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The effect of nitrogen doses on morpho-physiological traits of safflower at different levels of deficit irrigation

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Abstract: This experiment aimed to evaluate the effects of irrigation regimes based on potential evapotranspiration (100 %, 60 %, and 40 % PET) and doses of nitrogenous fertilizers (0, 40, and 80 kg ha-1) on the performance of safflower in Qazvin, Iran. Three fractions of potential evapotranspiration: 100 %, 60 %, and 40 % PET are considered as full irrigation (FI), mild deficit irrigation (MDI) and severe deficit irrigation (SDI), respectively. Results revealed that the effectiveness of nitrogen fertilizers was discernable under FI and MDI conditions, however, under SDI, the application of nitrogen fertilizers did not have any improvement effects on evaluated traits. The highest seed yield was recorded in FI + N80 (1253 kg ha-1) and the seed yield of MDI + N80 (1121 kg ha-1) was in the second place with a difference of 132 kg ha-1. However, the best seed quality in terms of protein percentage was related to plants grown under SDI + N80 (23.44 %), which was 43 % higher than FI + N0 (16.45 %). The plants grown under FI + N80 and SDI + N80 conditions showed the highest seed oil content with 28 % and 27.1 %, respectively. The obtained results showed that MDI can be used as a strategy to improve the efficiency of water consumption under water scarcity conditions in the semi-arid region.

Key words: canopy width, chlorophyll content, potential evapotranspiration, seed oil content, water shortage

Učinek odmerkov dušika na morfološke in fiziološke lastnosti žafranike pri različnih načinih deficitnega namakanja

Izvleček: Namen poskusa je bil ovrednotiti učinke načina namakanja, ki so bili osnovani na potencialni evapotranspiraciji (100 %, 60 %, in 40 %; PET) in odmerkov dušičnih gnojil (0, 40, in 80 kg ha-1) na uspevanje žafranike v Qazvinu, Iran. Tri vrednosti potencialne evapotranspiracije (100 %, 60 %, in 40 %) so bile glede na način namakanja opredeljene kot polno namakanje (FI), blago deficitno namakanje (MDI) in izrazito deficitno namakanje (SDI). Rezultati so pokazali, da je bila učinkovitost dušičnih gnojil opazna v razmerah FI in MDI, medtem, ko gnojenje z dušikom v razmerah SDI ni dalo nobenih učinkov izboljšanja pri obravnavanjih. Največji pridelek semena je bil ugotovljen pri obravnavanju FI + N80 (1253 kg ha^{-1}), na drugem mestu je bil pridelek semena pri obravnavanju MDI + N80 (1121 kg ha^{-1}), z razliko 132 kg ha^{-1}. Najboljša kakovost semen glede na odstotek beljakovin je bila ugotovljena pri rastlinah, ki so rastle v razmerah SDI + N80 (23,44 %), ki je bila za 43 % večja kot pri obravnavanju FI + N0 (16,45 %). Rastline v obravnavanjih FI + N80 in SDI + N80 so imele največjo vsebnost olja, 28 % in 27,1 %. Dobljeni rezultati so pokazali, da bi obravnavanje MDI lahko uporabili kot strategijo za izboljšanje učinkovitosti rabe vode v razmerah njenega pomanjkanja na semiaridnih območjih.

Ključne besede: obseg nadzemnega dela rastline, vsebnost klorofila, potencialna evapotranspiracija, vsebnost olja v semenih, pomanjkanje vode

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1 INTRODUCTION

Optimal management of irrigation is a technique to improve water efficiency and is implemented according to the water requirement of crops (Wu et al., 2022). In semi-arid region precipitation is spatially and temporally diverse and not sufficient to meet crop water requirementsTherefore, it is necessary to use irrigation in some sensitive stages of plant development. However, the available water for irrigation is also severely limited in these areas, and this trend has intensified in recent years due to climate change (Peng et al., 2023). Indiscriminate use of groundwater and failure to recharge the aquifer level will cause many problems in the future, and this process will worsen with the intensification of climate change and global warming (Araya et al., 2017). Therefore, the optimal use of available water resources by using precise or regulated deficit irrigation techniques can play a significant role in sustainable water consumption. However, it must be noted that water deficit stress during the reproductive stage and especially throughout the stages when the primordia of the yield components are forming can decrease the final economic yield (Sah et al., 2020).

Oilseed plants are very important in providing food security. Among oilseed plants, safflower (*Carthamus tinctorius* L.), whose origin seems to be southern Asia, is an underutilized or forgotten oilseed crop, and yields about 32-40 % seed oil (Leus, 2016). Safflower oil is multipurpose and is used in many industries and food preparation. Safflower is relatively tolerant under stressful conditions especially drought stress, because it develops a root system in the soil. Safflower is able to survive under drought stress conditions through its deep root system and the ability to use some protective mechanisms (Hussain et al., 2016).

