ORIGINAL PAPER

# Water stress imposed on muskmelon (*Cucumis Melo* L.) with subsurface and surface drip irrigation systems under semi-arid climatic conditions

**E. Dogan · H. Kirnak · K. Berekatoglu · L. Bilgel · A. Surucu**

**Abstract** In 2005 and 2006, a study was conducted to determine the effect of subsurface and surface drip irrigation systems and to determine optimum irrigation water using six different irrigation levels imposed on muskmelon (*Cucumis Melo* L. cv. Ananas F1) under semi-arid climatic conditions. Irrigation treatments received 0, 25, 50, 75, 100, and 125% of class A pan evaporation rates. In 2005, average yield from subsurface and surface drip irrigation systems ranged from 16.2 ($I_0$) to 31.1 ($I_{75}$) t ha$^{-1}$ and from 16.2 ($I_0$) to 43.8 ($I_{75}$) t ha$^{-1}$, respectively. While in 2006, fruit yields for the same systems ranged from 8.2 ($I_0$) to 40.4 ($I_{75}$) t ha$^{-1}$ and from 8.2 ($I_0$) to 38.9 ($I_{100}$) t ha$^{-1}$. Regression analysis of the yield data indicated no significant ($P > 0.05$) difference between years and irrigation systems. The highest muskmelon yields from subsurface and surface drip irrigation systems were obtained at 83 and 92% of class A pan. Bigger fruits were obtained with optimum irrigation amounts for both of the irrigation systems. However, there was no clear indication of irrigation water amounts on total soluble solid and flesh thickness of muskmelon fruits.

Communicated by J. Ayars.

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## Introduction

The Harran Plain has about 1,51,000 ha of agricultural land of which currently about 1,30,000 ha is irrigated. Irrigation development began in 1995 as a part of Southeastern Anatolian Project (GAP). About 1.7 million ha of agricultural land will be irrigated when the project is completed. At the beginning of the project it was projected that in most of the GAP region the dominant agronomic crops would be cultivated along with some vegetables and fruits. In 1996 and in the following years, cotton was planted on about 90% of Harran Plain. However, in recent years that percentage is decreasing with the increase of horticultural crops such as vegetables, melon and watermelon. Most of the plain is irrigated using surface irrigation, mostly furrows and borders. Although there is enough water for all farms in the plain, because of inefficient surface irrigation practices, some of the farms, especially at the lower side of plain close to the Syrian border have difficulties in obtaining enough freshwater at times. Since the climate in the region is semi-arid, summer crops require irrigation. Therefore, farmers in this region need more efficient irrigation systems such as surface and subsurface drip irrigation systems for their high-income crops. Since there is a shortage of freshwater, crops are deficit irrigated. Deficit irrigation practices were well studied on agronomic crops such as corn, soybean, and wheat (Stewart et al. 1975; Musick and Dusek 1980; Lamm et al. 1994; Dogan et al. 2006).

In general, it is well accepted that irrigation affects yield and yield components of melon under semi-arid climatic conditions (Fabeiro et al. 2002). Depending on meteorological characteristics of a given area, muskmelon production may vary from 12–15 to 25–30 t ha$^{-1}$ under dryland and irrigated condition, respectively (Srinivas et al.

1989). On the other hand, Bhella (1985) and Shmueli and Goldberg (1971) reported that compared to dryland conditions, drip irrigation increased yield but reduced soluble solid content (Lester et al. 1994). Pew and Gardner (1983) indicated that over irrigation resulted in reduced yield and fruit-soluble solids content of melon. NeSmith (1999) stated that there was a yield difference between planting watermelon seed and plant seedling. However, if farmers wanted to have an earlier yield, they might consider planting seedlings rather than direct seeding. He also indicated that final root depths from seed and seedling-planted plots was similar and was at maximum depth of 75 cm. Srinivas et al. (1989) studied the effect of surface drip irrigations and deficit irrigation practices on watermelon yield and drip irrigation system produced more watermelon yield than surface irrigation systems. Additionally, fully irrigated plots had more yield compared to deficit irrigated ones. Orta et al. (2003) and Wang et al. (2004) applied water stress on watermelon plants and found that fully irrigated treatments produced the highest yield. It is reported that irrigation increased yield of melon and quality compared to deficit-irrigated crops (Meiri et al. 1995; Detar et al. 1983; Bhella 1985). In general, studies conducted in the Harran Plain indicated that 125% of class A pan evaporation values applied to watermelon produced the highest yield with about 80 t ha$^{-1}$ (Simsek et al. 2004; Gündüz and Kara 1995). Irrigation studies with horticultural crops such as melon are limited. In addition, use of subsurface and surface drip irrigation systems with horticultural crops are relatively new and the effects of those highly efficient irrigation systems on crop yield and yield components are not well documented.

