Effects of Sowing Date and Limited Irrigation Water Stress on Spring Safflower (Carthamus tinctorius L.) Quantitative Traits

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ABSTRACT

Deficit irrigation is an optimization strategy in which irrigation water applied during drought-sensitive growth stages of a crop. This study was carried out to determine the effect of sowing date and limited irrigation water stress on quantitative characters of spring safflower cultivar (Arak 2811) grown in Agricultural Research Centre of Faculty of Agriculture and Natural Resources of Tehran University, in Karaj, Iran, during 2008 and 2009. The treatments comprised three sowing dates as main plots and limited irrigation treatments as subplots. The evaluated traits in this study were plant height, heads number and seed number per head, 1000 seed weight, seed yield, biological yield and harvest index. Interactive effects of sowing date and limited irrigation water stress indicated that plant response to irrigation is depended on the sowing date. Early sowing date and normal irrigation treatments at various safflower growth stages were identified maximum for all traits and minimum for the cut irrigation in the last sowing date at heads forming, flowering and grain filling stages, respectively. Under these conditions, optimal sowing date and irrigation application for safflower at reproductive stages could be a great management option to lessen the negative aspects of temperature and drought stress.

Keywords: Drought stress, Safflower, Sowing date, Yield, Yield components

INTRODUCTION

The safflower plant (Carthamus tinctorius L.) is a member of the Compositae family, tolerant to severe drought and salinity and an important alternative oil sources (Gegeel et al., 2007). There are at least 25 species of the Carthamus genus that are grown in the wild world (Yuan, 1989). The deep root and the many fine laterals, allow safflower to survive in periods of moisture shortage also limit the areas of the world where safflower can be cropped successfully.

Many grain crops have little yield response to water stress during vegetative stage and late reproductive or grain fill growth stages. However, crops are sensitive to water stress during reproductive growth stage and yields will be impacted during this period (Schaneekloth et al., 2010). In arid and semi-arid regions with limited water resources safflower is a high-quality forage.
crop (Bar-Tal et al., 2008) that can also be grown successfully on poorly fertile soil and in areas with relatively low temperatures (Koutroubas et al., 2008). Safflower is the most heat and drought tolerant of the alternative agronomic crops commercially available (Kephart et al., 1990). Yau (2006) indicated that later sowing of spring safflower in semi-arid and high elevation Mediterranean environment resulted in lower seed yield and later flowering does not allow an escape from the terminal drought and heat. Si and Walton (2004) suggested that a combination of an early sowing date with an early flowering cultivar would be essential for the production of high seed yield in the lower rainfall area. Kar et al. (2007) observed that under water deficit condition, supplemental irrigation during reproductive phases had a significant effect on increasing seed yield. Water stress at flowering negatively influenced the formation of pods, seed size, resulting in lower final seed yield. Although the importance of sowing date, water and high temperature stress on canola have been investigated (Ozer, 2003) but little information is available on the interactive effects of temperature and supplemental irrigation on seed yield and WUE.

One way of increasing the water use efficiency is the practice of deficit irrigation. Due to rapid population growth, increasing food requirement and limited water resources in Iran, deficit irrigation is inevitable. Therefore, knowledge on the irrigation schedule and water use efficiency of safflower under deficit irrigation condition becomes more important. This is because all field crops respond differently in different phenological stages to changing water status of the soil under deficit irrigation, which means that plants are more sensitive to water deficit at some stages than other stages. For example, these sensitive stages include flowering and boll formation in cotton, vegetative growth in soybean, flowering and seed filling stages in wheat, vegetative and yielding stages in sunflower and sugar beet (Kirda, 2002). Seed yield was reduced by water stress during the latter phases of reproductive development in lentil (Oweis et al., 2004), cotton (Henggeler et al., 2002), soybean (Sincik et al., 2008) and safflower (Lovelli et al., 2007) in varying locations. Juknevicius and Pekarskas (2002) found that the highest seed yield of safflower was obtained in the first sowing date (2000 kg ha⁻¹). In addition, they observed that 9-18 days delaying in sowing date, decreased seed yield by 510-850 kg ha⁻¹. Tahmašebizadeh et al. (2008) declared that the number of capituls in safflower plant was influenced significantly by planting date. Mirzakhani et al. (2002) noted that number of sub-shrubs per plant, number of capitul per plant, number of seeds per capitul and plant height in safflower had a significant decrease in the delayed planting date than the first planting date. Omidi and Sharif Moghadas (2010) noted that the effect of cultivar and planting date was significant on the safflower yield. Similar negative effects on seed yield have been observed with water stress during flowering and seed filling (Stoker and Carter, 1984, Nielsen, 1997). This study was proposed to evaluate the effects of three sowing times and four different irrigation regimes on safflower yield to determine optimal sowing date and suitable amount of irrigation water requirements.