Most of the precipitation in the semi-arid regions of the middle and northern parts of Iran falls during the cold months of the year and partly at the beginning of the spring season. In such a situation, it seems that the use of regulated irrigation techniques such as deficit irrigation can lead to significant improvement of water use efficiency (WUE) in addition to saving water for the dry months of late spring and early summer. However, water shortage during flowering (BBCH scale 61-69) and fruit development (BBCH scale 75-79) can significantly affect seed yield (Singh et al., 2016; Flemmer et al., 2015). Deficit irrigation is designed based on less water consumption during drought-resistant or drought-insensitive growth stages and water saving for critical and drought-sensitive stages. Water-saving irrigation strategies are applied in various regions of semi-arid areas in which water used in irrigation systems is less than the amount of water needed for evapotranspiration in the plant, therefore can lead to an increase in WUE (Sidhu et al., 2021). In this strategy, the irrigation schedule is done in such a way that sufficient water provides *during* the specific *crop* development periods (drought-sensitive stages) to improve the WUE, by exposing the crops to some degree of water shortage and an acceptable yield reduction (Geerts & Raes, 2009). Deficit irrigation methods will be considered based on the amount of precipitation, water storage in the soil, and plant needs in different growth periods. It seems that the moisture condition of the soil and the amount of irrigation can affect the availability of some nutrients such as nitrogen in the soil (He et al., 2023). The application of nitrogen by developing vegetative structures and increasing leaf surface can affect water loss by increasing the transpiration and *stomatal conductance* (Mu & Chen, 2021). Despite some investigations regarding the effect of water stress on safflower in these areas, the safflower performance under deficit irrigation and nitrogen fertilizers application has not been well studied. This research aimed to evaluate the effect of deficit irrigation and nitrogen fertilizer on the growth characteristics and seed yield of safflower.

2 MATERIAL AND METHODS

2.1 CLIMATE OF THE SITE AND SOIL CHARACTERISTICS

A field experiment was designed to scrutinize the impacts of various irrigation levels and nitrogen doses on safflower growth and yield components during 2021-2022 growing seasons in the Qazvin, middle and northwest, Iran (1270 m height above sea level. between 36°15′ N latitude and 50°03′ E longitude). The climate of the studied area is cold semi-arid (Type BSk) based on the Köppen Climate Classification System. The soil texture of the studied location was clay loam. Soil characteristics were: pH = 7.62, electrical conductivity = 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}. The amount of annual potential evaporation and transpiration in the studied area was 1415 mm. The monthly evapotranspiration, temperature, and precipitation during the growing season are shown in Table 1.

2.2 PREPARATION OF THE SEED BED

The mentioned farm was under wheat cultivation during the previous years. The field was *plowed* in the

Table 1: Monthly evapotranspiration, temperature and precipitation in the field experiment area during the growing season of safflower (2022).

	Mar	Apr	May	Jun	July
Average of minimum temperature (˚C)	8.9	13.2	20.4	25.2	24.3
Average of maximum temperature (˚C)	16.2	23.4	31.9	36.0	34.4
Average of temperature (˚C)	12.55	18.30	26.15	30.6	29.3
Total evapotranspiration (mm)	89.2	129.5	208.4	282.3	299.4
Total rainfall (mm)	40.36	26.38	5.2	3.1	1.0

autumn by a moldboard plow to a depth of 35 cm deep and then a disc harrow was used to crush the lumps and mix the residues and animal manure. Rotten farmyard manure was added to the land at the rate of 20 t ha^{-1} and mixed with the topsoil with secondary tillage. In the early spring, before planting, the soil was re-tilled by a rotary cultivator to achieve a fine tilth seedbed. The experimental field was divided into plots (4 × 3 m). The distance between the blocks was chosen to be 1 meter to avoid merging the effects of fertilizer and irrigation treatments. The seeds were sown manually in experimental plots that included 8 rows by 50 cm distance between adjacent rows and 15 cm plant to plant distance and 3 m row length. The experimental field included 27 plots. The planting dates were 13 May 2022. The seed of safflower (*Carthamus tinctorius*'Saffeh' was selected by taking into account features such as spring type, drought resistance, acceptable seed yield, and relatively high adaptability to the semi-arid conditions of Iran. The seeds were obtained from Pakan Bazr of Isfahan, Iran.