Hartz (1997) claimed that the use of drip irrigation system to irrigate melon production was increasing in semi-arid regions of the USA. In general, it was reported that drip irrigation system increases melon yield compared to furrow irrigations (Shmueli and Goldberg 1971; Bogle and Hartz 1986; Lester et al. 1994). Lester et al. (1994) also indicated that a 4-day irrigation interval produced the highest melon yield. Fabeiro (2002) claimed that similar to other agronomic and horticultural crops, the effect of irrigation water on melon production was found to be positive (Pier and Doerge 1995; Meiri et al. 1995).

Worldwide, Turkey's annual melon production capacity (1,700 Mt) is ranked as second biggest after China (FAO http://www.fao.org/defolt.htm, 2005). Therefore, melon production is important to Turkey's economy. The objectives of this study were (1) to determine the effect of subsurface and surface drip irrigation systems on yield and (2) to determine optimum class A pan evaporation rate for maximum muskmelon yield and yield components under semi-arid climatic conditions.

## Materials and methods

In 2005 and 2006, this study was conducted at Talat Demiroren research station, (37°08′N, 38°46′E, 370 m above sea level) to determine the effect of both subsurface and surface drip irrigation systems and different class A pan evaporation levels on muskmelon yield and yield components (Cucumis melo L. var. Ananas F1) under semi-arid climatic conditions of Sanlıurfa, Turkey. The study area's clay soil had gravimetric-based field capacity and wilting point values of 31 and 20%, respectively (Table 1). Average soil bulk density, pH, and electrical conductivity values of top 90 cm were 1.53 g cm$^{-3}$, 7.9, 0.26 dS m$^{-1}$, respectively. Climatic conditions in 2005 and 2006 years were typical of long-term weather conditions of the study area, which has a semi-arid climate. In 2005, seasonal average temperatures, relative humidity, solar radiation, and wind speed during melon-growing season were 28.9°C, 38.7%, 567.7 cal cm$^{-2}$, and 2.4 ms$^{-1}$, while in 2006, those values were 30.1°C, 44.2%, 541.9 cal cm$^{-2}$, and 1.8 ms$^{-1}$, respectively (Table 2).

In the spring of 2005, a subsurface drip irrigation system with 16-mm lateral diameter (Goktepe, Turkey), was buried 30 cm beneath the soil surface. Each plot had three 7.5-m long and 2-m apart drip irrigation laterals. Typically, subsurface drip irrigation laterals are buried at around 30 cm depth for fruits (Anthony et al. 1974; Bucks et al. 1982) and vegetables (Clark et al. 1993). Each row had ten plants right above emitters. Emitters were 0.75 m apart (one for each plant) and had a constant discharge rate of 4 l h$^{-1}$. Treatment plots had 30 plants in total. Each plot had a valve and flow meter at the entrance of the drip

**Table 1** Some of the selected properties of study area soil

| Soil depth | FC % | PWP % | Bulk density | OM | Soil particle distribution (%) | | | Texture |
|---|---|---|---|---|---|---|---|---|
| | | | | | Clay | Silt | Sand | |
| 0–30 | 32.5 | 19.5 | 1.17 | 1.45 | 54.4 | 23.8 | 21.8 | Clay |
| 30–60 | 32.4 | 21.5 | 1.41 | 1.16 | 56.4 | 22.4 | 21.20 | Clay |
| 60–90 | 32.4 | 21.8 | 1.50 | – | 56.2 | 22.6 | 21.2 | Clay |

FC field capacity, PWP permanent wilting point, AWC available water capacity, OM organic mater

**Table 2** Climatic condition during the experiments

| Mounts | Maximum air temperature (°C) | Minimum air temperature (°C) | Average air temperature (°C) | Average relative humidity (%) | Total solar radiation (cal cm$^{-2}$) | Wind speed (ms$^{-1}$) |
|---|---|---|---|---|---|---|
| 2005 | | | | | | |
| May | 35.0 | 7.8 | 23.1 | 41.4 | 544.3 | 2.3 |
| June | 38.5 | 15.1 | 27.4 | 35.9 | 594.7 | 2.6 |
| July | 43.7 | 20.4 | 33.0 | 32.8 | 602.7 | 2.8 |
| August | 43.5 | 20.0 | 32.1 | 44.7 | 529.4 | 1.7 |
| 2006 | | | | | | |
| May | 39.1 | 13.4 | 23.8 | 45.9 | 539.6 | 1.6 |
| June | 44.0 | 18.0 | 30.8 | 40.8 | 605.1 | 1.9 |
| July | 43.0 | 20.8 | 32.2 | 45.5 | 560.5 | 2.0 |
| August | 44.5 | 22.8 | 33.4 | 44.6 | 462.2 | 1.5 |

