Effect of Supplemental Irrigation on Lentil Yield and Growth in Semi-Arid Environment

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Abstract

Lentil is one of the most promising legume crops providing nutritional and food assurance to human beings. Due to extensive production of lentil crop in rain-fed agriculture system, its growth and yield are mainly determined by the levels of precipitation. Consequently, it usually faces drought stress during the generative stage resulting in low yield. In such scenario, controlled supplemental irrigation (SI) can improve and stabilize the productivity. Therefore, the present study was conducted to determine the effect of supplemental irrigation on the growth and yield of lentil crop under semi-arid climate conditions of Turkey. An experiment was performed during two consecutive crop seasons at Sanliurfa, Turkey with annual mean rainfall of 196 and 275 mm in the first and second experimental year, respectively. Six supplementary irrigation treatments were given using drip irrigation system [no supplement irrigation (I0), 25% (I25), 50% (I50), 75% (I75), 100% (I100, full irrigation) and 125% (I125) supplement irrigation depending on the available soil water content]. Results obtained in the study indicated that in both study years, highest biomass, harvest index and grain yield values were obtained from fully irrigated treatments (I100), while non-supplementary irrigated treatments have provided lowest values. It should be clearly noticed that growth parameters including yield were lower under over-irrigation treatment (I125). Hence, it is recommended that farmers need to optimize the supplemental irrigation technique to obtain desired yields. This study will support the successful usage of the supplemental irrigation technology to improve lentil productivity, particularly under semi-arid environment.

Keywords: drought, lentil, rain-fed agriculture, supplemental irrigation, semi-arid climate, yield components

Introduction

Lentil (Lens culinaris Medik.) is one of the most important pulse crops of the world that is consumed for its high protein and mineral content. The crop including red, green and black types is an excellent source of dietary fibers and B-complex vitamins. In addition to human consumption, high-quality lentil hay is extensively used as animal feed (Lardy and Anderson, 2009). It also supports crop rotation due to its potential to sustain soil productivity by nitrogen fixation (Abi-Ghanem et al., 2011).

In 2015, the total world lentil production was around 4.9 million tons. Since more than last one decade, Turkey has been the third largest producer of lentils in the world, after Canada and India (FAOSTAT 2015). USDA GAIN report mentions that South-eastern part of Turkey contributes 75-80% of total red lentil production (Sertas, 2009; Sarker and Kumar, 2011). However, this region is characterized by dry summers and poses a challenge of terminal drought stress for the plants resulting farmers to plant the crop during autumn and harvest in early summer. In addition, intermittent drought stress occurs during the vegetative growth period and adversely affects the yield.

In last decade, farmers in the South-eastern Turkey has low lentil yields mainly due to elevated temperature and low precipitation. In such scenario, supplemental irrigation can be an efficient technique to cope with the limited water availability and to stabilize the crop yields (Oweis and Hachum, 2012). Supplemental irrigation is the partial supply of water to the crops, when soil moisture is low and during critical growth stages to increase the crop growth and water productivity (Oweis and Hachum, 2003).

A number of researchers have conducted studies to estimate the effects of supplemental irrigation on crop yields under different growth environments and at different growth stages (Saxena, 1981; Pala and Mazid, 1992; Hamidi et al., 1992; Salim et al., 1993; Zhang et al., 2000; Oweis et al., 2004; Shamsi et al., 2010; Baker et al., 2012; Erkul et al., 2012; Dogan et al., 2013; Girma and Haile, 2014; Sui et al., 2014; Soltani et al., 2015; Ali et al., 2016).
Other than these studies on lentil, Pandey et al. (2013) established a novel approach to simulate supplemental irrigation and possible benefits of a rainwater harvesting system in rain-fed agricultural regions. Employing the approach, they estimated the soil moisture availability, crop yields in both irrigated and rain-fed environments and the impact of size of an on-farm reservoir (OFR) system.

In Turkey, South-eastern Integrated Development Project (SIDP) has targeted to utilize 1.2 million hectare land in South-eastern Turkey for irrigation farming. This will promote the lentil production as it is the second most extensively grown crop in the region. As information on the effect of supplementary irrigation on lentil yield in different regions of the world is limited; current study was performed to determine the effect of supplemental irrigation on crop growth parameters and the resulting lentil yield under the semi-arid climatic conditions of the South-eastern region of Turkey known as the Fertile Crescent.

