African Journal of Biotechnology Vol. 10(49), pp. 10009-10018, 31 August, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1601
ISSN 1684–5315 

*Full Length Research Paper*

# Effects of different irrigation regimes and nitrogen levels on yield and quality of melon (Cucumis melo L.)

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Accepted 27 July, 2011

**In order to study the effects of different irrigation regimes and nitrogen (N) levels on yield and some yield components of melon, a research was conducted at the Agricultural Experimental Field of the Harran University (Sanliurfa, Turkey) during the growth periods of 2007 and 2008. The growing season of melon was divided into four phenological stages: (i) Stage I, from seed germination to beginning of flowering; (ii) stage II; from beginning of flowering to small fruit, (iii) stage III; from small fruit to full-expanded fruit and (iv) stage IV; from full-expanded fruit to harvesting. Regulated deficit irrigation (RDI), deficit irrigation (DI), full (I-full) and excessive irrigation (I-excessive) strategies were examined. The irrigation treatments were 33% (I0.33), 67% (I0.67), 100% (I1.00), and 133% (I1.33) ratios of total irrigation water applied (IW)/cumulative pan evaporation (CPE) with four day irrigation interval. Totally, 28 treatments were designed and applied as combination of nitrogen and irrigation levels. Four nitrogen treatments were: Control (N1), basic fertilizer (100 kg ha$^{-1}$ pure N); N2, basic fertilizer + 30; N3, basic fertilizer + 60 and N4, basic fertilizer + 90 kg ha$^{-1}$ as urea. The field experiment was setup employing a randomized split-plot design with three replications. N levels were assigned to the main plot and irrigation to the sub plot. Irrigation water amount applied, fruit yield and some quality parameters, yield response factor, irrigation water use efficiency, water use efficiency, water saving at different N levels and irrigation regimes were determined. Results show that irrigation regimes and N levels had significant effects on fruit yield. The best combination of treatments was N3*DI-low (T19) with a yield of 59.77 t ha$^{-1}$ which corresponds to 10% yield loss providing 55% water saving. It could be applied for sustainable production, saving a significant amount of water and increasing the nitrogen use efficiency, where water is scarce.**

**Key words:** Melon, regulated deficit irrigation (RDI), nitrogen, yield.

## INTRODUCTION

The world production of melon (Cucumis melo L.) is almost 28.0 million t in total area of 1.3 million ha. Turkey is the second largest producer (1.7 million t) of melon after China, but the average fruit yield (16.0 t ha$^{-1}$) is considerably lower than China's productivity of 25.0 t ha$^{-1}$. It is followed by Iran with 15.4 t ha$^{-1}$ (FAO, 2009).

The main message of the 5th World Water Forum was that the water has been the heart of crises affecting the world. The climate and other global changes have negative impacts on water resources. Development and moder-nization of irrigation strategies are urgently needed to improve water demand management, productivity and water use for agriculture. Many farmers believe that: "the more the water, the more the crop yield"; on the contrary, over-irrigation and over-fertilization have significant adverse effects on water resources (Anonymous, 2009).

Water is vitally important in order to maintain the efficient crop production and higher yields. The demand for the irrigation water from agricultural user triggers the compe-tition for water resources and increases the environ-

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**Abbreviations: FWt,** Fruit weight; **FWh,** fruit width; **FL,** fruit length; **SCD,** seed cavity diameter; **SSDM,** soluble solid dry matter; **WUE,** Water use efficiency; **IWUE,** irrigation water use efficiency; **RDI,** regulated deficit irrigation;**IR,** irrigation regimes; **I-$_{full}$,** full; **ET$_c$,** crop evapotranspiration.

**Table 1.** Average of daily values of air temperature ($T_a$), relative humidity (RH), precipitation (P), solar radiation ($R_s$) and wind speed at 2 m height ($u_2$) for the month of June to October at Sanliurfa, during the experiments as compared to the long term mean.

| Year | Month | $T_a$ (°C) | RH (%) | P (mm) | $R_s$ (MJ $m^{-2}$ $day^{-1}$) | $u_2$ (m $s^{-1}$) |
|---|---|---|---|---|---|---|
| | June | 30.4 | 36.9 | 0.8 | 25.7 | 2.3 |
| | July | 34.0 | 31.3 | 8.0 | 23.2 | 2.1 |
| **2007** | August | 32.2 | 41.9 | 3.2 | 21.8 | 1.6 |
| | September | 28.4 | 36.4 | - | 17.9 | 1.7 |
| | October | 21.6 | 47.7 | 14.5 | 13.4 | 1.3 |
| | June | 29.8 | 29.8 | 8.6 | 26.5 | 2.7 |
| | July | 32.7 | 34.7 | - | 25.7 | 1.7 |
| **2008** | August | 33.0 | 46.8 | 0.5 | 20.2 | 1.6 |
| | September | 26.0 | 52.6 | 83.2 | 17.2 | 1.6 |
| | October | 20.5 | 55.6 | 22.5 | 13.4 | 1.1 |
| | June | 27.9 | 32.4 | 3.0 | 24.4 | 3.0 |
| | July | 33.1 | 29.6 | 0.6 | 23.5 | 3.1 |
| **Long run average (1929 to 2008)** | August | 31.2 | 32.3 | 0.9 | 21.5 | 2.7 |
| | September | 26.7 | 35.1 | 1.1 | 18.3 | 2.4 |
| | October | 20.1 | 44.8 | 23.8 | 13.2 | 1.8 |

mental concern (Doorenbos and Kassam, 1979).