lateral in order to control irrigation water amounts. Additionally, there was a 2-m empty gap between plots in order to eliminate any water movement from adjacent plots. Treatments included; (1) surface and subsurface drip irrigation systems and (2) Six levels of irrigation [0.0 ($I_0$), 0.25 ($I_{25}$), 0.50 ($I_{50}$), 0.75 ($I_{75}$), 1.0 ($I_{100}$), and 1.25 ($I_{125}$) of class A pan evaporation] with three replications. A standard class A pan located close by the research area was used to determine evaporation from open water surface and then irrigation amounts depending on treatment rates were determined.

Prior to transplanting, muskmelon seeds were sown on the fourth of April, 2005 and seventh of April, 2006 in small plastic bags (one seed per bag), holding equal amounts of soil obtained from the experimental site and mixed with animal manure. Then, at two true leaves stage, seedlings selected for size uniformity were transplanted to treatment plots on 21st of April, 2005 and 26th of April, 2006. Right after transplanting, irrigation was started and equal amounts of water was applied to all plots until muskmelon plants reached 30% field coverage. At the same time, some of the cultivation practices such as hand-hoeing, pesticide (Thiodan Conc. 35 ec, 360 g l$^{-1}$ Endosulfan ai. at 2,000 ml ha$^{-1}$) and herbicide (Fusilade forte ec, 150 g l$^{-1}$ Fluazifob-P-Butyl ai. at 1,000 g l$^{-1}$) applications and fertilizations were completed. In both of the years, all plots received nitrogen at 100 kg ha$^{-1}$ rate as ammonium sulfate in five equal amounts injected through drip irrigation system. Phosphoric acid was periodically injected through drip irrigation system at 25 mg l$^{-1}$ rate for emitter maintenance. The irrigation treatments were applied to experimental plots using a 3-day irrigation interval. Irrigation water amounts were determined using the following equation (Doorenbos and Pruitt 1992)

$$I = E_{pan}AK_{cp}P$$

where $I$ irrigation water amounts (mm), $E_{pan}$ evaporation from a standard class A pan (mm), $A$ plot area (m$^2$), $K_{cp}$ crop pan coefficients (0.0, 0.25, 0.50, 0.75, 1.0, 1.25), and $P$ crop coverage (%)

The time of melon fruit harvest was determined based on visual observations, and all mature muskmelon fruits were hand harvested. Results from middle row of each plot were used in this study and the other two rows were border rows. There were a total of three harvest events in both 2005 and 2006. During harvest, fruit weight with a balance, fruit number, fruit flesh thickness with a digital compass, and soluble solid content ($^0$Bix) of muskmelon with a digital pocket reflectometer (Atagon, Japan) were measured. Additionally, as an indicator of fruit size, mean fruit weight (MFW) for all treatments and replications were determined by dividing total weight to total number of fruits from treatment plots. Any fruit bigger than 0.5 kg was assumed to be of an acceptable size and any fruit smaller and/or had any blemishes was assumed not to be marketable and therefore was not considered in this study.

### Statistical analysis

The experiments were based on complete randomized block design with three replications. Differences in measured values among main (irrigation systems) and sub-main effects (irrigation levels) were analyzed using regression tests, Walt specification test (Geene 1997) and ANOVA test procedure.

### Results and conclusions

In 2005 and 2006, until 30% field coverage, 27.5 mm and 30.5 mm of irrigation water (IW) was applied to all treatment plots in order to ensure a good plant stand. After that,

fully irrigated treatment plots in 2005 and 2006 received a total of 379 and 451 mm irrigation water with 19 and 23 irrigation events, respectively. Total plant water use, including soil water deficit plus applied irrigation from transplanting to harvest, of all treatments was 124, 215, 312, 406, 501 mm and 144, 257, 370, 481, 497 mm in 2005 and 2006, respectively. Irrigation water amounts in this study from 2006 were higher than 2005 because of about a 12-day longer growing season along with more severe climatic conditions. On average, monthly maximum, minimum and average temperature in 2006 were 2.5, 2.9, and 1.2°C higher compared to 2005 (Table 2).