2.3 EXPERIMENTAL DESIGN

The experiment was conducted as a split-plot design (SPD) over randomized complete block design (RCBD) with three replications. Different irrigation treatments including full irrigation (FI) or irrigation to 100 % potential evapotranspiration (ETP), 60 % ETP as mild deficit-irrigation (MDI), and 40 % EPT as severe deficit-irrigation (SDI) assigned to the main plots. The subplots were assigned to different doses of nitrogen fertilizer, which consisted of N_0: no use of nitrogen fertilizer, N_{40}: application of 40 kg ha^{-1} of nitrogen through urea fertilizer, and N_{80}: utilization of 80 kg ha^{-1} of nitrogen through urea fertilizer. The level setting of nitrogen fertilizer is based on the soil background value.

2.4 FIELD IRRIGATION

In this research, the irrigation method was chosen as a surface drip irrigation system with a cycle of 6-10 days (according to plant requirement and soil water depletion), and irrigation was measured by volumetric water meters. In this study a time domain reflectometry (TDR) with two parallel probes of 7.5 cm length have used to calculate soil volumetric water content. The water requirement at each time was determined based on potential evapotranspiration, irrigation cycle, and the relevant plant coefficient. Potential evapotranspiration was estimated through the relationship $ETP = E_{pan} \times K_{pan}$. Where K_{pan} was the coefficient of evaporation pan and E_{pan} was the amount of evaporation from the pan in millimeters per day, which was considered a cumulative amount during the growth period (Doorenbos and Pruitt 1975). For K_{pan} value of 0.70 was used as the 50-year average of the experimental site. The irrigation depth was calculated through the Vermeiren and Jobling (1980) suggested method. The irrigation depth in the growing season was 242 mm (SDI), 326 mm (MDI), and 465 mm (FI). Total rainfall was 76 mm during the growing season (April– August). To prevent the possible reducing effects of deficit irrigation on the yield components, the amount of irrigation during the critical stages, i.e. beginning of flowering to fruit development, was applied as full irrigation.

2.5 DATA RECORDING

During the filling stage, chlorophyll was measured in the upper leaves using a portable chlorophyll meter (Chlorophyll Meter SPAD-502- Japan). Canopy width was measured by measuring the amount of canopy expansion from the right to the left of the plant through a ruler. The height of the plant and lateral branches was measured at the maturity stage. In the physiological maturity stage, the mass of 1000 seeds and the yield after harvesting 2 m^2 from the central parts of the plots were randomly weighed. The biological yield was determined after oven-drying of total aboveground biomass at 75 °C until constant mass. The electrical balance was used to take the fresh and dry mass. The American Association of Cereal Chemists AACC-30-10 (2003) was used for the assessment of the seed oil content. Seed protein content was determined using a near-infrared seed analyzer (ZX-50SRT, Zeltex, USA).

2.6 STATISTICAL ANALYSIS

Before analysis of variance, the homogeneity of variances was done with Anderson–Darling homogeneity test. All figures (box plots) were created using SOSS 19. Analyses of variance ANOVA) was fitted using the general linear model procedure in software SAS. Means comparison was done using the least significance difference test at $p < 0.05$.

3 RESULTS

The results of the meteorological data indicated that most of the spring rains occur during March and April, and with the increase in temperature and decrease in rainfall during the following months, the amount of evaporation and transpiration in the field increased sharply (Table 1). The highest water requirement was recorded during July, which coincided with the stages of seed filling, and the use of continuous deficit irrigation can cause a sharp decrease in yield under the mentioned conditions.

3.1 PLANT AND CAPITULUM HEIGHT

The results of the analysis of variance indicated the presence of significant interaction effects of irrigation × fertilizer on the plant height component (Table 2). So, the longest plants were observed in full irrigation conditions and the improving effect of nitrogen in the mentioned conditions on the height was quite evident and obvious. Consumption of 80 kg ha^{-1} of nitrogen in full irrigation conditions increased the height by 18 % compared to the control (no fertilizer consumption). However, in SDI conditions, the effect of nitrogen fertilizer application on height was not very noticeable and caused a slight increase in plant height. Evaluation of FCH (distance between *ground level* and the *first* capitulum) showed that its response to nitrogen was largely similar to the plant height. High use of nitrogen under FI conditions increased the FCH, however, the lowest FCH was recorded under the MDI condition (Table 2).

3.2 CHLOROPHYLL CONTENT AND CANOPY WIDTH

Table 2: Effect of deficit irrigation and nitrogen fertilizer doses on growth parameters of safflower (*Carthamus tinctorius* L.).