**MATERIALS AND METHODS**

The research was carried out in Agricultural Research Centre of Faculty of Agriculture and Natural Resources of Tehran University in the city of Karaj, Iran (Lat. 35°, 59’ Long. 50°, 75’, elevation 1312m), as split plot arrangement based on randomized complete block
design with three replicates during two growing season (2008 and 2009). The treatments comprised three sowing dates (19 April, 5 May and 20 May) as main plots and four limited irrigation water stress levels (I0: irrigation after 60mm evaporation from class “A” pan as control; I1: cut irrigation at heads forming; I2: cut irrigation at flowering; I3: cut irrigation at grain filling) as subplots. Soil moisture determined gravimetrically using augers. All treatments were irrigated with equal amount of water in each time, which was measured with a 15 cm throat Parshall flume fixed in the irrigation channel. The data for day length (h), temperature (ºC), relative humidity (%) and precipitation (mm) were obtained from Karaj meteorological substation (Figure 1). Karaj is located in the central regions of Iran and has a mean annual temperature of 14.1 ºC and average annual rainfall of 251mm. Soil samples were taken before sowing (0-30 cm). According to soil analysis, the soil of the research area had a silty loam texture. Some physical and chemical compositions of the soil of the research area are given in Table 1.

Based on soil analysis, 120 kg/ha urea and 80 kg/ha ammonium phosphate fertilizer were applied to the site and harrowed before seedbed preparation. Half of needed nitrogen was applied before sowing and the remaining half was applied top dressed at flower-bud-visibility stage. The area of each plot was 10 m² consisting of 8 rows, 5 m long and 25 cm apart. Seeds were sown 4 cm apart at about 4-5 cm depth. Plots were over seeded and subsequently thinned to final density of about 100 plants m⁻² at seedling stage. Weeds were controlled by both Trifluralin (2.5 L/ha) as preplant and by hand as needed. Seed yields were taken at maturity by harvesting the center six rows of each plot for seed yield determination. Subsamples were dried at 105 ºC for moisture determination. All measurements were reported on a dry weight basis (9% moisture content). Twenty plants were randomly collected from the central six rows with edging shears (0.1m cutting width) and the characteristics were recorded for each plot included plant height (cm), number of heads per plant, seed number per heads, thousand seed weight (g), seed yield (kg/ha), biological yield (kg/ha) and harvest index (%). The number of seeds per head was determined on a random subsample of 20 fruits. Seed yield and 1000 seed weight was recorded. Plots were harvested at maturity and seeds were dried to uniform moisture content for 24-48 h at 75-80 ºC. Harvest index was calculated by following formula:

Harvest index = Seed yield / Biological yield × 100  

Analysis of variances of data for each attribute and combined analysis of the split plot designs in two years were computed using the SAS computer program (SAS Institute 2001). F test in combined analysis of the experiments was carried out using expected values of the mean squares which year and replication were assigned as random variables and sowing date and limited irrigation were considered as fixed variables. The Duncan's multiple range tests at 5% level of probability was used to test significant main effects. The MSTAT-C software package was used to test significant interaction effects between treatments (MSTAT-C 1993). The coefficient of linear regression equation between the traits mean as the dependent variables and growth degree day (GDD) of all the growth season of safflower as the independent variable are calculated by SAS. Accumulated GDD were calculated by summing the daily degree day values (ºC) obtained by adding the maximum (Tmax) and minimum (Tmin) temperatures for the day, dividing by two and subtracting the base temperature (Tb), which for safflower is 5 ºC:

GDD = ((Tmin + Tmax)/2) - Tb  

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In this study for calculating GDD, if daily average temperature was equal to or lower than basic temperature, GDD=0 would considered.