In 2005, muskmelon fruit yields from subsurface and surface drip irrigation systems ranged from 16.2 ($I_0$) to 31.1 ($I_{75}$) t ha$^{-1}$ and from 16.2 ($I_0$) to 43.8 ($I_{75}$) t ha$^{-1}$, respectively. In 2006, subsurface and surface drip irrigation system fruit yields varied from 8.2 ($I_0$) to 40.4 ($I_0$) t ha$^{-1}$ and from 8.2 ($I_0$) to 38.9 ($I_{100}$) t ha$^{-1}$, respectively. Observed yield data in this study were similar to previous study results conducted by Hartz (1997). In the present study, there was up to a threefold increase from $I_0$ to $I_{25}$ treatment in both of the years (Table 3 and Fig. 1). This increase between irrigated and non-irrigated treatments in muskmelon fruit yield (FY) was attributed to semi-arid climatic conditions of study area. There were no similar yield changes among other treatments. Fruit yield analysis of 2005 data using ANOVA test procedure indicated that there was significant ($P < 0.05$) difference among irrigation levels and the highest yield ($P < 0.05$) was from $I_{50}$

and $I_{75}$ treatments from subsurface and surface drip irrigation systems, even though the highest mean yield was from $I_{75}$ treatment in both of the irrigation systems. Similar
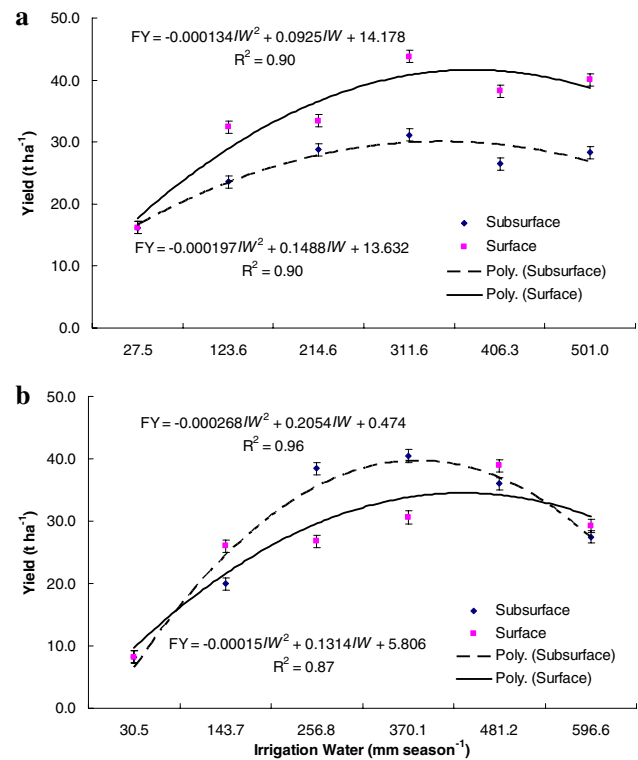