Irrigation becomes a bigger issue when the area is under harsh climatic conditions where water and land sources are limited and the rainfall amount is considerably low. For these regions, RDI strategies can be thought to be alternative to the traditional irrigation scheduling due to its advantages of cutting down the usage of water to meet the needs of plants (Stewart and Nielsen, 1990). RDI is primarily based on the idea of plant sensitivity to water stress which is considered not to be the same during the growth season. Therefore, the intermittent water stress can be acceptable and useful with regards to water saving and better water use efficiency (Mitchell et al., 1984; Silber et al., 2007). This strategy has been applied for many crop productions such as maize (Kang et al., 2000), onion (Bekele and Tilahun, 2007) and watermelon (Gonzalez et al., 2009).

The objectives of this study were to determine the effects of different irrigation strategies such as regulated deficit, deficit and excessive irrigation, different amount of N levels on the FY, yield components and the WUE of melon through its different growth stages under semi-arid climate conditions.

## MATERIALS AND METHODS

### Site description and climate

Field experiments were carried out at the Agricultural Experimental Research Station of the University of Harran, Sanliurfa, Turkey (latitude of 37° 08' N, longitude 38° 46' E, 464 m above sea level) during the summer of 2007 and 2008. The site is in a continental semi-arid temperate zone with a mean annual precipitation of 364.2 and 314.1 mm in 2007 and 2008, respectively. The texture of the study area was characterized as high-clay content (60%) in the effective root zone (0.0 to 0.60 m). The soil had a field capacity and permanent wilting point based on volumetric water content [(v/v)%]: 40.8 to 42.6% and 28.7 to 30.3%, respectively. The bulk density and organic matter were 1.33 to 1.39 gcm-3 and 1.8 to 2.7%, respectively. The plant available water up to 1.0 m was between 161 and 171 mm for the vertical zone. Some climatic variables for experimental years and averages of long years are presented for the months in which the experiments were conducted (Table 1).

### Crop management, irrigation and nitrogen levels, and statistical analysis

A field experiment was conducted during two years. Melon seeds (cv Futuro F1, FITO seed comp.) were sown in the field on June 25, 2007 and July 18, 2008. Seeds were spaced with 50 cm in a row and 200 cm between rows (plant density of about 10,000 plant $ha^{-1}$).

The whole growing season of melon was divided into four phenological stages: (i) stage I: From seed germination to the beginning of flowering (day after sowing (DAS); DAS: 22, 2007 and DAS: 22, 2008); (ii) stage II: from the beginning of flowering to small fruit (DAS: 21, 2007 and DAS: 21, 2008), (iii) stage III; from the small fruit to the full-expanded fruit (DAS: 21, 2007 and DAS: 18, 2008) and (iv) stage IV; from full-expanded fruit to first harvesting (DAS: 21, 2007 and DAS: 20, 2008).

All treatment plots received the same amount of basic fertilizer (100 kg $ha^{-1}$ N; 60 kg $ha^{-1}$ P2O and 300 kg $ha^{-1}$ K2O5). All recommended phosphorus and one-third of potassium and nitrogen (ammonium nitrate) were applied just before sowing. The remaining nitrogen and potassium were applied at two equal dosages, 3rd and 6th weeks after sowing with the automatic fertigation system. Nine weeks after sowing (at full-expanded fruit stage), 0, 30, 60 and 90 kg $ha^{-1}$ urea (46 N%) (referred as to N1, N2, N3 and N4) were

**Table 2.** Treatment design for irrigation regimes experiment in the field.

| N | Irrigation regime | Treatment | Growth stage (I, II, III and IV) and irrigation regime (CPE‡ ratio: 0.33, 0.67, 1.00 and 1.33) | | | |
|---|---|---|---|---|---|---|
| | | | I | II | III | IV |
| $N_1$ | I-$_{full}$ | $T_1$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_1$ | $T_2$ | $I_{1.00}$ | —† | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_2$ | $T_3$ | $I_{1.00}$ | $II_{1.00}$ | — | $IV_{1.00}$ |
| | $RDI_3$ | $T_4$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | — |
| | DI-$_{low}$ | $T_5$ | $I_{1.00}$ | $II_{0.33}$ | $III_{0.33}$ | $IV_{0.33}$ |
| | DI-$_{medium}$ | $T_6$ | $I_{1.00}$ | $II_{0.67}$ | $III_{0.67}$ | $IV_{0.67}$ |
| | I-$_{excessive}$ | $T_7$ | $I_{1.00}$ | $II_{1.33}$ | $III_{1.33}$ | $IV_{1.33}$ |
| $N_2$ | I-$_{full}$ | $T_8$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_1$ | $T_9$ | $I_{1.00}$ | — | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_2$ | $T_{10}$ | $I_{1.00}$ | $II_{1.00}$ | — | $IV_{1.00}$ |
| | $RDI_3$ | $T_{11}$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | — |
| | DI-$_{low}$ | $T_{12}$ | $I_{1.00}$ | $II_{0.33}$ | $III_{0.33}$ | $IV_{0.33}$ |
| | DI-$_{medium}$ | $T_{13}$ | $I_{1.00}$ | $II_{0.67}$ | $III_{0.67}$ | $IV_{0.67}$ |
| | I-$_{excessive}$ | $T_{14}$ | $I_{1.00}$ | $II_{1.33}$ | $III_{1.33}$ | $IV_{1.33}$ |
| $N_3$ | I-$_{full}$ | $T_{15}$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_1$ | $T_{16}$ | $I_{1.00}$ | — | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_2$ | $T_{17}$ | $I_{1.00}$ | $II_{1.00}$ | — | $IV_{1.00}$ |
| | $RDI_3$ | $T_{18}$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | — |
| | DI-$_{low}$ | $T_{19}$ | $I_{1.00}$ | $II_{0.33}$ | $III_{0.33}$ | $IV_{0.33}$ |
| | DI-$_{medium}$ | $T_{20}$ | $I_{1.00}$ | $II_{0.67}$ | $III_{0.67}$ | $IV_{0.67}$ |
| | I-$_{excessive}$ | $T_{21}$ | $I_{1.00}$ | $II_{1.33}$ | $III_{1.33}$ | $IV_{1.33}$ |
| $N_4$ | I-$_{full}$ | $T_{22}$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_1$ | $T_{23}$ | $I_{1.00}$ | — | $III_{1.00}$ | $IV_{1.00}$ |
| | $RDI_2$ | $T_{24}$ | $I_{1.00}$ | $II_{1.00}$ | — | $IV_{1.00}$ |
| | $RDI_3$ | $T_{25}$ | $I_{1.00}$ | $II_{1.00}$ | $III_{1.00}$ | — |
| | DI-$_{low}$ | $T_{26}$ | $I_{1.00}$ | $II_{0.33}$ | $III_{0.33}$ | $IV_{0.33}$ |
| | DI-$_{medium}$ | $T_{27}$ | $I_{1.00}$ | $II_{0.67}$ | $III_{0.67}$ | $IV_{0.67}$ |
| | I-$_{excessive}$ | $T_{28}$ | $I_{1.00}$ | $II_{1.33}$ | $III_{1.33}$ | $IV_{1.33}$ |

