Figure 6).

Table 2. Agronomical characteristics of rapeseed (*Brassica napus* L.) under application of different levels of farmyard manure and different deficit irrigation

			CHL	HP	DM	BN	SL	TSW	BY	HI
Hydromel	FC_{100}	FYM_0	53.25^{de}	102.25^{gh}	274^{ijk}	9.1825^{b}	5.285^{d}	3.22^{cd}	5118.0^{d}	30.3^{ef}
	FC_{100}	FYM_{15}	57.75^{bc}	110.25^{efg}	281.5^{bcd}	9.4225^{ab}	5.9975^{ab}	3.5^{b}	5352.7^{c}	31.8^{cde}
	FC_{100}	FYM_{30}	64^{a}	123^{cd}	284.5^{a}	9.96^{a}	6.2^{a}	3.44^{bc}	5810.2^{a}	31.0^{def}
	FC_{80}	FYM_0	51^{e}	92.5^{ji}	269.5^{lm}	7.7^{cd}	4.865^{fg}	3.10^{def}	4745.9^{ef}	29.6^{fg}
	FC_{80}	FYM_{15}	57.75^{bc}	115.5^{def}	278.25^{efg}	9.1675^{b}	5.7125^{c}	3.74^{a}	5184.25^{cd}	32.4^{bcd}
	FC_{80}	FYM_{30}	59.5^{b}	108.75^{fgh}	279^{def}	8.9525^{b}	5.8625^{bc}	3.18^{de}	5584.0^{b}	30.5^{def}
	FC_{60}	FYM_0	38.5^{hi}	82.75^{k}	272.5^{jk}	6.8^{f}	4.4125^{h}	2.92^{fgh}	4037.6^{i}	22.0^{j}
	FC_{60}	FYM_{15}	43^{fg}	91.25^{jk}	274.5^{hij}	7.7675^{cd}	5.0^{ef}	3.25^{cd}	4702.2^{efg}	23.9^{ij}
	FC_{60}	FYM_{30}	46.5^{f}	102.25^{gh}	275.75^{ghi}	7.7825^{cd}	5.02^{ef}	2.97^{efg}	4720.7^{ef}	23.5^{j}
Nathalie	FC_{100}	FYM_0	45.75^{f}	118.5^{de}	282.25^{abc}	7.755^{cd}	4.835^{fg}	2.79^{gh}	4037.6^{i}	35.2^{a}
	FC_{100}	FYM_{15}	51.75^{de}	139.25^{ab}	282.25^{abc}	8.0975^{c}	5.0275^{ef}	2.80^{gh}	4794.4^{e}	26.7^{h}
	FC_{100}	FYM_{30}	55^{cd}	143.25^{a}	276.75^{ghi}	8.005^{c}	5.29^{d}	3.12^{def}	4587.6^{gf}	34.0^{abc}
	FC_{80}	FYM_0	45.25^{fg}	110.25^{efg}	279.75^{cde}	6.975^{f}	4.3525^{hi}	2.84^{gh}	3766.7^{j}	33.2^{abc}
	FC_{80}	FYM_{15}	50.75^{e}	131.25^{bc}	282.75^{ab}	8.225^{c}	4.8125^{fg}	2.86^{gh}	4519.2^{gh}	27.4^{gh}
	FC_{80}	FYM_{30}	50.25^{e}	135.5^{ab}	268.5^{m}	8.0175^{c}	5.165^{de}	2.86^{gh}	4355.5^{h}	32.2^{bcde}
	FC_{60}	FYM_0	34.5^{j}	100.5^{hi}	277^{efgh}	7.21^{def}	4.1475^{i}	2.7^{hi}	3446.1^{k}	27.6^{gh}
	FC_{60}	FYM_{15}	36^{ij}	110.25^{efg}	271.5^{kl}	7.5675^{cde}	4.265^{hi}	2.73^{hi}	3832.8^{j}	26.0^{hi}
	FC_{60}	FYM_{30}	42^{gh}	120.5^{d}	274^{ijk}	9.1825^{b}	4.6575^{g}	2.56^{i}	3867.0^{ij}	25.9^{hi}
						Statistical significance				
C			<.0001	<0.0001	<0.0001	<0.0001	<.0001	<.0001	0.4521	0.0002
I			<.0001	<0.0001	<0.0001	<0.0001	<.0001	<.0001	<.0001	<.0001
FYM			<.0001	<0.0001	<0.0001	<0.0001	<.0001	<.0001	<.0001	0.001
C×I			0.2019	0.6339	0.0014	0.001	0.0038	0.444	<.0001	0.0016
C×FYM			0.4467	0.4075	<.0001	0.9399	<.0001	<.0001	0.0312	<.0001
I×FYM			0.0428	0.0352	0.0064	0.0208	0.0434	0.0029	<.0001	0.0117
C×I×FYM			0.4788	0.2229	0.0025	0.4665	0.5404	0.1992	0.4756	0.0052

FC_{100}, FC_{80} and FC_{60}: irrigation up to 100%, 80%, and 60% field capacity, FYM_0, FYM_{15} and FYM_{30}: application of 0, 15, and 30 t ha^{-1} farmyard manure. C: cultivars of rapeseed (Hydromel and Nathalie), I: irrigation level. BY: biological yield (kg ha^{-1}), HP: the height of the plant (cm), CHL: chlorophyll content in upper leaves (SPAD unit), HI: harvest index (%), BN: branch number, SL: length of silique (cm), TSW: Thousand seed weight (g), In each trait, the means with the same letters do not have statistically significant differences. For statistical significance, P values smaller than 0.05 at the statistical level of 5 percent are significant. P values greater than 0.05 are statistically insignificant.