**RESULTS**

*Effect of year*

The combined analysis of variances revealed highly significant differences between both years for all safflower traits except seeds number per head (Table 2). Data revealed that the plant height, heads number per plant, thousand seed weight, seed yield, biological yield and harvest index were significantly higher in year 2009 than 2008 (Table 3).

*Effect of sowing date*

Sowing dates had a significant effect on heads number per plant, thousand seed weight, seed yield and biological yield (Table 2). The maximum plant height, heads number per plant, thousand seed weight, seed yield, biological yield and harvest index of safflower obtained on April 19th sowing, and lower values for traits acquired when safflower was sown on May 20th. The April 19th and May 5th sown safflower produced statistically similar thousand seed weight, seed yield, biological yield and harvest index (Table 3).

<table>
<thead>
<tr>
<th>pH</th>
<th>Organic matter (%)</th>
<th>Total nitrogen (ppm)</th>
<th>Assumable phosphorus (ppm)</th>
<th>Exchangeable potassium (ppm)</th>
<th>E.C. (ds.m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.40</td>
<td>0.53</td>
<td>0.11</td>
<td>6.3</td>
<td>275</td>
<td>2.36</td>
</tr>
</tbody>
</table>

Figure. 1. Ambient temperature, rainfall and relative humidity during safflower growing season on 2008 and 2009 in Karaj

Table 1. Some physical and chemical compositions of the soil in the experiment field
Effect of irrigation levels

Differences between limited irrigation treatments were significant at 1% level of probability for all safflower traits in the combined analysis of variances except seeds number per head (Table 2). Plant height, heads number per plant, seeds number per head, thousand seed weight, seed yield, biological yield and harvest index values were significantly affected by limited irrigation water stress. These safflower characteristics were the highest at control irrigation (I0) and cut irrigation at grain filling, respectively (Table 3).

Table 2. Combined analysis of variance for the effects of year, sowing dates and limited irrigation water stress on quantitative characters of spring safflower (r=3)

<table>
<thead>
<tr>
<th>S.O.V</th>
<th>d.f.</th>
<th>Plant height</th>
<th>Head number per plant</th>
<th>Seed number per head</th>
<th>Thousand seed weight</th>
<th>Seed yield</th>
<th>Biological yield</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1</td>
<td>932.8**</td>
<td>637.8**</td>
<td>0.934ns</td>
<td>167.8**</td>
<td>5404376**</td>
<td>69832562**</td>
<td>94.53**</td>
</tr>
<tr>
<td>R/Y</td>
<td>4</td>
<td>2.22</td>
<td>1.44</td>
<td>1.27</td>
<td>1.09</td>
<td>2624.2</td>
<td>29427</td>
<td>0.091</td>
</tr>
<tr>
<td>T</td>
<td>2</td>
<td>1066.8ns</td>
<td>168*</td>
<td>70.06ns</td>
<td>162.4*</td>
<td>3874849</td>
<td>48216012*</td>
<td>66.03ns</td>
</tr>
<tr>
<td>Y×T</td>
<td>2</td>
<td>59.01**</td>
<td>5.81ns</td>
<td>37.88**</td>
<td>6.1*</td>
<td>137298**</td>
<td>1231948**</td>
<td>3.5**</td>
</tr>
<tr>
<td>R×T(Y)</td>
<td>8</td>
<td>3.74</td>
<td>1.6</td>
<td>2.06</td>
<td>1.11</td>
<td>6147</td>
<td>55096</td>
<td>0.143</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
<td>1014**</td>
<td>179.3*</td>
<td>256.8**</td>
<td>412.5**</td>
<td>690874**</td>
<td>101514982**</td>
<td>76.55*</td>
</tr>
<tr>
<td>T×I</td>
<td>6</td>
<td>30.83**</td>
<td>9.36*</td>
<td>1.93**</td>
<td>3.97**</td>
<td>29667**</td>
<td>462697**</td>
<td>0.651ns</td>
</tr>
<tr>
<td>Y×I</td>
<td>3</td>
<td>28.99**</td>
<td>7.06**</td>
<td>43.54**</td>
<td>7.28**</td>
<td>81407**</td>
<td>2476839**</td>
<td>3.38**</td>
</tr>
<tr>
<td>Y×T×I</td>
<td>6</td>
<td>1.54ns</td>
<td>1.42ns</td>
<td>1.93**</td>
<td>1.95**</td>
<td>39528**</td>
<td>506843**</td>
<td>0.811**</td>
</tr>
<tr>
<td>Pooled error</td>
<td>36</td>
<td>5.34</td>
<td>1.45</td>
<td>1.62</td>
<td>1.99</td>
<td>4299.5</td>
<td>39060</td>
<td>0.141</td>
</tr>
</tbody>
</table>