—†: Non irrigated; CPE‡: cumulative pan evaporation.

supplied to the experimental plots in addition to the basic fertilization, referred as supplemental N.

In the present study, RDI, DI, full and excessive irrigation strategies were applied. Seven irrigation regimes (IR) were established using four growth stages. Full (I-full), RDI regimes (RDI1, RDI2, and RDI3), deficit irrigation (DI-low: IW/CPE 0.33 and DI-medium: IW/CPE 0.67) and excessive irrigation (I-excessive: IW/CPE 1.33) were applied according to the growth stage (Table 2). Totally, 28 treatments were designed and applied in combination with nitrogen and irrigation levels.

The field experiment was setup in a randomized split-plot design with three replications. N levels and irrigations were assigned to the main plot and to the sub plot, respectively. TARIST statistical computer program (Acikgoz et al., 2004) was used for analysis of variance (ANOVA). Treatment means were separated by LSD (least significant differences) test.

**Soil water content and water-use**

Soil water content was monitored gravimetrically for each 0.30 m layer, down to 0.60 m depth. Soil samples were taken every 12 days during the experiment in both years. The volumetric water content (v/v)% of each soil layer was determined according to Stone et al. (1987), and the effective root zone was taken as 60 cm. Seasonal crop water use (ETc) was estimated according to the following water balance equation (Doorenbos and Pruit, 1992):

IR = IW/CPE ratios (full, deficit and excessive)

$$ETc = IR + P - D - R \pm DS$$

$$V = A \times IR \times CP$$

Where, IR is the irrigation regime (mm); IW is the total irrigation

**Table 3.** Analysis of variance for melon FWt, FWh, FL, SCD, SSDM and FY.

| Source of variation | Degree of freedom | Mean square | | | | | |
|---|---|---|---|---|---|---|---|
| | | FWt | FWh | FL | SCD | SSDM | FY |
| Replication | 2 | 124812.9ns | 1.9ns | 0.7ns | 92.5ns | 8.5ns | 746402.8ns |
| **Year (Y)** | 1 | 363909.3* | 91.5* | 1.7ns | 171.0* | 66.2* | 947852.1ns |
| Error -1 | 2 | 14746.3 | 2.0 | 1.4 | 7.8 | 0.6 | 74532.3 |
| **Nitrogen (N)** | 3 | 145232.6* | 15.8* | 27.0** | 269.2** | 15.1* | 2696806.1** |
| Y X N | 3 | 213328.2* | 20.6* | 2.5ns | 31.0ns | 0.3ns | 100574.5ns |
| Error -2 | 12 | 38622.7 | 3.5 | 2.9 | 33.6 | 4.0 | 58366.8 |
| **Irrigation (I)** | 6 | 1018842.6** | 1.9ns | 8.6* | 183.7* | 3.9ns | 831915.7** |
| Y X I | 6 | 120361.2ns | 1.4ns | 0.7ns | 11.7ns | 1.7ns | 31761.6ns |
| N X I | 18 | 104341.5ns | 3.1* | 3.8ns | 176.5** | 2.8ns | 77372.8ns |
| Y X NXI | 18 | 24841.2ns | 2.2ns | 1.4ns | 22.9ns | 0.7ns | 95802.5ns |
| Error | 96 | 221983.2 | 1.7 | 3.3 | 68.4 | 1.8 | 75217.2 |
| Total | 167 | 195527.4 | 3.2 | 3.6 | 77.9 | 2.7 | 162888.2 |

* Significant at P<0.05, ** Significant at P<0.01, *** Significant at P<0.001 and ns; not significant. FWt**,** Fruit weight; FWh, fruit width; FL, fruit length; SCD, seed cavity diameter; SSDM, soluble solid dry matter.

water applied; CPE is the cumulative pan evaporation; ETc is the seasonal crop evapotranspiration; P is the precipitation; D is the water lost due to deep percolation, all expressed in mm. Run-off (R) was taken to be zero since it did not occur with the use of drip irrigation system and ±ΔS is the variation in water content of the soil profile. V is the volume of irrigation water applied; A is the plot area (m2) and percentage of soil crop cover (CP). Whenever field capacity was exceeded, the deep percolation water was calculated by subtracting soil water content from field capacity. The evaporation data were obtained from a Class "A" pan evaporimeter sited near the experimental field and were collected on a daily basis. The average discharges of the emitters were found to be 2 L h-1 and the uniformity coefficient was more than 90% for all the plots.