Discussion

The soil of the experimental site was not in a suitable condition in terms of organic carbon content and available nutrients. However, this feature can be seen in most semi-arid areas. Therefore, the use of organic fertilizer, especially with its high amounts (FYM_{30}), significantly increased growth characteristics such as height, number of branches, and biological yield. These results confirm our previous findings on safflower, where the application of farm yard manure significantly increased vegetative growth and reproductive characteristics in a semi-arid and relatively similar region (Janmohammadi et al., 2016). However, the growth characteristics of the rapeseed plants decreased with the reduction of irrigation water supply in some cases, this state was more evident especially under FC_{60} conditions. However, the application of animal manure could mitigate the effects of water shortage to some extent. This condition was more obvious under the FC_{80} condition. The amount of growth or yield reduction due to mild deficit irrigation (FC_{80}) was negligible under the FYM applied condition. These results are in agreement with the results of

Liyanage et al. (2022) who reported that the application of fertilizers and improving the soil conditions of the plant through the provision of essential nutrients can improve the efficiency of water use in rapeseed. Therefore, improving irrigation management and fertilizer management should be considered simultaneously.

However, under non-application of FYM in the Mediterranean semi-arid region, deficit irrigation, although it increases the water use efficiency, but due to the dry spell at the end of the growth season can reduces the rapeseed yield (Dogan et al., 2011). However, there is a correlation between soil moisture content and the dynamics of the ratio of C/N, and under DI conditions, the perdurability of carbon and nitrogen released from the used organic fertilizers increases (Rodriguez-Ramos et al., 2022). Considering the climate changes, the need to save water seems essential (Janmohammadi & Sabaghnia, 2023a). Therefore, providing the soil moisture content under the full field capacity preferably during non-sensitive reproductive stages, especially in semi-arid areas with more frequent irrigation application due to the cultivation of the different spring crops may increase water productivity (Yang et al., 2022). The water requirement of rapeseed can be affected by the variety of characteristics, the purpose of production, and agronomic management, and this plant is highly sensitive to water scarcity during the growth period from flowering to seed maturity (Raza et al., 2017). Identifying the soil moisture threshold in crops under any environmental conditions is of great importance and it seems that in the current experiment, FC_{60} could not provide accessible water to the root system up to a critical level. The obtained results indicated that increasing levels of FYM application and irrigation water increased the height of the plant, the number of side branches, and other characteristics of vegetative growth.

Although the improving effects of the mentioned factors were observable on the seed yield characteristics, the stimulant and improving effects of the application of FYM and irrigation on the vegetative growth were more distinguishable than the yield components, and this caused a decrease in the harvest index under optimum conditions. The use of FYM, especially under the conditions of providing moisture or mild deficit irrigation (FC_{80}), through improving soil fertility was able to meet the nutritional requirements of the plant and increase the yield components in both investigated cultivars. However, the cultivar Hydromel showed a greater reaction to the investigated treatments, which could be due to the difference in rooting depth, canopy structure and architecture, hydraulic conductivity of the roots, more efficient vascular system, and the presence of more aquaporins in the root cells and higher efficiency of absorption of nutrients (Raza et al., 2017; Kalra et al., 2023). On the other hand, it appears that the use of FYM improved the biological and physical characteristics of the soil, by increasing the availability of nutrients, reducing nitrogen leaching, improving the fine capillary pores in the soil, and increasing the water-holding capacity (Guo et al., 2021). The improvement of soil characteristics could alleviate the negative effects of water deficiency under FC_{80} and stabilize the growth and seed yield. Because of the low organic matter in the soil of semi-arid regions, the application of farmyard manure can significantly improve the efficiency of other agronomic management (Janmohammadi & Sabaghnia, 2023b). Although, in the present experiment, FC_{80} did not have much negative effect on the growth and yield of rapeseed, it is necessary to pay attention to the fact that rapeseed is highly sensitive to water scarcity during the reproductive period, and providing water during the flowering period can reduce yield loss (Istanbulluoglu et al., 2010).