* p <0.05; ** p ≤ 0.01; ns: non-significant; R: Block; Y: Year of sowing; T: sowing date; I: Irrigation treatments.

Table 3. Duncan’s mean comparison test for the effects of year, sowing dates and limited irrigation water stress (±SE) on quantitative characters of safflower

<table>
<thead>
<tr>
<th>Factors</th>
<th>Plant height</th>
<th>Head number per plant</th>
<th>Seed number per head</th>
<th>Thousand seed weight</th>
<th>Seed yield</th>
<th>Biological yield</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year(Y)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y1</td>
<td>82.4±1.75a</td>
<td>16.69±0.72b</td>
<td>25.06±0.82b</td>
<td>27.1±0.91b</td>
<td>1277±113b</td>
<td>6156±443b</td>
<td>19.66±0.45b</td>
</tr>
<tr>
<td>Y2</td>
<td>89.6±1.24a</td>
<td>22.65±0.55a</td>
<td>25.28±0.55a</td>
<td>30.15±0.71a</td>
<td>1825±104a</td>
<td>8125±368a</td>
<td>21.95±0.34a</td>
</tr>
<tr>
<td>Sowing date (T)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>91.7±1.27a</td>
<td>22.2±0.67b</td>
<td>26.65±0.77a</td>
<td>30.65±0.94a</td>
<td>1909±129a</td>
<td>8436±465b</td>
<td>22.14±0.39a</td>
</tr>
<tr>
<td>T2</td>
<td>87.8±1.46ab</td>
<td>19.89±0.96b</td>
<td>25.56±0.79a</td>
<td>29.52±0.99b</td>
<td>1629±140a</td>
<td>7358±517b</td>
<td>21.33±0.52b</td>
</tr>
<tr>
<td>T3</td>
<td>78.7±2.14b</td>
<td>16.92±1.03b</td>
<td>23.3±0.86a</td>
<td>25.69±0.95b</td>
<td>1116±114b</td>
<td>5627±476b</td>
<td>18.95±0.47b</td>
</tr>
<tr>
<td>Irrigation levels (I)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I0</td>
<td>92±1.31a</td>
<td>22.48±0.83a</td>
<td>28.63±0.51a</td>
<td>34.02±0.56a</td>
<td>2208±101a</td>
<td>9523±292a</td>
<td>23±0.37a</td>
</tr>
<tr>
<td>I1</td>
<td>75.9±2.4c</td>
<td>15.52±1.17c</td>
<td>20.36±0.8b</td>
<td>22.68±0.61d</td>
<td>797±102d</td>
<td>4113±424b</td>
<td>18.46±0.54b</td>
</tr>
<tr>
<td>I2</td>
<td>84.8±1.73b</td>
<td>18.96±1.11b</td>
<td>24±0.54b</td>
<td>27.45±0.83b</td>
<td>1329±128b</td>
<td>6497±476b</td>
<td>19.79±0.54b</td>
</tr>
<tr>
<td>I3</td>
<td>91.4±1.28a</td>
<td>21.7±0.65b</td>
<td>27.7±0.53a</td>
<td>30.34±0.75a</td>
<td>1872±99b</td>
<td>8429±332a</td>
<td>21.98±0.35b</td>
</tr>
</tbody>
</table>