**Water use efficiency (WUE) and irrigation water use efficiency (IWUE)**

WUE expressed in kg of fruits m-3 was calculated by taking the quotient of the fruit yield (kg $ha^{-1}$) and seasonal crop evapotranspiration depth (m3 $ha^{-1}$). IWUE expressed in kg of fruits m-3 was calculated by taking the quotient of the fruit yield (kg $ha^{-1}$) and the seasonal irrigation amount water (m3 $ha^{-1}$) as described in Howell et al. (1998).

**Crop sensitivity to water stress**

The effect of irrigation regimes on fruit yield was also evaluated by calculating the yield response factor (ky). ky is defined as the ratio between the relative fruit yield decrease and the relative evapotranspiration deficit as shown in the following equation (Doorenbos and Kassam 1979):

1-Y_a/Y_m =k_y (1-〖ET〗_a/〖ET〗_m )

Where, Ya is the actual fruit yield (t $ha^{-1}$); ETa (ETc) is the actual evapotranspiration (mm); Ym is the maximum yield (t $ha^{-1}$) and ETm represents the maximum evapotranspiration.

When ky < 1, evapotranspiration deficit is important than yield loss; when ky > 1, yield loss is more important than evapotranspiration deficit and when ky = 1, yield loss is equal to evapotranspiration deficit (line 1:1).

**Fruit yield and yield component measurements**

The harvest was done twice: on September, 17 and October, 3, in 2007 and on October, 6 and October, 16 in 2008. Fruit weight (FWt), fruit width (equatorial, FWh), fruit length (polar, FL), seed cavity diameter (SCD) and soluble solid dry matter (SSDM) values were calculated from randomly chosen 5 fruits per replicate. Yield values per hectare (FY: t $ha^{-1}$) for each plot were calculated.

## RESULTS AND DISCUSSION

The irrigation regimes started at 15 and 14 DAS and ended at 82 and 70 DAS in 2007 and 2008, respectively. Fruits were harvested twice on September, 17 (DAS: 85) and October, 3 (DAS: 101) in 2007 and on October, 6 (DAS: 82) and 16 (DAS: 92) in 2008. As can be seen in Table 3, while years and N levels were found to be significant for all fruit quality parameters, irrigation strategies were also significant for these parameters, except SSDM. In addition, although, N levels and irrigation strategies were significant for the fruit yield, years did not influence the fruit yield.

Significant differences were observed in FWt among N levels and between years. While mean FWt was determined as 3.4 kg for N1 and N3, it was measured as 3.5 kg for N2 and N4 (Table 4).

**Table 4.** Mean FWt (g) of N levels and years.

| N level | Year | | Mean of treatment |
|---|---|---|---|
| | 2007 | 2008 | |
| $N_1$ | 3410.48$^a$ | 3418.33$^a$ | 3414.41$^c$ |
| $N_2$ | 3517.05$^a$ | 3536.91$^a$ | 3526.98$^a$ |
| $N_3$ | 3400.00$^a$ | 3438.57$^a$ | 3419.29$^{bc}$ |
| $N_4$ | 3355.62$^b$ | 3661.67$^a$ | 3508.64$^{ab}$ |
| $LSD_{(0.05)}$ | 132.20 | | 93.48 |
| Mean of years | 3420.78$^b$ | 3513.87$^a$ | |
| $LSD_{(0.05)}$ | 80.62 | | |

The numbers followed by the same letter horizontally (for years) and vertically (for means of treatments) are not significantly different using LSD test.

**Table 6.** Mean FWh (cm) of N levels and years.

| N level | Year | | Mean of treatment |
|---|---|---|---|
| | 2007 | 2008 | |
| $N_1$ | 18.71$^a$ | 18.14$^a$ | 18.43$^a$ |
| $N_2$ | 16.48$^b$ | 18.19$^a$ | 17.33$^b$ |
| $N_3$ | 15.81$^b$ | 18.24$^a$ | 17.02$^b$ |
| $N_4$ | 16.19$^b$ | 18.52$^a$ | 17.36$^b$ |
| $LSD_{(0.05)}$ | | | 0.90 |
| Mean of years | 16.80$^b$ | 18.27$^a$ | |
| $LSD_{(0.05)}$ | 0.94 | | |

The numbers followed by the same letter horizontally (for years) and vertically (for means of treatments) are not significantly different using LSD test.

**Table 5.** FWt according to irrigation treatments.

| Irrigation regime | FWt (g) |
|---|---|
| $I_{-full}$ | 3574.71$^{ab}$ |
| $RDI_1$ | 3382.08$^{bc}$ |
| $RDI_2$ | 3220.83$^c$ |
| $RDI_3$ | 3284.36$^{bc}$ |
| $DI_{-low}$ | 3363.36$^{bc}$ |
| $DI_{-medium}$ | 3713.42$^a$ |
| $I_{-excessive}$ | 3732.50$^a$ |
| LSD (0.01) | 270.31 |

The results demonstrate that FWt was highly influenced by the total amount of irrigation water during whole growth stages. The treatments with maximum irrigation water applied (I-excessive) had the highest FWt, while treatments with no irrigation water during the stage III (RDI2) had the lowest FWt. On the other hand, low water deficit during the fruit growth and maturation stages had no significant effects on the FWt, while high water deficits during growth stage highly affected FWt (Table 5).

Increasing rates of nitrogen had a positive impact on the FWt. According to the results, applications of RDI caused greater water stress than the one of DI application. RDI resulted in a greater fruit yield loss as compared to other regimes. This could be associated with the low FWt. Irrigation regimes were found to be more effective than N levels on the fruit weight. Cabello et al. (2009) and Kirnak et al. (2005) reported that DI practices reduced fruit weight of melon as compared to full-irrigation. Yildirim et al. (2009) found similar findings, but relatively larger fruit size and heavier weight in the treatments of irrigation during ripening and harvesting were found. Our results show that the combination of full irrigation and basic fertilization gave the largest size fruit. Excessive irrigation and fertilization resulted to smaller fruits. RDI treatments gave the lowest FWt. In general, N leads to the formation of larger cells in plants and the coarse textured fruit (Aktas and Ates, 1998). In the present study, fruit size and weight were affected by N levels, and supplemental N fertilization resulted in puffy fruit. Puffiness in fruit could be related to high N application. In contrast, the FWt was found to be similar to full irrigation but heavier than DI treatments.