Among the studied traits, the chlorophyll content as one of the important indicators related to the efficiency and capability of the photosynthetic apparatus increased with the increase in the use of FYM, and this was more apparent in the cv. Hydromel. Therefore, it seems that one of the reasons for the superiority of cv. Hydromel over cv. Nathalie has a higher rate of photosynthesis, as well as the high durability of the green surface and the higher production and more partitioning of photoassimilates to the reproductive organs, which has led to the high yield in this variety. However, the rate of yield loss under deficit irrigation conditions compared to full irrigation conditions was higher in cv. Hydromel than cv. Nathalie. It showed that cv. Nathalie had a higher relative tolerance to water deficit stress (FC_{60}). However, the cv. Hydromel is still recommended as a suitable option for FC_{80}conditions due to its higher absolute tolerance. The application of FYM simultaneously increased the growth characteristics (source) and the number and size of reproductive components (sink) through the manipulation of source-sink relationships. However, severe water stress causes lower leaf area index, therefore may result in less radiation use efficiency and lower yield (Hamzei & Soltani, 2012). In this context, it seems that irrigation planning according to the maximum allowable depletion of available soil water can affect the efficiency of consumption of nutrients and yield of rapeseed, and the best result in rapeseed was obtained after 45% moisture depletion (Kamkar et al., 2011). Furthermore, application of FYM can improve soil hydro-physical properties and mitigate negative effects in water-stressed conditions and increases the activity of the source and sink by meeting the water requirement. (Abdelfattah & Abdelfattah, 2024).

The results obtained in this study showed that proper nutrition management is very important under deficit irrigation conditions. Among the yield components, the highest correlation with yield was demonstrated by the number of siliques per plant so this trait can be used to investigate deficit irrigation treatments on rapeseed and to select drought-tolerant cultivars. The present study showed that in organic amended soils of drought prone area, it is possible to produce an acceptable rapeseed yield by using mild deficit irrigation technique, and saved water resource can be provided for other existing crops.

Conclusion

The obtained results showed that in both studied cultivars, FC_{60} caused a significant decrease in growth and seed yield. However, this decrease was more severe in cv. Nathalie. According to the soil characteristics of the studied area and the low-organic matter, the application of animal manures under full irrigation and mild deficit irrigation conditions strengthened the growth and increased the seed yield. The use of farmyard manures (FYM_{30}) under FC_{80} resulted in an acceptable seed yield, saved 20% in water consumption. Therefore, the use of FYM_{30} is strongly recommended in semi-arid areas for improving rapeseed yield. The use of FC_{80} along with cultivation drought-tolerant cultivars can be considered as a valuable solution to preserve fresh water resources.

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Uticaj režima navodnjavanja i organskog đubrenja na uljanu repicu u polusušnom području

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Sažetak: Klimatske promene i cena vode za navodnjavanje u polusušnim područjima ozbiljno smanjuju dostupnost vode za navodnjavanje. U ovim regionima neophodna je optimalna alokacija vodnih resursa za navodnjavanje i ograničavanje prekomerne eksploatacije vode. Poljski ogled je imao za cilj da proceni režime navodnjavanja (60, 80 i 100% na osnovu poljskog vodnog kapaciteta, skraćeno kao FC_{60}, FC_{80} i FC_{100}) i organskog đubriva (0, 15 i 30 t ha^{-1} stajnjaka, skraćeno kao FYM) na dve sorte uljane repice (Hydromel i Nathalie) u polusušnom regionu Kazvin, Iran. Najveći bočni prirast (broj grana) zabeležen je kod sorte Hydromel uz primenu 15 i 30 t ha^{-1} stajnjaka (FYM_{30} i FYM_{15}) u uslovima FC_{100} i FC_{80}. Poređenje bočnog rasta među sortama pokazalo je da je đubrenje i navodnjavanje imalo manjeg uticaja na sortu Nathalie. Sadržaj hlorofila se smanjio pod FC_{60}, međutim nije primećena značajna razlika između FC_{80} i FC_{100}. Sorta Nathalie je sazrela ranije od sorte Hydromel. Međutim, upotreba FYM značajno je produžila dane do zrelosti kod sorte Hydromel. Iako je dužina ljuske kod sorte Nathalie bila za 13% manja nego kod sorte Hydromel, ova komponenta je značajno smanjena u Hidromelu u uslovima nedostatka vode (FC_{80} i FC_{60}). Najveći broj ljuski je zabeležen kod sorte Hydromel pod FYM_{30}+FC_{100} i FYM_{30}+FC_{80}. Režim navodnjavanja od 60% prouzrokovao je značajno smanjenje broja ljuski. Iako je prinos semena sorte Hydromel bio viši od prinosa semena sorte Nathalie, stabilnost prinosa semena kod Nathalie je bila očiglednija pod FC_{80} i FC_{60}. Dobijeni rezultati pokazuju da sorta Hidromel može dati prihvatljiv prinos pod FYM_{30}+FC_{80} i uštedeti 20% potrošnje vode. Rezultati pokazuju da je režim navodnjavanja od 60% predstavljao stresno deficitarno navodnjavanje i da se ne može preporučiti za proučavani polusušni region.

Ključne reči: broj ljuski, dani do zrelosti, deficit navodnjavanja, poljski vodni kapacitet, sadržaj hlorofila, uljana repica