**Fig. 1** Relationship between seasonal applied irrigation water and crop fruit yield for 2005 (**a**) and 2006 (**b**)

**Table 3** Quantitative muskmelon yield and yield components for 2005 and 2006

| Treatment | Irrigation amounts (mm) | | Yield (kg ha$^{-1}$) | | Fruit number | | Fruit flesh thickness (cm) | | $^0$Brix | | Mean fruit weight (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Subsurface | Surface | Subsurface | Surface | Subsurface | Surface | Subsurface | Surface | Subsurface | Surface | Subsurface | Surface |
| **2005** | | | | | | | | | | | | |
| $I_0$ | 27.5 | 27.5 | 16.2$^a$ | 16.2$^a$ | 20.7$^a$ | 20.7$^a$ | 3.4$^a$ | 3.4$^a$ | 12.1$^*$ | 12.1$^a$ | 1.17$^a$ | 1.17$^a$ |
| $I_{25}$ | 123.6 | 123.6 | 23.6$^b$ | 32.4$^b$ | 22.7$^{ab}$ | 34.3$^{bd}$ | 3.5$^{ab}$ | 4.1$^b$ | 10.9 | 10.9$^{ab}$ | 1.56$^b$ | 1.42$^b$ |
| $I_{50}$ | 214.6 | 214.6 | 28.8$^{cd}$ | 33.4$^b$ | 26.7$^c$ | 27.3$^c$ | 3.7$^{ab}$ | 3.7$^b$ | 11.2 | 9.7$^b$ | 1.62$^b$ | 1.84$^d$ |
| $I_{75}$ | 311.6 | 311.6 | 31.1$^c$ | 43.8$^c$ | 24.3$^{ac}$ | 37.0$^d$ | 3.8$^b$ | 4.1$^b$ | 11.5 | 10.4$^{ab}$ | 1.92$^c$ | 1.78$^{cd}$ |
| $I_{100}$ | 406.3 | 406.3 | 26.5$^{bd}$ | 38.2$^d$ | 25.0$^{bc}$ | 36.0$^{bd}$ | 3.9$^b$ | 3.9$^b$ | 10.3 | 11.0$^{ab}$ | 1.59$^b$ | 1.59$^{bc}$ |
| $I_{125}$ | 501.0 | 501.0 | 28.3$^{cd}$ | 40.0$^{dc}$ | 26.3$^c$ | 33.0$^b$ | 3.9$^b$ | 3.9$^b$ | 10.3 | 10.2$^{ab}$ | 1.61$^b$ | 1.82$^d$ |
| **2006** | | | | | | | | | | | | |
| $I_0$ | 30.5 | 30.5 | 8.2$^a$ | 8.2$^a$ | 10.3$^a$ | 10.3$^a$ | 3.4$^a$ | 3.4$^a$ | 11.3$^*$ | 11.3$^*$ | 1.20$^a$ | 1.20$^a$ |
| $I_{25}$ | 143.7 | 143.7 | 20.0$^b$ | 26.0$^b$ | 16.3$^b$ | 19.7$^{bd}$ | 4.0$^b$ | 4.3$^b$ | 11.3 | 11.3 | 1.85$^b$ | 1.99$^b$ |
| $I_{50}$ | 256.8 | 256.8 | 38.4$^{cde}$ | 26.8$^b$ | 22.0$^{cd}$ | 17.3$^c$ | 3.9$^b$ | 4.2$^b$ | 12.0 | 11.5 | 2.64$^c$ | 2.32$^c$ |
| $I_{75}$ | 370.1 | 370.1 | 40.4$^d$ | 30.6$^c$ | 23.0$^c$ | 18.3$^{bc}$ | 4.3$^b$ | 4.3$^b$ | 10.9 | 10.8 | 2.64$^c$ | 2.52$^{cd}$ |
| $I_{100}$ | 481.2 | 481.2 | 36.0$^e$ | 38.9$^d$ | 19.3$^{bcd}$ | 21.3$^d$ | 3.9$^b$ | 4.6$^b$ | 11.3 | 12.7 | 2.82$^c$ | 2.74$^d$ |
| $I_{125}$ | 596.6 | 599.6 | 27.4$^f$ | 29.2$^e$ | 16.7$^b$ | 18.7$^{bd}$ | 4.2$^b$ | 4.4$^b$ | 10.4 | 10.7 | 2.48$^c$ | 2.35$^c$ |

Mean values followed by the same letters in the same year and column are not significantly different at a level of $P = 0.05$

* Statistically not significant values at the same year and row at $P = 0.05$ level

results were obtained from 2006; however, in that year the highest yield ($P < 0.05$) was obtained from $I_{75}$ among subsurface drip irrigated plots, while, $I_{100}$ produced the highest yield ($P < 0.05$) among surface drip irrigated plots (Table 3). Regression test results of fruit yields in 2005 for subsurface and surface drip irrigation systems and all irrigation water levels indicated that the best fit was quadratic and equations were FY = –0.000134(IW)$^2$ + 0.09254 (IW) + 14.178 for subsurface irrigation and FY = –0.000197(IW)$^2$ + 0.1488(IW) + 13.632 surface drip irrigation both had $r^2 = 0.90$ values. Similarly, in 2006 those equations were FY = –0.000268(IW)$^2$ + 0.2054(IW)+ 0.474 and FY = –0.00015(IW)$^2$ + 0.1314(IW) + 5.806 with $r^2$ values of 0.96 and 0.87 for subsurface and surface drip irrigation systems, respectively. The variation in fruit yield was explained by all four equations significantly ($P < 0.01$) (Fig. 1). Fabeiro et al. (2002) also reported yield function of melon with a quadratic relationship. Using FY equations, maximum yields were calculated at optimum irrigation water amounts for both of the years and irrigation treatments. In the present study in general, these quadratic equations indicate that with higher or lower-than-optimum amounts of irrigation water the yield reduced gradually. Reduction in yields compared to maximum calculated yield was more pronounced at $I_{25}$ and $I_{50}$ treatments at all plots irrigated with both irrigation systems and the rates of average reductions in 2005 and 2006 were 64 and 37% in subsurface drip irrigation plots, while in surface drip irrigation plots those values were 71 and 29%, respectively (Table 3). In 2005, optimum irrigation water amounts for subsurface and surface drip irrigation systems were calculated to be 345 and 377 mm, respectively. On the other hand, in 2006 for the same irrigation systems optimum irrigation water amounts turned out to be 383 and 436 mm, respectively. These calculated optimum irrigation water amounts for subsurface and surface drip irrigation systems were average 83 and 92% of seasonal A Pan evaporation rate in 2005 and 2006, respectively. Corresponding calculated optimum yields for subsurface and surface irrigation systems in 2005 and 2006 were 30.1, 41.7 t ha$^{-1}$ and 39.8, 34.4 t ha$^{-1}$, respectively. In both of the years, subsurface drip irrigation system used less irrigation water than surface irrigation system with an average difference of 43 mm (about 10% of class A pan evaporations), while yield difference was 2.6 t ha$^{-1}$ (Table 3). Difference in yields was not significantly ($P < 0.05$) different. Fabeiro et al. (2002) conducted a study to determine the effect of deficit irrigations on muskmelon yield and fruit quality and found that no more than 400 mm irrigation water should be applied for the best results under semi-arid climatic conditions. Similarly, Lovelli et al. (2005) and Fabeiro et al. (2002) reported similar values. Therefore, in the present study applied and calculated optimum irrigation