### Materials and Methods

#### Experimental site and weather conditions

The experiment was conducted during two consecutive crop seasons at Faculty of Agriculture, Harran University, Turkey. The study area had clay loam soil (Vertic Calciorthid Aridisols) with average field capacity of 31.9%, permanent wilting point of 22.1%, available water of 77.7 mm at 60 cm, and infiltration rate of 13 mm h\(^{-1}\). The soil bulk density value was approx. 1.4 g cm\(^{-1}\). The soil pH was 7.2. Soil organic matter was low ranging from 0.6 to 0.8%, available water of 77.3 mm at field capacity, permanent wilting point of 22.1%, active root depth was assumed to be 60 cm for irrigation. The average field capacity of 0.31 dS m\(^{-1}\), and a SAR of 0.25 and was categorized as CgS1.

### Table 1. Weather data of the study area (Sanliurfa, Turkey) during both the experimental years

<table>
<thead>
<tr>
<th>Parameters / Months</th>
<th>Min. Air Temp. (°C)</th>
<th>Max. Air Temp. (°C)</th>
<th>Av. Temp. (°C)</th>
<th>Precipitation (mm)</th>
<th>Relative Humidity (%)</th>
<th>Solar Radiation (Cal cm(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>First Experimental Year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>November</td>
<td>2.2</td>
<td>26.8</td>
<td>12.5</td>
<td>15.4</td>
<td>58.1</td>
<td>252.0</td>
</tr>
<tr>
<td>December</td>
<td>-2.0</td>
<td>16.1</td>
<td>6.8</td>
<td>45.6</td>
<td>65.5</td>
<td>195.1</td>
</tr>
<tr>
<td>January</td>
<td>-3.2</td>
<td>13.5</td>
<td>3.7</td>
<td>57.1</td>
<td>52.2</td>
<td>230.1</td>
</tr>
<tr>
<td>February</td>
<td>-3.1</td>
<td>17.5</td>
<td>6.6</td>
<td>28.3</td>
<td>59.9</td>
<td>316.4</td>
</tr>
<tr>
<td>March</td>
<td>4.2</td>
<td>29.5</td>
<td>14.7</td>
<td>12.4</td>
<td>55.7</td>
<td>503.3</td>
</tr>
<tr>
<td>April</td>
<td>6.0</td>
<td>36.4</td>
<td>20.4</td>
<td>1.8</td>
<td>48.0</td>
<td>608.1</td>
</tr>
<tr>
<td>May</td>
<td>9.9</td>
<td>37.0</td>
<td>22.1</td>
<td>26.7</td>
<td>47.2</td>
<td>726.0</td>
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<tr>
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<td>29.8</td>
<td>8.6</td>
<td>29.8</td>
<td>797.7</td>
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<tr>
<td>Average</td>
<td>4.0</td>
<td>27.4</td>
<td>14.6</td>
<td>24.5</td>
<td>52.1</td>
<td>453.6</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>November</td>
<td>6.0</td>
<td>24.7</td>
<td>14.0</td>
<td>35.3</td>
<td>62.3</td>
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</tr>
<tr>
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<td>7.0</td>
<td>37.7</td>
<td>58.6</td>
<td>193.3</td>
</tr>
<tr>
<td>January</td>
<td>-4.7</td>
<td>15.7</td>
<td>5.7</td>
<td>29.8</td>
<td>59.1</td>
<td>213.9</td>
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<tr>
<td>February</td>
<td>0.1</td>
<td>17.3</td>
<td>8.0</td>
<td>54.5</td>
<td>72.2</td>
<td>253.9</td>
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<tr>
<td>March</td>
<td>1.5</td>
<td>23.0</td>
<td>10.0</td>
<td>55.3</td>
<td>65.6</td>
<td>460.1</td>
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<td>April</td>
<td>5.9</td>
<td>27.5</td>
<td>15.8</td>
<td>48.8</td>
<td>53.0</td>
<td>627.2</td>
</tr>
<tr>
<td>May</td>
<td>10.0</td>
<td>37.0</td>
<td>22.7</td>
<td>4.7</td>
<td>36.3</td>
<td>755.8</td>
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<tr>
<td>June</td>
<td>17.8</td>
<td>40.0</td>
<td>29.6</td>
<td>9.2</td>
<td>29.1</td>
<td>754.7</td>
</tr>
<tr>
<td>Average</td>
<td>4.4</td>
<td>25.6</td>
<td>14.1</td>
<td>34.4</td>
<td>54.5</td>
<td>440.0</td>
</tr>
</tbody>
</table>