Means with similar letters within each column for each treatment are not significantly different (Duncan 5%). Y1: 2008; Y2: 2009; T1: 19 April; T2: 5 May; T3: 20 May; I0: Normal irrigation at all growth stages; I1: Cut irrigation at heads forming; I2: Cut irrigation at flowering; I3: Cut irrigation at grain filling.
Interaction effect of year and sowing dates

The combined ANOVA revealed that all safflower traits were significantly influenced by year-sowing date interaction except heads number per plant (Table 2). Plant height, heads number per plant, seeds number per head, thousand seed weight, seed yield, biological yield and harvest index were significantly higher in the first sowing date, whereas the lowest values recorded for the last sowing date in both years (Figure 2).

In both years, for sowing dates treatments, there was a highly significant difference among aforementioned parameters except the sowing dates of 19 April and 5 May for seed number per heads, thousand seed weight and harvest index in 2009 that showed statistically similar results.

Interaction effect of sowing dates and irrigation levels

The combined analysis of variances revealed highly significant differences (p<0.001) between irrigation by sowing dates treatments for plant height and heads number per plant (Table 2). The maximum safflower plant height, heads number per plant, seeds number per head, thousand seed weight, seed yield, biological yield and harvest index obtained from early sowing date with supplementary irrigation at all growth stages and minimum safflower traits obtained for the last sowing date under limited irrigation water stress at heads forming, flowering and grain filling stages, respectively (Figure 3).

![Figure 2. Duncan’s mean comparison test for the interaction effects of year and sowing date (±SE) on plant height, seed number per head, thousand seed weight, seed yield, biological yield and harvest index of safflower. Mean of each treatment with similar letters are not significantly different (Duncan 5%). T1: 19 April; T2: 5 May; T3: 20 May](www.SID.ir)
Figure 3. Duncan’s mean comparison test for the interaction effects of sowing dates and limited irrigation stress (±SE) on plant height and head number per plant of safflower. Mean of each treatment with similar letters are not significantly different p<0.05. T1: 19 April; T2: 5 May; T3: 20 May.; I0: Normal irrigation at all growth stages; I1: Cut irrigation at heads forming; I2: Cut irrigation at flowering; I3: Cut irrigation at grain filling.

Interaction effect of year and irrigation levels

Year – irrigation interaction was significant (p<0.01) for all safflower characteristics (Table 2). Mean comparison revealed that higher plant height, heads number per plant, seeds number per head, thousand seed weight, seed yield, biological yield and harvest index were recorded from normal irrigation at all growth stages and limited irrigation water stress at head forming, flowering and grain filling stages, respectively in 2008 and 2009 (Figure 4), followed by the limited irrigation water stress at head forming and flowering stages.

Regression model

The relationship between GDD (x) and the safflower factors (Y) was significant at 0.01 level in all cases in pooled values for 2008 and 2009 (Table 5, Figure 5). A regression analysis revealed that the quantitative safflower traits were increasing with the increase of GDD. The highest value of GDD was recorded in the first sowing date compared to second and third sowing date of safflower in the both years. The results revealed that duration (days) for the maturity of safflower by normal irrigation were highest and reduced with limited irrigation stress at heads forming, flowering and grain filling stages (Table 4).
Figure 4. Duncan’s mean comparison test for the interaction effects of year and limited irrigation stress (±SE) on plant height, head number per plant, seed number per plant, thousand seed weight, seed yield, biological yield and harvest index of safflower. Mean of each treatment with similar letters are not significantly different p<0.05. I0: Normal irrigation at all growth stages; I1: Cut irrigation at heads forming; I2: Cut irrigation at flowering; I3: Cut irrigation at grain filling

Table 4. Safflower growing period (Duration) under different treatments of sowing dates and limited irrigation stress in 2008 and 2009.