water amounts agree with the previous studies' results. Regression analysis of the fruit-yield data in our study indicated that yield increased until optimum irrigations amounts were applied, and then decreased; but the reduction was not sharp (Fig. 1). A simple dummy indicator was included in the quadratic regression analysis to show any difference attributed to the subsurface and surface drip irrigation systems. Analysis of fruit-yield data from both of the years and irrigation systems indicated that there was no positive and significant difference between subsurface and surface drip irrigation systems. However, when individual years were analyzed surface drip irrigation significantly ($P < 0.05$) produced higher yield compared to subsurface drip irrigation system in 2005. In 2006 on the contrary, subsurface drip irrigation system produced higher ($P < 0.05$) yield.
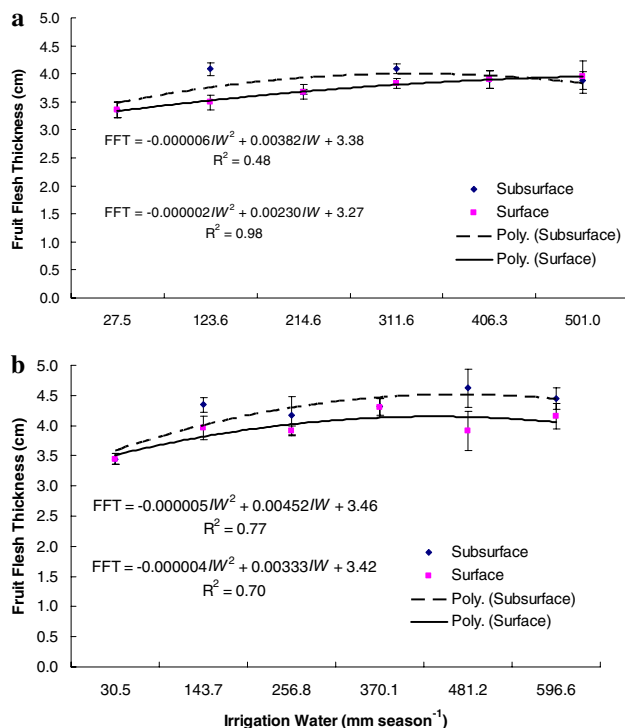
Similar to fruit yield results, ANOVA test results of fruit numbers also indicated higher ($P < 0.05$) at $I_{75}$ and $I_{100}$ compared to all other treatments in subsurface and surface-irrigated plots and in both of the study years. Regression analysis of the fruit-number data obtained in 2005 indicated that fruit-number data were better explained with quadratic relationships as a function of irrigation water amounts and turned out to be FN = –0.000033 (IW)$^2$ + 0.0275(IW) + 20.204 and FN = –0.000120 (IW)$^2$ + 0.0865(IW) + 20.027 with $r^2$ values of 0.72 and 0.64 for subsurface and surface drip irrigation systems, respectively. Moreover, the same data attained in 2006 had FN = –0.000112(IW)$^2$ + 0.0808(IW) + 7.816 ($r^2 = 0.96$) and FN = –0.000153(IW)$^2$ + 0.108(IW) + 7.46 ($r^2 = 0.95$) quadratic equations for subsurface and surface drip irrigation systems, respectively. Quadratic relationships significantly ($P < 0.05$) explained the fruit numbers of both years (Table 3 and Fig. 2).