Source: Turkish State Meteorological Services
In both the years, the climatic conditions of the study area during the growth period were closer to long-term averages, first experimental year had higher temperature and solar radiation values with low humidity in comparison to the second year. In addition, considering the temperature and rainfall, the first year was drier than the second year. The rainfall amounts in first and second year were 196 and 275 mm, respectively (Table 1).

**Experimental design and treatments**

The experimental area was twice cultivated prior to sowing. Size of the experimental plots was 6 x 1.2 m, consisting of six rows with 1.7 cm spacing within the rows and 20 cm distance between each row. In each trial plot, lentil seeds were sown to obtain a density of 300 seeds m$^{-2}$ and 20 kg ha$^{-1}$ fertilizer containing pure nitrogen and phosphorus was supplied to each plot. In both the study years, seeds were sown and harvested in the month of November and May, respectively. Plants from the middle four rows of each plot were included in vegetative and generative stages.

Nitrogen and phosphorus was supplied to each plot. In both the years, although the climatic conditions of the study area during the growth period were closer to long-term averages, first experimental year had higher temperature and solar radiation values with low humidity in comparison to the second year. In addition, considering the temperature and rainfall, the first year was drier than the second year. The rainfall amounts in first and second year were 196 and 275 mm, respectively (Table 1).

**Table 2. Measured lentil crop parameters and obtained statistical results for both the experimental years**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Year</th>
<th>I$_{0}$</th>
<th>I$_{50}$</th>
<th>I$_{100}$</th>
<th>I$_{25}$</th>
<th>I$_{50}$</th>
<th>I$_{100}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal Irrigation Amount (L mm)</td>
<td>1st Year</td>
<td>25</td>
<td>67</td>
<td>109</td>
<td>151</td>
<td>193</td>
<td>235</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>25</td>
<td>88</td>
<td>93</td>
<td>126</td>
<td>160</td>
<td>194</td>
</tr>
<tr>
<td>Seasonal Crop Water Use (ETc. mm)</td>
<td>1st Year</td>
<td>158</td>
<td>204</td>
<td>246</td>
<td>288</td>
<td>330</td>
<td>330</td>
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<td></td>
<td>2nd Year</td>
<td>215</td>
<td>287</td>
<td>329</td>
<td>362</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>Plant Height (cm)</td>
<td>1st Year</td>
<td>14.3</td>
<td>25.0</td>
<td>28.0</td>
<td>25.0</td>
<td>33.7</td>
<td>32.0</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>17.3</td>
<td>23.3</td>
<td>24.3</td>
<td>26.7</td>
<td>30.7</td>
<td>32.7</td>
</tr>
<tr>
<td>Number of Branch</td>
<td>1st Year</td>
<td>3.0</td>
<td>5.7</td>
<td>6.5</td>
<td>6.0</td>
<td>7.0</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>3.7</td>
<td>5.0</td>
<td>5.7</td>
<td>6.3</td>
<td>8.0</td>
<td>7.3</td>
</tr>
<tr>
<td>1000 seed weight (g)</td>
<td>1st Year</td>
<td>35.5</td>
<td>36.2</td>
<td>32.3</td>
<td>29.2</td>
<td>31.3</td>
<td>31.3</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>35.5</td>
<td>27.2</td>
<td>31.2</td>
<td>30.5</td>
<td>27.7</td>
<td>35.5</td>
</tr>
<tr>
<td>Biomass (kg ha$^{-1}$)</td>
<td>1st Year</td>
<td>2611.1</td>
<td>4263.8</td>
<td>4944.5</td>
<td>5583.6</td>
<td>6111.4</td>
<td>5666.7</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>3481.1</td>
<td>4888.5</td>
<td>5976.0</td>
<td>6509.8</td>
<td>6912.8</td>
<td>6033.4</td>
</tr>
<tr>
<td>Yield (kg ha$^{-1}$)</td>
<td>1st Year</td>
<td>291.1</td>
<td>415.3</td>
<td>767.6</td>
<td>1018.7</td>
<td>1536.1</td>
<td>1403.1</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>257.7</td>
<td>1233.5</td>
<td>1468.1</td>
<td>1566.5</td>
<td>1788.2</td>
<td>1726.9</td>
</tr>
<tr>
<td>Harvest Index</td>
<td>1st Year</td>
<td>0.06</td>
<td>0.10</td>
<td>0.16</td>
<td>0.18</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>0.17</td>
<td>0.25</td>
<td>0.25</td>
<td>0.24</td>
<td>0.26</td>
<td>0.29</td>
</tr>
<tr>
<td>Water Use Efficiency (kg ha mm$^{-1}$)</td>
<td>1st Year</td>
<td>0.0</td>
<td>1.4</td>
<td>2.7</td>
<td>3.1</td>
<td>4.3</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>0.0</td>
<td>2.3</td>
<td>3.1</td>
<td>3.0</td>
<td>3.4</td>
<td>--</td>
</tr>
<tr>
<td>Irrigation Water Use Efficiency (kg ha mm$^{-1}$)</td>
<td>1st Year</td>
<td>0.0</td>
<td>4.8</td>
<td>6.2</td>
<td>6.1</td>
<td>7.5</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>2nd Year</td>
<td>0.0</td>
<td>7.5</td>
<td>9.6</td>
<td>7.8</td>
<td>7.6</td>
<td>--</td>
</tr>
</tbody>
</table>