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration(Day)</td>
<td>119</td>
<td>66</td>
<td>85</td>
</tr>
<tr>
<td>GDD (ºCday)</td>
<td>2090</td>
<td>1059</td>
<td>1413</td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration(Day)</td>
<td>132</td>
<td>91</td>
<td>113</td>
</tr>
<tr>
<td>GDD (ºCday)</td>
<td>2233</td>
<td>1458</td>
<td>1885</td>
</tr>
</tbody>
</table>

Table 5. Regression relationship between growth degree day and some quantitative traits of safflower during growing season (pooled values for 2008 and 2009)

<table>
<thead>
<tr>
<th>Plant height</th>
<th>Head number per plant</th>
<th>Seed number per head</th>
<th>Thousand seed weight</th>
<th>Biological yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>52**</td>
<td>2.75</td>
<td>11.8**</td>
<td>9.3**</td>
</tr>
<tr>
<td>b</td>
<td>0.02**</td>
<td>0.01**</td>
<td>0.008**</td>
<td>0.01**</td>
</tr>
<tr>
<td>R²</td>
<td>0.78</td>
<td>0.76</td>
<td>0.68</td>
<td>0.90</td>
</tr>
</tbody>
</table>

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DISCUSSION

Plant height

Variations for safflower plant height within two years could be due to difference in the environmental factors. Delaying sowing caused a reduction in plant height (Table 3, Figure 2) which was due to increase in terminal temperature strain during the growing season, which is also affirmed by Taylor et al. (1991). The sowing date by irrigation interaction for plant height indicated that safflower in April sowing was faced a more favorable thermal and moisture regime than in the May sowing (Table 3, Figure 3, 4).

Heads number per plant

The number of heads per plant in safflower is commonly a major yield determinant and this character dependent on the number of flowers produced by plant. The differences in sowing dates had significant influences on safflower heads number (Table 2). Pollen development, fertilization, and asynchrony of stamen and gynoecium’s development are sensitive to temperatures during flowering (Croser et al., 2003; Boote et al., 2005). Therefore, episodes of high temperature during safflower flowering would severely affect pollen production and decreased fruit-set lead to safflower heads number (Hall, 2004). The fully irrigated safflower produced the most heads/plant which was owing to sowing date by irrigation interaction (Table 3, Figure 3, 4) which was in accordance with Farid and Ehsanzadeh (2006) who reported a similar trend in safflower. Lovelli et al. (2007) also reported that water stress greatly reduced the safflower heads number per plant, while other production components were not influenced. In the present study, the number of heads per plant was significantly correlated with seed yield.

Seed number per head

The minimum seeds number per head was found in safflower sown on May 20th due to a high temperature effect in later sowing date (Table 3, Figure 2). Duthion and Pigeaire (1991) reported high temperature stress during reproductive development at late sowing date that might have affected flower abortion, sequent sink site, and later pod abscission resulting to a decreased number of seeds per plant. The highest seeds number per head was observed when drought stress occurred by elimination of irrigation at heads forming, flowering and grain filling stages (Table 3, Figure 4). This was probably because of
senesced leaf, which led to a lower seeds number per head. The reduction of seed number per head under water stress may due to lower photosynthetic production, because of excessive loss of leaves at the flowering stage (Rauf, 2008). Tayebi et al. (2012) showed that some main factors in decreasing the number of fertile capituls are lack of water, high temperature, decrease in photosynthetic materials and prematurity.

**Thousand seed weight**

Mean seed weight was depended on sowing date and year. Both factors interacted significantly with irrigation levels (Table 3, Figure 2, 4). Apparently, warmer temperatures promoted growth of safflower from the later sowing dates. However, the decrease in mean seed weight in the present study was compensated by a marked increase in the head number per plant. High temperature stress during reproductive development may have negatively affected cell expansion, cotyledon cell number and thus seed filling rate, resulting in the lowered weight per seed (Munier and Ney 1998).