	PH	FCH	CHL	CNP	CD	TSM	BYM	HI	OIL	
FI	N0	71.99d	41.00b	46.98de	9.17c	14.48bc	31.23c	7097.88c	14.55e	25.58bc
	N40	80.57b	39.33c	55.39c	10.99b	15.29b	31.81bc	7620.72b	14.71e	26.25b
	N80	85.62a	44.22a	66.42a	12.21a	16.75a	32.72a	8388.56a	14.98e	28.19a
MDI	N0	61.72ef	37.00c	47.10de	8.61c	14.02cd	30.11d	5746.07f	15.75d	25.18bc
	N40	75.10c	38.00bc	50.14d	10.17b	14.67bc	31.23c	6147.86e	16.41c	26.28b
	N80	81.37b	39.66bc	59.43b	12.38a	15.47b	32.04b	6490.77d	17.27b	27.61a
SDI	N0	56.93g	40.66b	41.02fg	6.91d	12.04e	28.72e	4559.81h	18.99a	23.99d
	N40	60.66f	39.66bc	39.79g	7.30d	13.25d	29.10e	4774.23g	18.62a	25.01cd
	N80	63.86e	41.00b	43.81ef	8.79c	33.88cd	28.15f	4897.99g	17.70b	24.88cd
					statistical significance					
I	**	**	**	**	**	**	**	**	**	
N	**	*	**	**	**	**	**	*NS*	**	
I×N	**	*NS*	**	*	*NS*	*	**	**	*NS*	

FI: full irrigation (100 % PET), MDI: mild deficit irrigation (60 % PET), SDI: sever deficit irrigation (40 % PET), N0: no nitrogen application (control), N40: application of nitrogen at doses 40 kg ha-1, N80: application of nitrogen at doses 80 kg ha-1, PH: plant height (cm), FCH: the height of first capitulum from the ground level (cm), CHL: leaf chlorophyll content (SPAD unit), CNP: capitulum number per plants, CD: capitulum diameter (mm), TSM: thousand seed mass (g), BYM: biological yield (kg ha-1), HI: harvest index (%), OIL: seed oil content (%). In each column rows with different letters have statistically significant differences at the 5% level ($p \le 0.05$). **: significant at 0.01 level, *: significant at 0.05 level, NS: not statistically significant.

Chlorophyll content as one of the important photosynthetic pigments was investigated under the influence of the treatments. The highest amount of chlorophyll SPAD value in upper young leaves was recorded in the flowering stage under FI and N80 conditions. However, low irrigation treatments significantly reduced the amount of chlorophyll. The use of MDI and SDI reduced the amount of leaf chlorophyll by about 8 and 26 %, respectively, compared to FA conditions (Table 2). The application of both levels of nitrogen under full irrigation conditions (FI+N_{40}, FI+N_{80}) significantly increased the chlorophyll content of leaves. Under MDI conditions, only using 80 kg ha^{-1} of nitrogen improved the chlorophyll content. Under SDI conditions, nitrogen application had no significant effect on leaf chlorophyll content. It did no influence the content of this article. In addition, canopy width is considered an important component describing vegetative growth. Results showed that the maximum canopy width was recorded under IF and the application of 40 and 80 kg ha^{-1} nitrogen in the mentioned conditions increased the canopy width by 10 % and 25 %, respectively, compared to the condition of no nitrogen fertilizer application (Figure 1). However, the use of N_{40} under MDI conditions and the use of N_{40} and N_{80} under SDI conditions could not positively affect the canopy width. Although the use of low levels of nitrogen under MDI conditions did not improve the lateral growth of the canopy, the use of N_{80} was able to improve the canopy width by about 13 % compared to the condition of not using fertilizer under the aforementioned irrigation regime.

3.3 SEED YIELD COMPONENTS

Assessment of the number of secondary branches (NSB) showed that irrigation treatments and application of nitrogen fertilizer strongly affected this component and reducing the amount of irrigation causes a significant decrease in the number of lateral branches. However, the application of N_{80} under MDI conditions was able to stimulate lateral growth to some extent and improved the number of lateral branches by 47 % compared to SDI+N_0 conditions (the lowest NSB). The highest number of NSB was recorded in the condition of applying large amounts of nitrogen and providing a large volume of water in irrigation with 10.5 branches. The lowest number of NSB was recorded under SDI + N_{80}, which was 60 % less than plants grown with the same nitrogen level under FI condition (Figure 2).