Any two numerical values followed by different letters are significantly different from each other at 5% level of significance.

Crop water use during the growing season was calculated using the water budget method (Doorenbos and Kasam, 1979).

$$ET = I + P \cdot D \cdot R_{r} \pm \Delta t$$

(1)

Here, ET is evapotranspiration (mm), I is irrigation water (mm), P is the effective rainfall plus capillary rise (mm), D is drainage (mm), Rr is runoff (mm), and $\Delta t$ is the change in the soil moisture content (mm).

In order to determine the water content, 30 cm layers were gravimetrically sampled to a depth of 90 cm prior to irrigation. As drip irrigation system was used and there were no excess irrigations or runoff during the irrigation seasons of either year, Rs and D, were assumed to be zero, thus, reducing the equation to

$$ET = I + P \pm \Delta t$$

(2)

Again, here, ET is evapotranspiration (mm), I is irrigation water (mm), P is the effective rainfall plus capillary rise (mm) and $\Delta t$ is the change in the soil moisture content (mm).

The yield, biomass, plant height and 1000-seed weights of all the plants were determined, and the resulting harvest index (HI), water use efficiency (WUE) and irrigation water use efficiency (IWUE, kg ha$^{-1}$ mm$^{-1}$) were calculated. The water use efficiency (WUE, kg ha$^{-1}$ mm$^{-1}$) and irrigation water use efficiency (IWUE) were calculated with the following equations (equations 3, 4, and 5), as outlined by Kanber (1999).

$$HI = Yt / BM$$

(3)

$$WUE = (Yt - Yc) / I$$

(4)

$$IWUE = (Yt - Yc) / ETc$$

(5)

Here, Yt is the yield value (kg ha$^{-1}$), BM is the biomass value (kg ha$^{-1}$) of each trial plot, Yc is the yield value from the control treatment (kg ha$^{-1}$), I is the seasonal applied irrigation water (mm), ETc is the seasonal crop water consumption (mm), and HI is the harvest index of each treatment. All the experiments were carried out in a randomized complete block design with three replications.
Data analysis

Analysis of Variance (ANOVA) was performed to test the differences among the main supplementary irrigation treatments. Seasonal irrigation amounts were regressed against each of the variables using the statistical program SPSS (2002). Both, ANOVA and regression tests were considered significant at p<0.05.

Results and Discussion

As mentioned above, due to higher temperature, higher solar radiation and lower humidity, climatic conditions were more challenging in the first study year. This resulted in a short growth period of the lentil plants in the first year than the second year even after the sufficient irrigation water supply to the full-irrigation treatments.