Effects of N levels on FWh were statistically significant in both years. FWh from standard fertilizer applied plant were larger than FWh in all supplemental N applications (Table 6).

N levels and irrigation regimes resulted in significant differences in FL. Supplemental N fertilization decreased FL and the highest FL was obtained from plant with basic fertilization (N1). While the longest fruit was obtained from I-full and RDI1 applications, the shortest fruit was obtained from I-excessive irrigation regimes (Table 7).

Irrigation regimes and N levels affected SCD significantly. SCD decreased in I-full, and as a result, an increase in edible portion was observed. All other irrigation regimes resulted in larger SCD. Although, the effects of increased N levels on SCD were not significant, the smallest SCD was found at the level of N3 (Table 8). The irrigation level was found to be more effective than the N level on SCD. High SCD resulted in less flesh, and therefore, less edible part. Contrary to the present study, Hartz (1997) observed that different irrigation regimes had no important effect on SCD, while the differences among cultivars were significant.

SSDM significantly (P <0.05) differed between years and among the N levels. The effects of irrigation regimes were not significant. Averages of SSDM were 12.76 0Brix and 14.01 0Brix in 2007 and 2008, respectively. According to N levels, the highest SSDM was 13.87 0Brix in N1-level while the lowest was 12.61 0Brix in N4 level. Increase in levels of N caused a decrease in the SSDM and it was found that N levels were more effective than irrigation levels. Similar results were noted by Nava et al. (2008) that nitrogen fertilization negatively affected flesh firmness and SSDM content in apple. Kirnak et al. (2005) found that the decrease in irrigation level increased SSDM, N-levels was not affected significantly but interac-

**Table 7.** Mean FL (cm) in different N levels and irrigation regimes.

| Irrigation regime | Nitrogen level | | | | Mean of irrigation treatment |
|---|---|---|---|---|---|
| | $N_1$ | $N_2$ | $N_3$ | $N_4$ | |
| I-$_{full}$ | 25.17 | 25.33 | 23.00 | 23.58 | $24.27^{a}$ |
| $RDI_1$ | 23.50 | 24.08 | 22.33 | 23.50 | $23.35^{a}$ |
| $RDI_2$ | 23.75 | 22.08 | 22.42 | 22.25 | $22.63^{ab}$ |
| $RDI_3$ | 25.75 | 23.67 | 22.50 | 22.08 | $23.50^{ab}$ |
| DI-$_{low}$ | 23.42 | 23.58 | 24.50 | 22.12 | $23.42^{ab}$ |
| DI-$_{medium}$ | 25.75 | 24.08 | 23.92 | 23.58 | $24.33^{b}$ |
| I-$_{excessive}$ | 24.58 | 23.17 | 23.33 | 21.75 | $23.21^{b}$ |
| LSD$_{(0.05)}$ | | | | | 1.05 |
| Mean of N levels | $24.56^{a}$ | $23.71^{ab}$ | $23.14^{b}$ | $22.70^{b}$ | |
| LSD$_{(0.01)}$ | | 1.14 | | | |

The numbers followed by the same letter horizontally (for mean of nitrogen levels) and vertically (for means of irrigation treatments) are not significantly different using LSD test.

**Table 8.** Mean seed cavity diameter (mm) in different N levels and irrigation regimes.

| Irrigation regime | Nitrogen level | | | | Mean of irrigation treatment |
|---|---|---|---|---|---|
| | $N_1$ | $N_2$ | $N_3$ | $N_4$ | |
| I-$_{full}$ | $62.62^{b}$ | $82.99^{a}$ | $66.33^{b}$ | $72.53^{ab}$ | $71.12^{c}$ |
| $RDI_1$ | $84.72^{a}$ | $75.91^{ab}$ | $71.99^{b}$ | $81.85^{ab}$ | $78.62^{a}$ |
| $RDI_2$ | $76.67^{a}$ | $73.28^{a}$ | $74.21^{a}$ | $80.02^{a}$ | $76.04^{ab}$ |
| $RDI_3$ | $73.91^{a}$ | $82.19^{a}$ | $69.93^{a}$ | $76.57^{a}$ | $75.65^{ac}$ |
| DI-$_{low}$ | $75.81^{a}$ | $78.25^{a}$ | $76.59^{a}$ | $71.52^{a}$ | $75.54^{ac}$ |
| DI-$_{medium}$ | $86.19^{a}$ | $82.52^{a}$ | $69.11^{b}$ | $77.59^{ab}$ | $78.85^{a}$ |
| I-$_{excessive}$ | $76.10^{a}$ | $68.85^{a}$ | $75.22^{a}$ | $72.43^{a}$ | $73.15^{bc}$ |
| LSD$_{(0.01)}$ | | 12.55 | | | 4.75 |
| Mean of N levels | $76.57^{a}$ | $77.71^{a}$ | $71.91^{b}$ | $76.07^{a}$ | |
| LSD$_{(0.01)}$ | | 3.87 | | | |

The numbers followed by the same letter horizontally (for irrigation treatments and mean of nitrogen levels) and vertically (for means of irrigation treatments) are not significantly different using LSD test.

tion of levels of irrigation and N had significant impact on SSDM. Unlike the results of our study, Cabello et al. (2009) reported that the effects of irrigation and N levels and their interactions on SSDM were not significant. SSDM is an important indicator in determining the eating quality of melon and it should be a minimum of 8 0Brix. If SSDM is 10 to 12 0Brix, fruit has much better quality (Ferrante et al., 2008; Cantwell, 1996).