Number of the capitula per plant (CNP) significantly affected by the interaction effects of irrigation and nitrogen ($p < 0.05$). The highest number of capitulum was obtained under IF and MDI along with the application of high levels of nitrogen. However, the use of nitrogen in SDI conditions did not have much effect on the improve-

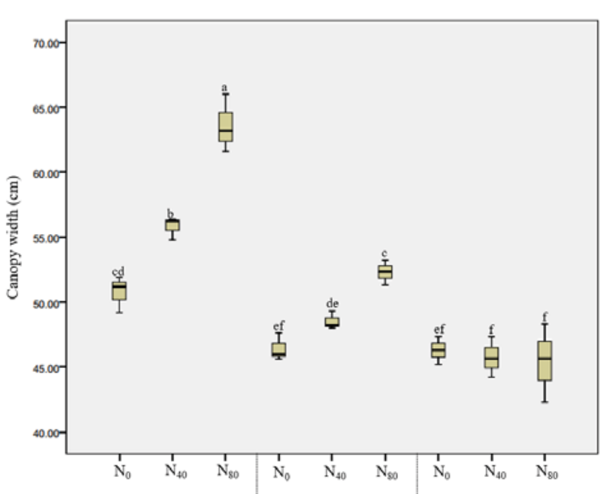

Figure 1: Mean comparison of the canopy width of safflower plants grown under different levels of deficit irrigation along with the application of different dose of nitrogen fertilizer. FI: full irrigation (100 % PET), MDI: mild deficit irrigation (60 % PET), SDI: sever deficit irrigation (40 % PET), N0: no nitrogen application (control), N40: application of nitrogen at doses 40 kg ha-1, N80: application of nitrogen at doses 80 kg ha-1. Boxes with different letters are statistically significant (p ≤ 0.05).

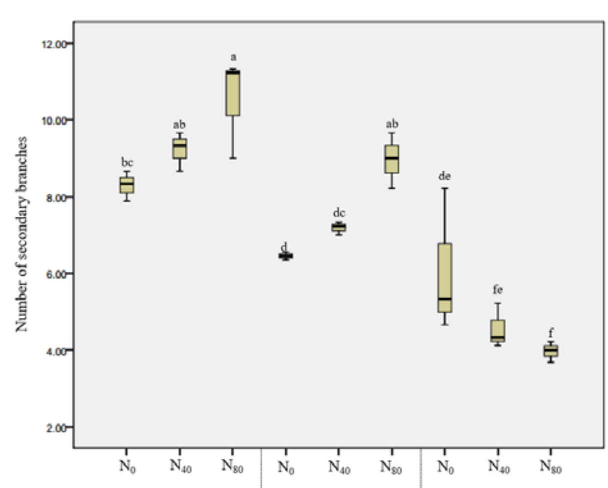

Figure 2: The effects of irrigation levels and nitrogen fertilizer doses on number of secondary branches of safflower. FI: full irrigation (100 % PET), MDI: mild deficit irrigation (60 % PET), SDI: sever deficit irrigation (40 % PET), N0: no nitrogen application (control), N40: application of nitrogen at doses 40 kg ha-1, N80: application of nitrogen at doses 80 kg ha-1. Boxes with different letters are statistically significant (p ≤ 0.05).

ment of this important yield component. The lowest CNP recorded for plants grown under SDI+N_0 and the use of N_{80} under FI and MDI increased this component by 44 %. Consumption of N_{80} under IF and MDI conditions increased CNP by about 15 %, while under SDI conditions it did not have a significant effect. Evaluation of capitulum diameter (CD) showed that application of N_{40} and N_{80} increased this trait by 6 % and 13 %, respectively. On the other hand, the mean comparison of CD among irrigation levels indicated that the use of SDI and MDI caused a decrease of 16 % and 6 % respectively in CD (Table 2). The examination of the mass of one thousand seeds showed that this component was very sensitive to irrigation treatments, so the use of MDI and SDI caused a significant decrease in the mass of seeds (4 % and 11 %). Nitrogen application was able to partially compensate adverse effects of water deficiency on seed weight under MDI conditions, however, the effect of nitrogen application under SDI conditions was not significant. Biological performance was strongly affected by irrigation and nitrogen treatments and their mutual effects. Although the application of N_{80} under IF conditions could improve biological yield by 18 %, the application of the same amount of fertilizer under MDI and SDI conditions led to an increase of 12 % and 7 %. In addition, the reduction of water consumption in MDI and SDI caused a reduction of 21 % and 39 % in biomass. The evaluation of seed yield indicated that the application of fertilizer under IF conditions significantly improve this trait (N_0: 1033 kg ha^{-1}, N_{40}: 1221 kg ha^{-1}, N_{80}: 1253 kg ha^{-1}). The increasing trend of fertilizer application on yield under MDA conditions was also visible (N_0: 905 kg ha^{-1}, N_{40}: 1049 kg ha^{-1}, N_{80}: 1161 kg ha^{-1}). However, fertilizer application could not have a positive effect under SDI conditions (Figure 3). Interestingly, the highest harvest index (HI) was recorded under SDI+ N_0 or N_{40} conditions, and the lowest harvest index was observed under full irrigation conditions. However, the application of N_{80} under MDI conditions significantly improves the HI.