Depending on the variable supplementary irrigation rates applied to the trial plots, water availability fluctuated the harvest date. In both study years, plants in the I0 and I25 treatments ripened 5-6 days earlier than those in the I50 and I75 treatments and 12-14 days earlier than those in the I100 and I125 treatments. The amount of irrigation applied to the trial plots ranged from 25 to 235 mm and 25 to 194 mm in the first and second year, respectively as first year was drier than the second study year. This resulted in a short growth period of the lentil plants in the first year than the second year even after the sufficient irrigation water supply to the full-irrigation treatments.

During the first half of the year, the supplementary irrigation treatments were applied to the trial plots, and the following data were observed:

- **PH**: Plant height
- **IW**: Irrigation water supply
- **NB**: Number of branches

**Fig. 1. Relationship between the applied seasonal irrigation water and plant heights obtained for the lentil crop in first and second study year.**

**Fig. 2. Relationship between the applied seasonal irrigation water and the number of branch per plant obtained for the lentil crop in first and second study year.**

The lentil plant heights (PHs), depending on the irrigation treatments, varied from 14.3 to 32.0 cm and from 17.3 to 32.7 cm in first and second year, respectively. The PHs in the second year were slightly higher than in the first year likely due to the different climate conditions. There was no statistically significant difference between the study years, but there was a considerable difference among treatments (p>0.05). Overall, plant heights increased with the increased irrigation supply. In both study years, there were significant differences between I0 and the other treatments demonstrating the advantage of supplemental irrigation and the effect of drought stress on plant height. When irrigation trials were compared, there were no significant differences among the I25, I50 and I75 treatments (Table 2). The fully irrigated and over-irrigated treatments (I100 and I125) produced the tallest (p<0.05) plants compared to the other treatments, possibly due to the available soil water content and longer growth period. Khourgami et al. (2012) conducted a study to determine the effect of supplementary irrigation on lentil yield components and found that supplementary irrigation significantly increased the lentil plant height that is consistent with our study results. Regression analyses of the plant height showed a significant positive linear relationship between plant height and irrigation with high R² values (0.75 for the first year and 0.99 for the second year), where an additional 1 mm of irrigation water supply resulted in a 0.9 mm increase in the plant height in both study years. The linear equations for the 2008 and 2009 data were PH = 0.0757 IW + 16.48 and PH = 0.0921 IW + 15.31, respectively (Fig. 1).

The number of branches per plant (NB) varied from 3.0 to 7.0 and 3.7 to 8.0 in the first year and second year, respectively. In the first year, the I0 trial had significantly (p<0.05) lower NB, but there were no differences among the other trials. The highest NB average occurred in the I100 trial. Similarly, the lowest NB average was in the I5 treatment and was significantly lower than the other treatments. The highest NB, on the other hand, was from the I100 trial and was significantly higher than the other trials, except I25. Panahyan-e Kivi et al. (2009) showed that an increase in the number of branches per plant is correlated with the increased irrigation amount. On the contrary, Khourgami et al. (2012) claimed that supplementary irrigation does not have a significant effect on the number of branches per plant in lentils.

A regression analysis of the current data indicated a linear relationship between irrigation water (IW) and the number of
lentil plant branches for both study years. The equations were $NB_{2008} = -0.0002\, IW^2 + 0.0545\, IW + 2.099$ ($R^2 = 0.88$) and $NB_{2009} = -6E0.05\, IW^2 + 0.038\, IW + 2.585$ ($R^2 = 0.90$) (Fig. 2).

The lowest 1000-seed weights (SW) from the first and second year crop growing seasons were 29.2 (l10) and 27.2 g (l15), while the highest were 36.2 (l10) and 33.5 (l15) (Table 2), respectively. There was no significant difference among all the trials in both years indicating that irrigation rates do not contribute to seed weights. The regression equations for the 1000-seed weight of the first and second growing seasons as a function of irrigation water were calculated as $SW_{2008} = -0.0002\, IW^2 + 0.0303\, IW + 33.175$ ($R^2 = 0.47$) and $SW_{2009} = 0.0003\, IW^2 - 0.0566\, IW + 31.41$ ($R^2 = 0.32$) (Fig. 3).