**Seed yield**

Amount of rainfall from April to October from flowering to seed filling periods of safflower at normal sowing date was compared. The difference between the two succeeding years was even higher (Figure 1). Under arid and semi-arid conditions of Karaj (Iran), there are some years with inadequate rainfall, particularly during critical periods of reproductive stages, to achieve potential seed yield, led to dramatic decrease in seed yield. Therefore, during these years, supplemental irrigation is an important tool to increase seed yield (Oweis et al., 2004). The increase safflower yield was particularly due to increase in heads number per plant, seed number per heads, thousand seed weight (Table 3). Lower safflower seed yield of last sowing compared with the first and second sowing dates apparently relates to high temperatures and unfavorable warm conditions during reproductive stage in May 20th sowing (Table 3, Figure 2, 4). Gan et al. (2004) found that the seed yield of canola decrease by 58% when high temperature stress was delayed to the period of flowering, and further to 77% when the stress was delayed to the pod developmental stage. The results showed that the positive yield response to irrigation of safflower was due to the significant positive correlation of seed weight, harvest index and head number per plant with seed yield.

**Biological yield**

The minimum biological yield was at later sowing date (Table 3, Figure 2), could be ascribed to high temperature hastens the development, shortens the duration (Table 4) and reduces the biological yield per day from sowing to harvest that confirms the results of Garsid (2004). In comparison, biological yield produced under I1 and I2 was significantly lower than that of the other irrigation treatments (Table 3, Figure 4). It appears that water stress hampered flowering and reduced the probability of developing flower to heads and its occurrence during flowering and capsule formation resulted in capsule abortion and therefore produce more biological yield. In this study, water stress caused a reduction in biological yield (Table 3), as confirmed by Naderi et al. (2004). High dry matter production from the fully irrigated chickpea plants probably increased vegetative demand for assimilates (Palta and Plaut, 1999).
Harvest index

Harvest index of safflower in 2009 was more than 2008, led to higher seed yield in 2009 (Table 3). That was particularly due to better distribution of rainfall and radiation in 2009 compared to 2008 (Figure 1). In early sown crop, the grain formation stages coincided with favorable lower temperature, whereas the late sown crop (May 20th) suffered severely from heat stress during grain formation leading to abnormal development and poor production. With a delay in sowing date, harvest index was obviously reduced due to increase in terminal temperature stress, resulting in reduced seed yield. The April sowing date allows the safflower to mature before experiences significant water stress and with a higher seed yield, resulted in an increased HI in the both years (Table 3, Figure 2). Concurrently, at different sowing dates the HI was significantly higher under higher irrigation. These results coincide with limited irrigation stress research conducted by Dybing and Zimmerman (1965) who found their minimum harvest index at higher temperature. Results of this study agree with findings of Cox and Julliff (1988) who reported that with reducing water consumption, biological yield production decreased but the reduction of grain yield in response to drought stress was more than the reduction of biological yield. Pandey et al. (2001) suggested that the reason of harvest index reduction at severe drought stress is the higher sensitivity of reproduction growth to undesirable conditions in comparison with generative growth.

Regression model

Different planting dates caused flowering and seed development to occur during periods of different temperatures, radiation and day length (Figure 1, Table 4). There was a positive linear relationship between GDD and all of safflower studied traits (Table 4, Figure 5). These results are in consistent with the findings of Mundel et al. (1994) and Tomar (1995), who showed there is a significant positive relation between growing degree days and yield and yield components in safflower. So a correct decision on the planting date should be based in a through understanding of the environmental factors influencing safflower growth and yield.

CONCLUSION

In areas where the available water supply limits agricultural production, deficit irrigation will gain importance over time as farmers strive to increase the productivity of their limited land and water resources. Farmers must choose crops and irrigation strategies carefully to maximize the value of their crop and livestock production activities, while ensuring the sustainability of agriculture. Late planting usually results in shorter plants, less branching, and lower seed yield and yield components, even if damage from frost or disease does not occur. Planting date should be selected such a way that the process does not coincidence in stress-sensitive plants. Deficit irrigation will play an important role in farm-level water management strategies, with consequent increases in the output generated per unit of water used in agriculture. This suggested that it is possible to obtain high seed yield with less applied water, when the irrigation halt happens at a tolerant phenological stage.

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