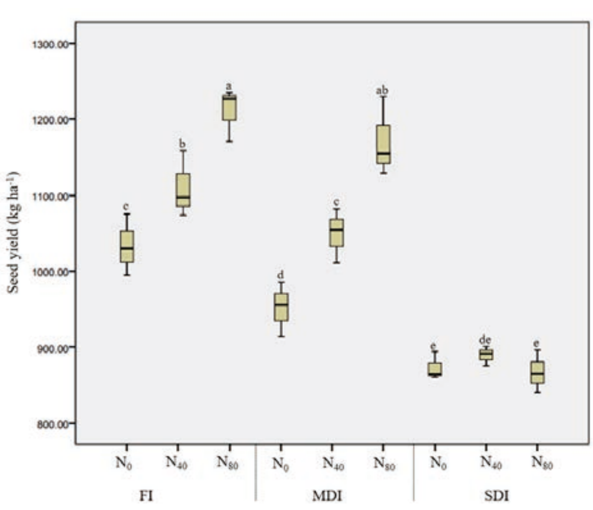

Figure 3: The effects of irrigation levels and nitrogen fertilizer doses on seed yield of safflower. FI: full irrigation (100 % PET), MDI: mild deficit irrigation (60 % PET), SDI: sever deficit irrigation (40 % PET), N0: no nitrogen application (control), N40: application of nitrogen at doses 40 kg ha-1, N80: application of nitrogen at doses 80 kg ha-1. Boxes with different letters are statistically significant (p ≤ 0.05).

3.4 SEED OIL AND PROTEIN CONTENT

Nitrogen application increased the seed oil content. The seed oil content of plants grown under the application of N_0, N_{40}, and N_{80} was 24.92 %, 25.84 %, and 26.89 % respectively. Applying SDI reduced the seed oil content by 2 % compared to full irrigation. The evaluation of seed protein content showed that this trait was significantly affected by nitrogen and the application of nitrogen at all irrigation levels increased the percentage of seed protein. However, the highest protein percentage was recorded under SDI+N_{80} (23.6 %), and the lowest protein percentage was related to the plants grown under FI+N_0 (Figure 4).

The clustering of traits classified them into three

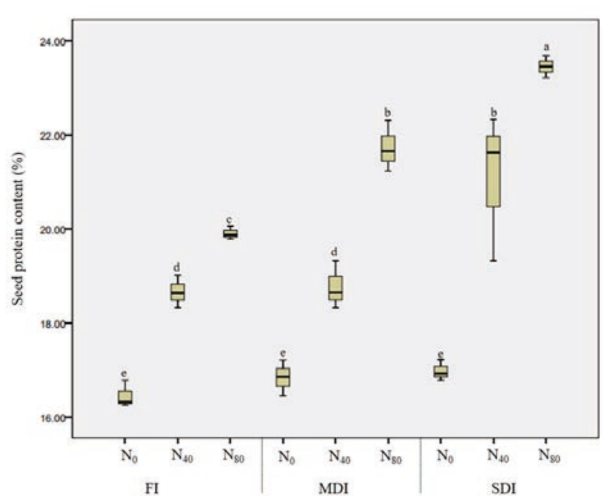

Figure 4: Mean comparison of the seed protein content of safflower plants grown under different levels of deficit irrigation along with the application of different dose of nitrogen fertilizer. FI: full irrigation (100 % PET), MDI: mild deficit irrigation (60 % PET), SDI: sever deficit irrigation (40 % PET), N0: no nitrogen application (control), N40: application of nitrogen at doses 40 kg ha-1, N80: application of nitrogen at doses 80 kg ha-1. Boxes with different letters are statistically significant (p ≤ 0.05).

groups in terms of similarity based on response to the investigated treatments. Cluster I include traits that showed their best performance under full irrigation conditions and with the application of high levels of nitrogen fertilizer. Cluster II included FCH, which was significantly reduced under MDI conditions. Cluster III included seed protein percentage and harvest index, which were increasingly stimulated by decreasing the amount of irrigation (Figure 5).