In both study years, the lowest and highest biomass (BM) values were from non-irrigated (l0) and fully irrigated treatments (l15) (2611 and 5583 kg ha⁻¹ in the first year and 3481 and 6912 kg ha⁻¹ in the second year). The difference in the BM values between the study years can be attributed to climatic conditions that led to an earlier harvest resulting in the low BM in the first study year. Analysis of the data indicated that the BM in both study years significantly increased with increased irrigation amounts, resulting in maximum BM under full-irrigation treatments. Similar to our results, Hosseini et al. (2011) reported that lentil BM values from irrigated plots were higher when compared to the non-irrigated plots. The relationship between irrigation treatments and biomass was linear and statistically significant ($p<0.05$). The equations for both years were $BM_{2008} = -0.1123\, IW^2 + 43.805\, IW + 1645.2$ ($R^2 = 0.85$) and $BM_{2009} = -0.1774\, IW^2 + 56.389\, IW + 2031.9$ ($R^2 = 0.89$), with both of the equations being significant ($P<0.05$).

In both trial seasons, the lowest yield (Y), as anticipated, was from the l0 (dry land conditions) trials (291 kg ha⁻¹ in the first year and 577 kg ha⁻¹ in the second year), while the highest yields were from the l15 treatment (1536 kg ha⁻¹ in the first year and 1788 kg ha⁻¹ in the second year). Several researchers have determined similar effects of supplementary irrigation on lentil yield. Lal et al. (1988) claimed that drought during the filling stage of lentil reduces both the number of pods per plant and the number of seeds per pod resulted in reduced yield. Erskine and Ashkar (1993) and Hudak and Patterson (1995) claimed that irrigation during the lentil grain filling stage increases the yield. Bhattacharya (2009), Hosseini et al. (2011) and Khourgami et al. (2012) also indicated that the supplementary irrigation had positive effect on lentil yield. Sarker et al. (2003) indicated that irrigation during the reproductive stage increases the lentil yield. In current study, the low yield values obtained from the l0 (dryland) trial highlighted the necessity and importance of supplemental irrigation under semi-arid climatic conditions. Statistical analysis of the yield data indicated the differences in both, among the study years and among the irrigation treatments ($p<0.05$) (Table 2). Since there was no statistical difference in 1000 seed weights among all trials, it is confirmed that yield difference was due to number of seeds per plant. This clearly pointed out that supplement irrigation statistically increases the number of seeds per plant as observed in our yield data.

Fig. 3. Relationship between the applied seasonal irrigation water and 1000-seeds weight obtained for the lentil crop in first and second study year. SW, IW and $R^2$ denote the above ground biomass, irrigation water supply and proportion of variance, respectively.

Fig. 4. Relationship between the applied seasonal irrigation water and above ground biomass obtained for the lentil crop in first and second study year. BM, IW and $R^2$ denote the above ground biomass, irrigation water supply and proportion of variance, respectively.

Fig. 5. Relationship between the applied seasonal irrigation water and crop yield obtained for the lentil crop in first and second study year. Y, IW and $R^2$ denote the yield, irrigation water supply and proportion of variance, respectively.
In the first experimental year, the yield values were consistently lower than the second year likely due to shorter harvest time. Panahyan-e Kivi et al. (2009) conducted an experiment using different irrigation rates and lentil cultivars and reported a minimum yield of 869 kg ha\(^{-1}\) and a maximum yield of 1340 kg ha\(^{-1}\). While the yield from the non-irrigated plants in their study was higher than our study possibly due of higher precipitation, the other yields were similar to our results.

Irrigation amounts were regressed with yield values using a linear model, and high coefficient of determination (R\(^2\)) values were obtained for both study years.

Regression equations for 2008 and 2009 were:

\[
Y_{2008} = -0.006 IW^2 + 7.806 IW + 23.0 \quad (R^2 = 0.93)
\]

\[
Y_{2009} = 0.0483 IW^2 + 17.56 IW + 161.37 \quad (R^2 = 0.97)
\]

both of which were statistically significant (P<0.05) (Fig. 4).