In both of the study years, fruit flesh thickness was better explained with quadratic equations; however, there was no apparent indication of irrigation water stress. In general, the highest flesh thicknesses were from $I_{75}$ and $I_{100}$ treatments in both years and irrigation systems and flesh thicknesses from both years and subsurface and surface drip irrigation system averaged 3.8 and 4.0 cm, respectively (Table 3 and Fig. 3). Nevertheless, the ANOVA test did not indicate any significant ($P > 0.05$) difference between irrigation levels except $I_{25}$ that constantly produced less fruit flesh thickness compared to other treatments in both of the irrigation systems (Table 3). In 2005 and 2006, total soluble solid ($^0$Brix) values from subsurface drip irrigation system ranged from 10.3 to 12.1 and from 10.4 to 12.0, respectively, while, $^0$Brix values from surface drip irrigation system varied from 9.7 to 12.1 and from 10.7 to 12.7 in 2005 and 2006, respectively. $^0$Brix values of this study were close to the reported ones (Fabeiro et al. 2002). In general, ANOVA test of $^0$Brix values indicated no sig-
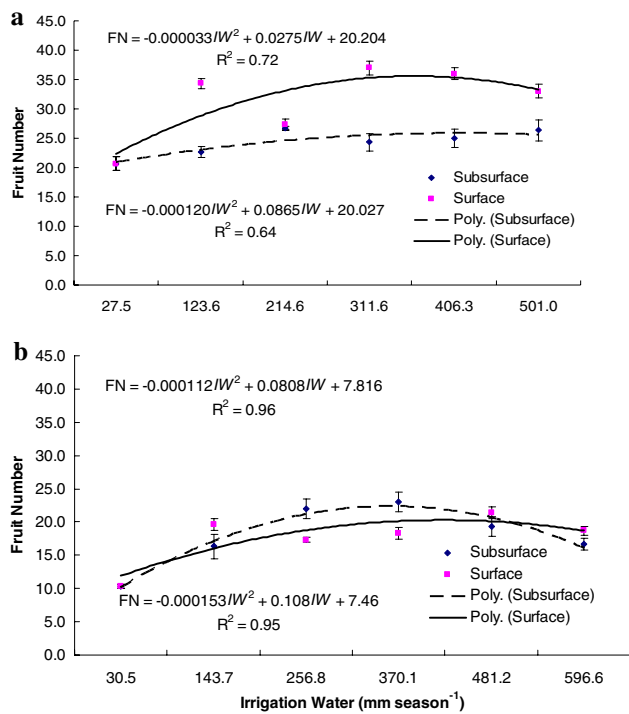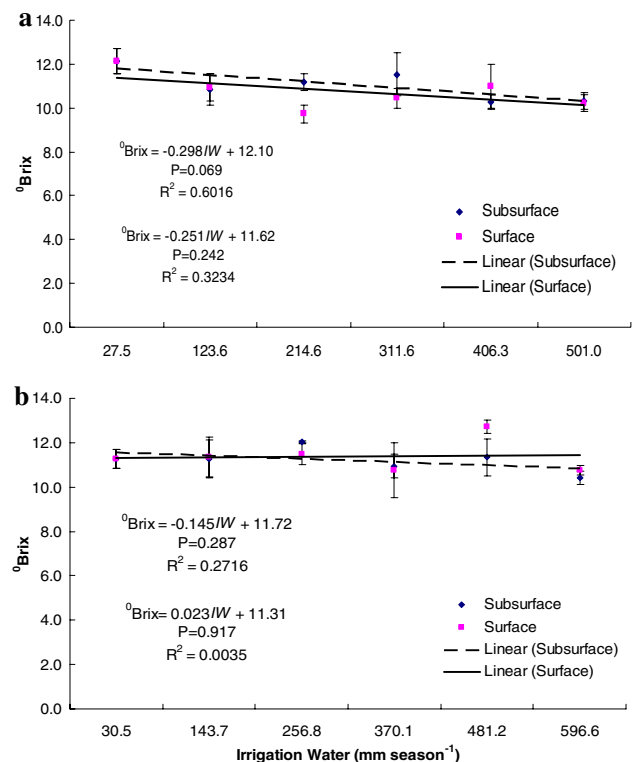
**Fig. 2** Relationship between seasonal applied irrigation water and fruit number for 2005 (**a**) and 2006 (**b**)

nificant difference ($P > 0.05$) between irrigation treatments of subsurface and surface drip irrigation systems. However, contrary to present study results literature indicates that with less-irrigation water, $^0$Brix value of muskmelon was increased (Bhella 1985; Shmueli and Goldberg 1971; Lester et al. 1994). Contrary to other observed parameters, linear-regression test better explained $^0$Brix with $r^2$ values of 0.60 and 0.32 for subsurface drip irrigation system and those $r^2$ values were 0.27 and 0.4 for surface drip irrigation system. However, Fabeiro et al. (2002) showed that with increased irrigation amount $^0$Brix decreased and a quadratic equation explained $^0$Brix better. On the other hand, fruit $^0$Brix values in this study were not affected by both, irrigation systems and water amount. It seemed an increase in irrigation amounts reduced $^0$Brix and average of all data from subsurface and surface drip irrigation system were 11.0 and 11.1, respectively (Table 3 and Fig. 4).