In our study, irrigation regimes and N levels had significant effects on fruit yield, but interactions between them were not significant. Fruit yield was highly influenced by the total amount of water at different growth stages. The results clearly show that reduced amounts of irrigation water at any growth stages resulted in fruit yield decrease. I-excessive treatment had the highest production with 62.97 t ha$^{-1}$, followed by I-full treatment with 60.56 t ha$^{-1}$. Non-irrigation during the fruit growth stage (RDI2) resulted in the lowest fruit yield, a decrease in fruit yield by 9% when compared with I-excessive. Results show that from fruit set until full fruit expanded stage (III) was the most sensitive growth stage to water stress. Application of N above the standard recommended level (N1) increased the yield. The highest yield of melon of 63.00 t ha$^{-1}$ was produced at N4. The yield was reduced at the lowest N level (N1). Although, the interaction between irrigation regimes and N levels was not significant, the highest yield of melon was produced at highest seasonal irrigation water amount and N level (N4*I-full) (Table 9). Sensoy et al. (2007) showed that the highest melon yield was obtained from the treatment employing the greatest frequency and quantity of irrigation. Camoglu et al. (2010) reported that while mean yield, fruit weight, fruit diameter, fruit length and flesh thickness were affected significantly with different irrigation treatments, pH and SSDM were not affected significantly in watermelon. In general, increasing levels of nitrogen and water caused an increase in the productivity (Lovelli et al., 2007; Ferreira and Goncalves,

**Table 9.** Mean of fruit yield (t $ha^{-1}$) according to N levels and irrigation regimes.

| Irrigation regime | Nitrogen level | | | | Mean of irrigation treatment |
|---|---|---|---|---|---|
| | $N_1$ | $N_2$ | $N_3$ | $N_4$ | |
| I-$_{full}$ | 58.42 | 59.79 | 60.28 | 62.37 | $60.56^{b}$ |
| $RDI_1$ | 56.85 | 58.92 | 61.65 | 63.07 | $59.49^{bc}$ |
| $RDI_2$ | 55.64 | 56.73 | 59.14 | 61.78 | $57.40^{d}$ |
| $RDI_3$ | 56.54 | 57.65 | 55.44 | 63.33 | $59.40^{bd}$ |
| DI-$_{low}$ | 55.29 | 56.26 | 60.08 | 59.51 | $57.70^{cd}$ |
| DI-$_{medium}$ | 56.20 | 58.55 | 59.77 | 64.27 | $59.75^{bc}$ |
| I-$_{excessive}$ | 61.29 | 60.28 | 59.98 | 66.70 | $62.97^{a}$ |
| Mean of nitrogen levels | $57.18^{c}$ | $58.31^{c}$ | $59.48^{b}$ | $63.00^{a}$ | |
| $LSD_{(0.01)}$ | | 1.61 | | | 2.08 |

The numbers followed by the same letter horizontally (for mean of nitrogen levels) and vertically (for means of irrigation treatments) are not significantly different using LSD test.

2007). The tendency to decrease in yield by water stress recreated an increasing trend with increasing N levels. T5 treatment in N1 level had the lowest yield (55.29 t $ha^{-1}$) and when compared with the same irrigation treatment (T12 and T19) at N2 and N3 level, yield values were increased to 56.26 and 59.77 t $ha^{-1}$, respectively. Further increase in the level of N (T26) did not cause a significant change and remained at the level of 59.51 t $ha^{-1}$.

In Table 10, irrigation water amount, evapotranspiration, fruit yield, relative deficit evapotranspiration, relative yield loss, yield response factor, irrigation water use efficiency, water use efficiency and water saving are reported. IW for I-full applications (T1, T8, T15 and T22) was calculated as 973 mm, whereas the values of ETa were 864, 875, 885 and 913 mm, respectively. The increase in ETa values were due to increase in N levels. However, ETa values never exceeded the value of IW in any treatments. IW values for treatments of RDI technique (T2, T3, T4, T9, T10, T11, T16, T17, T18, T23, T24 and T25) have been 667 for RDI1, 741 for RDI2 and 857 mm for RDI3. However, the ETa values have changed in parallel to the IW values. ETa was not lesser than IW. ETa values have increased parallel with increase in N-levels. Plant water consumption increased with increasing N levels. ETa values for all N levels were higher than IW values in DI treatments (T5, T6, T12, T13, T19, T20, T26 and T27). These values increased with N level, and were calculated as 16, 5, 18, 2, 21, 3, 25 and 5%, respectively.

According to N levels, the lowest yields were obtained from RDI2 treatments (T3, T10, T17 and T24) of RDI regimes. RDI2 was the treatment that no irrigation was applied during fruit development. It was determined that non-irrigated plants during this period bore lighter fruit. The low yield in this irrigation regime was due to low fruit weight. The results show that plants were sensitive to water stress during this period. Moreover, the findings of Kang et al. (2000) for maize and Simsek et al. (2011) for common bean were in agreement with our results. The low yield in this irrigation regime was due to low fruit weight. The results show that plants were sensitive to water stress during this period. According to N levels, yield reduction rates were 17, 15, 17 and 7% for N1, N2, N3 and N4, respectively. Under water stress conditions, nutrient uptake by roots was affected by a reduction in the transportation of nutrients from the soil surface to absorbing root and transportation from the roots to the shoots was also adversely affected (Buljovcic and Engels, 2001).

In treatments of I-excessive (T7, T14, T21, and T25), 1189 mm IW were applied. ETa was lower than IW. Plant did not consume all the water applied and at the end of the season, positive DS and deep percolation (Dp) was observed. Lower DS and Dp was seen with increasing N level. A linear relationship between fruit yield and ETa was observed in I-full regime. In this treatment, relative fruit yield decrease ranged from 12 to 6% when compared with the highest yield. Yield loss decreased with increase in the N level.