In the first year, the lowest, 0.06, and the highest, 0.25, harvest index values were obtained from the I\(_0\) and I\(_{100}\) treatments, respectively. ANOVA test results did not indicate any significant differences between I\(_0\) and I\(_{25}\), between I\(_{50}\) and I\(_{75}\) and between I\(_{100}\) and I\(_{125}\). On the other hand, in the second experiment year, even though irrigation seems to improve the harvest index, there was no significant (P<0.05) difference among all the trials, except I\(_0\) (Table 2).

Based on our results, it seems that supplementary irrigation improves the harvest index. Panahyan-e Kivi et al. (2009) reported the harvest index values ranging from 0.22 to 0.30 that were similar to the present study results. Regression analysis of the harvest index values against the total irrigation amounts indicated a positive polynomial equation for both the seasons. The statistically significant (p<0.05) regression equation of the combined harvest index data was:

\[
HI = -2E-06 IW^2 + 0.0018 IW + 0.033
\]

with R\(^2\) value of 0.92 (Fig. 6).

Water use efficiencies (WUE) in the first and second year varied from 1.4 (I\(_{25}\)) to 4.3 (I\(_{100}\)) and from 2.3 to 3.4, respectively. WUE values in the first year of the study were higher than the second year, and that difference was attributed to the drier climate conditions. As expected with increased irrigation amounts, the WUE also increased. Gholipoor and Soltani (2008) reported WUE values similar to the current study, and their values ranged from 3.5 to 5.2 depending on the location of the trials in Iran. Regression analysis of the WUE data indicated a significant relationship between the crop ET and WUE, and the equation was:

\[
WUE_{2008} = -0.0002 ET^2 + 0.057 ET - 1.29
\]

\[
WUE_{2009} = -3E.05ET^2 + 0.0301 ET - 0.75
\]

both equations having R\(^2\) value of 0.98 (Fig. 7).

In present study, irrigation water use efficiencies (IWUE) ranged from 1.4 to 4.3 kg ha\(^{-1}\) mm\(^{-1}\) from 2.3 to 3.4 kg ha\(^{-1}\) mm\(^{-1}\) for the first and second year, respectively. Overall, an increase in the yield resulted in significantly (p<0.05) increased IWUE. Regression analysis of the data indicated significant relationships for IWUE of both of the years, and the equations were:

\[
IWUE_{2008} = -0.0008 IW^2 + 0.2067 IW - 4.5374 \quad (R^2 = 0.95)
\]

\[
IWUE_{2009} = -0.0002 IW^2 + 0.0859 IW - 1.988 \quad (R^2 = 0.97)
\]

for 2008 and 2009, respectively (Fig. 8).
Conclusions

Lentil is one of the most significant pulse crops that can be a high protein source to the people unable to afford animal protein. As it is traditionally grown as a rain-fed crop, its production is highly influenced by rise in global temperature, diminished precipitation and persistent drought stress. In such situation, application of technologies like supplemental irrigation may serve as a viable option to improve crop productivity. Hence, in this study the effect of supplemental irrigation on lentil yield and its components under the semi-arid climate conditions of the Harran plain, Sanliurfa, Turkey was studied. Based on the study results, 400-450 mm of total moisture (including rainfall and supplementary irrigation) has been recommended for the optimum lentil growth and yield under similar climatic conditions. Moreover, on one hand, where appropriate supplementary irrigation improved the lentil yield, on other side, over-irrigation (more than full irrigation) lowered the measured parameters including yield. So, we can conclude that the farmers need to precisely understand the supplementary irrigation technology before employing it. Although the technique has emerged as a doable way to improve productivity, it must be properly organized with other soil management practices and efficient germplasm to obtain the preferred outcome. Additionally, under similar growth conditions and under no water stress, 6000-7000 kg ha\(^{-1}\) of above ground biomass and 1500-1800 kg ha\(^{-1}\) lentil yield could be expected. Moreover, methods used for supplementary irrigation should be cost-effective, automated, easily movable from one farm to another and efficient to make scheduled irrigations to fulfil the crop prerequisites at specific growth stages. Results obtained in the study would facilitate the farm irrigation practices especially in the semi-arid climatic conditions that consequently may improve the lentil production.

References


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