In general, ANOVA test of MFW showed bigger ($P < 0.05$) fruits at $I_{75}$ and $I_{100}$ indicating that with irrigation water amounts fruit were bigger compared to other treatments. In 2005 and 2006 the highest values from subsurface irrigation systems were 1.92 and 2.82 kg fruit$^{-1}$, while, for surface drip irrigation system those values were 1.84 and 2.74 kg fruit$^{-1}$. MFW data were fit better with quadratic equations as fruit yield and number were. Those



**Fig. 3** Relationship between seasonal applied irrigation water and fruit flesh thickness for 2005 (**a**) and 2006 (**b**)



**Fig. 4** Relationship between seasonal applied irrigation water and $^0$Brix for 2005 (**a**) and 2006 (**b**)

equation in 2005 were $MFW = -0.0000007(IW)^2 + 0.0044(IW) + 1.0801$ ($r^2 = 0.74$) and $MFW = -0.000005(IW)^2 + 0.0037(IW) + 1.0944$ ($r^2 = 0.65$) for subsurface and surface drip irrigation systems, respectively. Similarly, in 2006 those quadratic equations for subsurface and surface drip irrigation systems turned out to be $MFW = -0.00001(IW)^2 + 0.0106(IW) + 0.8804$ ($r^2 = 0.88$) and $MFW = -0.000009(IW)^2 + 0.0076(IW) + 0.9977$ ($r^2 = 0.92$) (Table 3 and Fig. 5). Regression analysis of the MFW data indicated no significant difference between years and systems.

## Conclusions

These study results indicated that in 2005 muskmelon fruit yields from subsurface and surface drip irrigation systems ranged from 16.2 ($I_0$) to 31.1 ($I_{75}$) t ha$^{-1}$ and 16.2 ($I_0$) to 43.8 ($I_{75}$) t ha$^{-1}$, respectively. While in 2006, subsurface and surface drip irrigation system fruit yields ranged from 8.2 ($I_0$) to 40.4 ($I_0$) t ha$^{-1}$ and from 8.2 ($I_0$) to 38.9 ($I_{100}$) t ha$^{-1}$. Overall, muskmelon fruit yield results indicated no significant difference between subsurface and surface drip irrigation system. Similar to reported studies, regression test on the yield data showed that in these studies quadratic equations satisfactorily explained fruit yields. Fruits size from both of the irrigation systems were bigger at close to optimum irrigation water amounts.

Overall, study results clearly showed that under semi-arid climatic conditions any reduction in irrigation amount from about 83 and 92% of class A pan evaporation values for subsurface and surface drip irrigation systems would result in reduced ($P < 0.05$) muskmelon yield along with fruit size. Hence, subsurface drip irrigation system used 10% less water and produced the same amount of muskmelon fruit yield. Therefore, under limited freshwater sources it could be recommended that farmer might use subsurface drip irrigation system under semi-arid climatic conditions.

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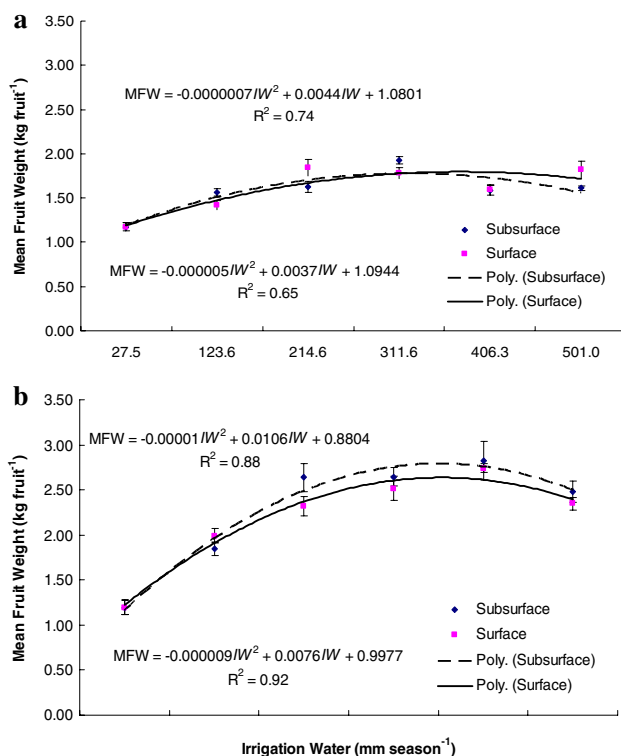


**Fig. 5** Relationship between seasonal applied irrigation water and mean fruit weight for 2005 (**a**) and 2006 (**b**)

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