Water savings in RDI regimes ranged from 28 to 44%. The lowest ky value of RDI regimes was determined as 0.16 in RDI1 of N4 level. Similarly, the lowest deficit evapotranspiration was calculated as 27% for this treatment (T24). As expected, the lowest yield (55.29 t $ha^{-1}$) was obtained from the lowest N level and DI-low (T5) treatment. The productivity of the DI-low regime increased with level of N increased. Our results show that DI-low in level of N3 (T19) with a yield of 59.77 t $ha^{-1}$ corresponded to 10% yield loss with 55% water saving. When DI-low and DI-medium regimes under each levels of nitrogen were compared, yield loss did not differ significantly, except under N4 level. In contrast, water saving showed significant differences. While water savings of DI-medium regime was 36%, this value was 55% for DI-low. Corresponding to 1% water conservation, 0.18% decrease occurred in the yield. The highest yield was obtained from I-excessive (T7, T14, T21, and T28) regimes under all N levels. Yield increased with increase of N levels, and reached the maximum value with 66.70 t

**Table 10.** Irrigation water amount, fruit yield, relative evapotranspiration deficit [1-($ET_a/ET_m$)], relative fruit yield decrease [1-($Y_a/Y_m$)], yield response factor, irrigation water use efficiency, water use efficiency and water saving [1-($W_a/W_c$)] at different N levels and irrigation regimes.

| Nitrogen level | irrigation regime | Treatment | IW (mm) | ETa (mm) | Fruit yield (t $ha^{-1}$) | 1-($ET_a/ET_m$) | 1-($Y_a/Y_m$) | ky | IWUE (kg $m^{-3}$) | WUE (kg $m^{-3}$) | 1-($W_a/W_c$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | I-$_{full}$ | $T_1$ | 973 | 864 | 58.42 | 0.21 | 0.12 | 0.58 | 6.00 | 6.76 | 0.18 |
| | $RDI_1$ | $T_2$ | 667 | 670 | 56.85 | 0.39 | 0.15 | 0.38 | 8.52 | 8.49 | 0.44 |
| | $RDI_2$ | $T_3$ | 741 | 745 | 55.64 | 0.32 | 0.17 | 0.52 | 7.51 | 7.47 | 0.38 |
| $N_1$ | $RDI_3$ | $T_4$ | 857 | 860 | 56.54 | 0.22 | 0.15 | 0.71 | 6.60 | 6.57 | 0.28 |
| | DI-$_{low}$ | $T_5$ | 534 | 620 | 55.29 | 0.43 | 0.17 | 0.39 | 10.34 | 8.92 | 0.55 |
| | DI-$_{medium}$ | $T_6$ | 757 | 793 | 56.20 | 0.28 | 0.16 | 0.57 | 7.42 | 7.09 | 0.36 |
| | I-$_{excessive}$ | $T_7$ | 1189 | 1038 | 61.29 | 0.05 | 0.08 | 1.50 | 5.15 | 5.91 | 0.00 |
| | I-$_{full}$ | $T_8$ | 973 | 875 | 59.79 | 0.20 | 0.10 | 0.51 | 6.14 | 6.83 | 0.18 |
| | $RDI_1$ | $T_9$ | 667 | 700 | 58.92 | 0.36 | 0.12 | 0.32 | 8.83 | 8.42 | 0.44 |
| | $RDI_2$ | $T_{10}$ | 741 | 754 | 56.73 | 0.31 | 0.15 | 0.48 | 7.66 | 7.53 | 0.38 |
| $N_2$ | $RDI_3$ | $T_{11}$ | 857 | 950 | 57.65 | 0.13 | 0.14 | 1.01 | 6.73 | 6.07 | 0.28 |
| | DI-$_{low}$ | $T_{12}$ | 534 | 628 | 56.26 | 0.43 | 0.16 | 0.37 | 10.53 | 8.96 | 0.55 |
| | DI-$_{medium}$ | $T_{13}$ | 757 | 770 | 58.55 | 0.30 | 0.12 | 0.41 | 7.73 | 7.61 | 0.36 |
| | I-$_{excessive}$ | $T_{14}$ | 1189 | 1033 | 60.28 | 0.06 | 0.10 | 1.65 | 5.07 | 5.84 | 0.00 |
| | I-$_{full}$ | $T_{15}$ | 973 | 885 | 61.65 | 0.19 | 0.08 | 0.39 | 6.34 | 6.97 | 0.18 |
| | $RDI_1$ | $T_{16}$ | 667 | 712 | 59.14 | 0.35 | 0.11 | 0.32 | 8.87 | 8.31 | 0.44 |
| | $RDI_2$ | $T_{17}$ | 741 | 759 | 55.44 | 0.31 | 0.17 | 0.55 | 7.49 | 7.31 | 0.38 |
| $N_3$ | $RDI_3$ | $T_{18}$ | 857 | 881 | 60.08 | 0.20 | 0.10 | 0.50 | 7.01 | 6.82 | 0.28 |
| | DI-$_{low}$ | $T_{19}$ | 534 | 646 | 59.77 | 0.41 | 0.10 | 0.25 | 11.18 | 9.26 | 0.55 |
| | DI-$_{medium}$ | $T_{20}$ | 757 | 779 | 59.98 | 0.29 | 0.10 | 0.35 | 7.92 | 7.70 | 0.36 |
| | I-$_{excessive}$ | $T_{21}$ | 1189 | 975 | 63.62 | 0.11 | 0.05 | 0.42 | 5.35 | 6.53 | 0.00 |
| | I-$_{full}$ | $T_{22}$ | 973 | 913 | 62.37 | 0.17 | 0.06 | 0.39 | 6.41 | 6.83 | 0.18 |
| | $RDI_1$ | $T_{23}$ | 667 | 727 | 63.07 | 0.34 | 0.05 | 0.16 | 9.46 | 8.68 | 0.44 |
| | $RDI_2$ | $T_{24}$ | 741 | 796 | 61.78 | 0.27 | 0.07 | 0.27 | 8.34 | 7.76 | 0.38 |
| $N_4$ | $RDI_3$ | $T_{25}$ | 857 | 906 | 63.33 | 0.17 | 0.05 | 0.29 | 7.39 | 6.99 | 0.28 |
| | DI-$_{low}$ | $T_{26}$ | 534 | 667 | 59.51 | 0.39 | 0.11 | 0.28 | 11.13 | 8.92 | 0.55 |
| | DI-$_{medium}$ | $T_{27}$ | 757 | 797 | 64.27 | 0.27 | 0.04 | 0.13 | 8.49 | 8.07 | 0.36 |
| | I-$_{excessive}$ | $T_{28}$ | 1189 | 1097 | 66.70 | 0.00 | 0.00 | 0.00 | 5.61 | 6.08 | 0.00 |