4 DISCUSSION

The results obtained in this research indicated that during the first months of the growing season, the rate of evapotranspiration was relatively low, but with the increase in temperature during the months of late spring and early summer, the rate of evapotranspiration increased significantly. The results of meteorological data showed that the amount of rainfall during the months of March to June was about 10 % of the amount of evaporation and transpiration from the evaporation pan. This indicates that the region is facing a severe lack of rainfall and the use of irrigation or the presence of water storage in the soil before cultivation is necessary. The evaluation of traits related to vegetative growth indicated that irrigation and nitrogen fertilizer treatments significantly affected these components. Plant growth is based on the accumulation of water in the vacuole and also due to the interaction of phytohormones (Pashkovskiy et al., 2022). On the other hand, due to the role of nitrogen-containing functional groups in key structures such as proteins and functional structures of enzymes, nitrogen is considered a key constituent in cells and its optimum supply is necessary for ideal plant growth (Govindasamy et al., 2023). However, consuming large amounts of nitrogen through increasing the level of evapotranspiration can accelerate the occurrence of drought stress in semi-arid areas. It appears that water shortage, such as the one observed under SDI conditions, causes the closing of the stomata, the reduction of photosynthesis, and finally the growth reduction through the rapid increase of abscisic acid (ABA) biosynthesis or increasing the release of previously made hormones from organelles such as chloroplasts (Car-

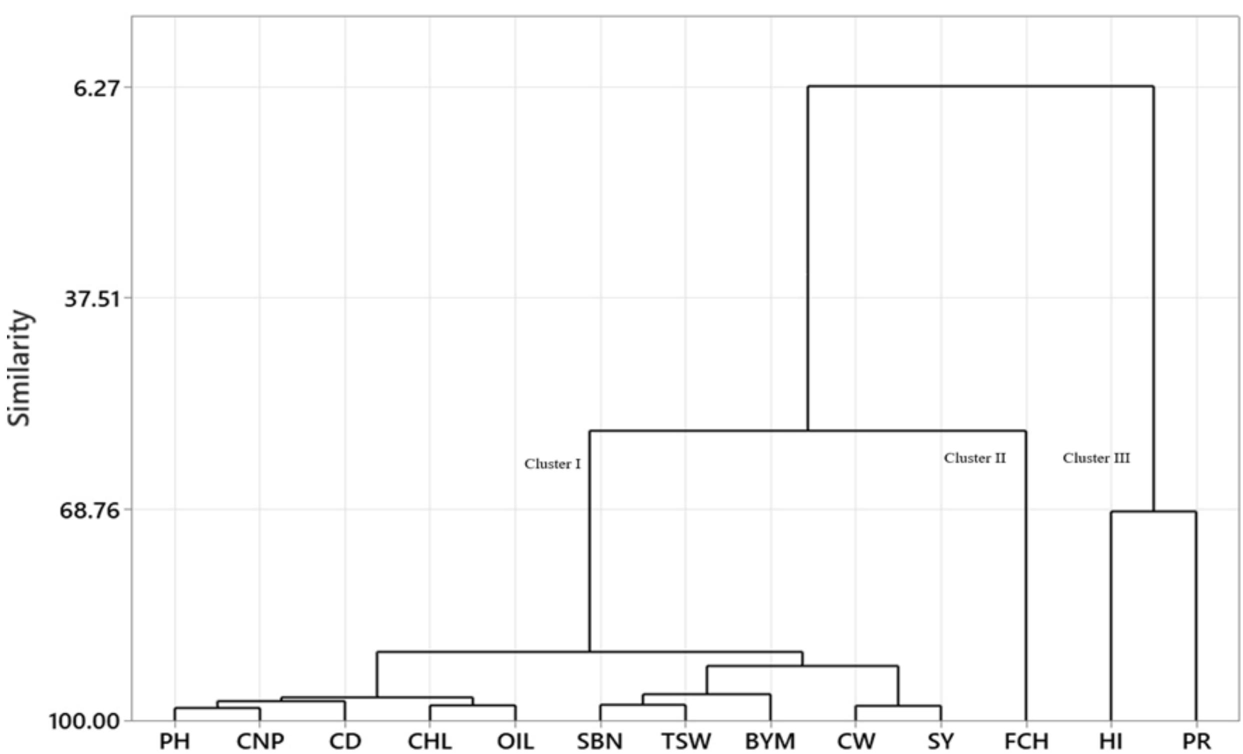

Figure 5: Clustering of different growth traits and yield components of safflower based on the response to different levels of irrigation and doses of nitrogen fertilizer. PH: plant height (cm), SBN: number of secondary branches, SY: seed yield, PR: seed protein content, FCH: the height of first capitulum from the ground level, CHL: leaf chlorophyll content, CW: canopy width, CNP: capitulum number per plants, CD: capitulum diameter, TSM: thousand seed mass, BYM: biological yield, HI: harvest index, OIL: seed oil content.

doso et al., 2020). However, nitrogen application under MDI conditions improved growth-related characteristics compared to MDI + N_0. The above results point out that water shortage under MDI conditions has not reached the limiting and extreme level. Probably water reduction in the mentioned conditions activated some adaptation mechanisms such as semi-*closed* stomata, preferential uptake of CO_2 and reduction of water loss through transpiration, increase of water absorption through the development of root growth and increased hydraulic conductivity has increased the efficiency of available water. Nitrogen utilization under MDI conditions was able to improve the efficiency of nitrogen and water consumption by stimulating growth and yield components and compensate the reduction caused by water shortage to a significant extent. The external application of nitrogen, as the most effective nutrient and agricultural input, can improve growth even in conditions of low water supply (Xing et al., 2019).