$W_a/W_c$: Actual amount of irrigation waster applied/maximum amount of irrigation water applied.

**Table 11.** Results of linear regression analysis of total amount of applied irrigation and fruit yield for N levels. The relationships between total amount of irrigation applied and fruit yield.

| N level | Slope | Intercept | $R^2$ |
|---|---|---|---|
| $N_1$ | 0.0089 | 49.907 | 0.85 |
| $N_2$ | 0.0055 | 53.780 | 0.62 |
| $N_3$ | 0.0078 | 53.589 | 0.45 |
| $N_4$ | 0.0083 | 56.247 | 0.64 |

**Table 12.** Results of linear regression analysis between seasonal crop evapotranspiration and fruit yield for N levels. The relationships between seasonal crop evapotranspiration and fruit yield.

| N level | Slope | Intercept | $R^2$ |
|---|---|---|---|
| $N_1$ | 0.0128 | 46.948 | 0.74 |
| $N_2$ | 0.0067 | 52.840 | 0.40 |
| $N_3$ | 0.0139 | 48.778 | 0.40 |
| $N_4$ | 0.0124 | 52.520 | 0.64 |

ha$^{-1}$ at N4 level (T28). The results show that N levels were more effective than water levels in yield increases. When IWUE and WUE were examined, the highest values were determined in DI-low (T5, T12, T19 and T26) regimes. It was calculated that both IWUE and WUE values were increased with the decrease in amount of water.

As reported, IWUE and WUE values decreased with the increase in the amount of water (Fabeiro et al., 2002; Yuan et al., 2003; Simsek et al., 2005). Our results show that the highest IWUE and WUE values were 11.18 and 9.26 kg m-3 with T19 treatment (DI-low), and the lowest was 5.07 and 5.84 kg m-3 with T14 treatment (I-excessive), respectively. Zeng et al. (2009) reported that maximum IWUE for potato was obtained with low irrigation. Fabeiro et al. (2001) and Kirnak et al. (2005) also reported similar results. Although, the lowest IWUE and WUE were determined in I-excessive, the maximum fruit yield was obtained from this treatment.

When I-excessive was applied to melon under low level of N (N1 and N2), ky values were greater than 1 (ky > 1) due to higher relative fruit yield decrease than relative evapotranspiration deficit. When N levels increased (N3 and N4), ky was calculated as less than 1 (ky<1) and the water saving was 0%. The lowest IWUE and WUE also occurred in these treatments.

Based on the results of the present study, excessive irrigation did not provide a significant yield increase in melon. It might be useful to avoid excessive and full irrigation where water is scarce and expensive, so the deep percolation could be prevented. Non irrigation during the small fruit to full-expanded fruit stage in RDI regimes at all N levels caused a reduction in fruit yield. This result showed that melon was sensitive to water stress during this period. As the melon has a shallow-root, it is highly sensitive to the drought stress and needs frequent and light irrigation to prevent the possible water deficiency in the plant root zone. Response to a unit change in amount of water applied fruit yield changed (0.0089 t ha-$^1$).

As can be seen in Table 11, while the poorest relationship (R2 = 0.45) was observed between total amount of applied irrigation and fruit yield in N3 level, the strongest relationship (R2 = 0.85) was seen in N1 level. Moreover, similar trend was determined between seasonal crop evapotranspiration and fruit yield (Table 12).

RDI and DI are optimization strategies applied to a crop plant, during stress sensitive developmental periods. Water is restricted during the vegetative stage and from full fruit expanded to physiological maturity stages of plant tolerant to water stress. Total applied irrigation water is not fully in need of irrigation during the growing season of the crop. In other words, RDI and DI aim to stabilized the yield and maximum WUE more than maximizing the yield (Geerts and Raes, 2009). WUE is the main factor that limits plant productivity; crop yield losses are inevitable when the plant is exposed to water stress (English, 1990). The correct application of the DI needs detailed assessment of economic yield losses caused by water stress (Kirda et al., 1999; Geerts and Raes, 2009).

It is important to apply optimum irrigation and fertilization programs for stabilization and maximization yield and quality. Optimization of the water and nutrient requirements of plant is also important due to both economic and environmental reasons (del Amor, 2006).

Based on these results, yield and quality parameters were found to be affected by irrigation regimes and N levels. To obtain high fruit yield, N level could be adjusted based on irrigation water availability.

Therefore, it can be concluded that N3*DI-low combination (T19) is advisable for sustainable production, saving a significant amount of water and increasing the nitrogen use efficiency, where water is the main limiting factor for agricultural production.

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