Another important result of the current experiment was that despite the tremendous effect of water in improving growth and yield characteristics, in optimal agricultural management, water supply alone is not enough to improve growth and achieve high yield, and other nutritional needs and ecological factors of the plant must be provided. These results further support the idea of Hu et al. (2023) who reported that the highest biomass of corn was obtained under the conditions of simultaneous application of nitrogen and water supply through supplementary irrigation during the stress-sensitive stages. These researchers found that the supply of moisture and nitrogen through increasing the activity of nitrate reductase, glutamine synthase, and glutamate dehydrogenase leads to more nitrogen supply to different parts of the plant and can produce a higher seed yield. The obtained results showed that the longitudinal growth of the plant as well as the canopy width and the size and the number of side branches increased with the supply of moisture (FI and MDI) and high level of nitrogen (N_{80}). Supplying sufficient nitrogen and moisture to the plant can increase the levels of auxin and cytokinin and intensify their positive interactions on vegetative growth (Abualia et al., 2023; Deepika et al., 2023). The application of nitrogen at different levels of irrigation had a different effect on chlorophyll. Under severe irrigation conditions, nitrogen application could not improve the chlorophyll content. This was predictable considering the key structural role of nitrogen in chlorophyll (Hirel et al., 2023). These results indicate that the nitrogen use efficiency is strongly influenced by the available moisture in the soil. The obtained results showed that despite less water consumption under MDI conditions, the utilization of N_{80} was able to increase the amount of this pigment up to the values recorded for plants grown under FI. This may refer to the compensatory effect of nitrogen in the mentioned conditions. In other words, under MDI conditions, the consumption of large amounts of nitrogen could compensate the diminishing effects of water deficiency to a significant extent. Chlorophyll content can be considered as an indicator of resource activity and ability to produce photo-assimilates. In the present experiment, nitrogen consumption under SID conditions could not have positive effects. The high correlation between yield and canopy width (closeness in clustering) indicates that higher canopy growth during the vegetative phase through the production of more photo-assimilates (larger source size) can better support the filling sinks during the reproductive stage. Since deficit irrigation was applied during the vegetative period and the end of reproductive stages, it seems that the differences between the yield components (CNP, CD, TSM, and SY) in different conditions of irrigation and nitrogen utilization were caused by the difference in the amount of photo-assimilates synthesized during vegetative growth and their remobilization from vegetative organ to the filling fruits. Koutroubas et al. (2021) stated that the remobilization of stored materials from the stem to the seed has a significant contribution to determine the yield of safflower, and management treatments such as irrigation and fertilization affect the amount of remobilization. Higher seed protein percentage under SDI conditions also confirm their findings. Our results showed that severe water shortage created by SDI increased the amount of protein in the seed. It has been determined that the protein content of the seed is largely dependent on the amino acids and nitrogen compounds that have reached to seed through remobilization and drought stress accelerates leaves *senescence* and the degradation of photosynthetic enzymes to amino acids and improves their remobilization to the filling seed (Hajibarat & Saidi, 2022). However, the response of oil content to the investigated treatments was largely similar to that of chlorophyll (Figure 5). These findings suggest that the seed oil content is largely dependent on the photo-assimilates produced in current photosynthesis, and its amount was significantly reduced under SDI and no nitrogen consumption conditions. However, nitrogen application under MDI condition leads to tuned growth and acceptable oil content. The current results showed that not necessarily all the water used under the FI is needed by the plant and sometimes it lacks improving effects on the yield, and low irrigation is regulated and mild along with the use of N_{80} while maintaining the yield at an acceptable level, the harvest index and some improves quality components.

5 CONCLUSION

The obtained results revealed that safflower production in the investigated climatic zone is not economical under rainfed or severe deficit irrigation condition (PET 40 %). Results showed regular supply of water in amounts less than full irrigation (PET 60 %) along with the application of nitrogen fertilizer (80 kg ha^{-1}) produced the acceptable seed yield and seed oil content. The results revealed that nitrogen application under mild deficit irrigation conditions (PET 60%), improved the growth and yield components to some extent, thereby slightly diminished the negative effects of water deficiency. Therefore, the policies should be in such a way that by supplying nitrogenous fertilizers to small-scale farmers and encourage the use of MDI increase the water productivity. The supply of cheap, subsidized nitrogenous fertilizers and the promotion of precise irrigation are considered an important step in the direction of preserving underground water resources.

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