

## Oxygen isotope discrimination of wheat and its relationship with yield and stomatal conductance under irrigated conditions

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**Abstract:** This study was carried out to determine the different irrigation regime effects on oxygen isotope discrimination of stem water ( $\Delta^{18}\text{O}_s$ ) and its relationship with grain yield (GY), aboveground biomass (BM), and stomatal conductivity ( $g_s$ ) of winter wheat. For this purpose a field experiment was conducted between 2009 and 2011 in a semiarid region of Turkey under rainfed (RF), deficit (DI), moderate (MI), and full irrigation (FI) conditions. The highest GY and BM ( $4.5 \text{ t ha}^{-1}$  and  $14.5 \text{ t ha}^{-1}$ ) were measured from the FI treatment. However, the difference between the yield of DI and FI treatments was insignificant. It might be recommended that the DI treatment be used for wheat irrigation to increase water-use efficiency for semiarid climate conditions. Average  $\Delta^{18}\text{O}_s$  values were obtained as 35.36‰, 34.56‰, 34.35‰, and 33.18‰ for RF, DI, MI, and FI treatments, respectively. Applied irrigation water and GY were found to be strongly negatively related to  $\Delta^{18}\text{O}_s$ , so it may be a useful predictor of yield in irrigation programs. Effects of water regime on yield probably reflected the correlation with the isotopic composition of transpiration. A negative relationship was obtained between average  $\Delta^{18}\text{O}_s$  and  $g_s$  at a significant level for which the correlation coefficient was 0.68. However, the relationship was positive between GY and  $g_s$ .

**Key words:** Stable isotopes, transpiration, semiarid conditions

### 1. Introduction

One of the most important consequences of climate change, perhaps the most important one, is its negative effects on water resources (Agnew, 2011). Turkey, and particularly the Central Anatolian Region where the main crop is wheat, is adversely affected due to high temperature and lack of precipitation (Türkeş and Akgündüz, 2011). Approximately 90% of the agricultural lands do not have sufficient precipitation during the crop-growing period (Çaycı et al., 2009). Irrigation is necessary for these lands to avoid water stress and maximize wheat yield.

It is possible to identify the water used by plants by measuring the natural abundances of oxygen in plants to determine the results of different irrigation treatments (Yepez et al., 2003; Williams et al., 2004). Several researchers have reported that throughout transpirations the vapor leaving the leaf has the same isotopic composition of water moving into the leaves from the

stems (Flanagan et al., 1991; Heng et al., 2014). Methods related to oxygen isotopes ( $^{18}\text{O}/^{16}\text{O}$ ) are effective and safe methods to determine the relationship between water stress and photosynthesis. When soil moisture content decreases in the root zone, the plant will naturally close its stomata so as to avoid transpiration under the conditions of stress. It would be possible to develop irrigation management techniques enabling the minimization of the evaporation from the soil. The aim of the present study was to determine the effect of different irrigation strategies on the isotopic composition of stem water and correlate this with yield and stomatal conductance of a wheat crop.

### 2. Materials and methods

The experiment was carried out at the Sarayköy research station of the Soil, Fertilizer, and Water Resources Central Research Institute ( $39^{\circ}57'\text{N}$ ,  $32^{\circ}53'\text{E}$ ) in the central part of Turkey during the growing season of 2009 to 2011. The soil

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of the research area is mostly silty clay and field capacity is about 35%, with wilting point of 20% by volume for the soil profile of 90 cm. The climate is characterized as semiarid where annual rainfall and evaporation are about 360 mm and 1300 mm, respectively, as the long-term averages. Wheat (*Triticum aestivum* L.) is the major crop, which is generally planted in the late fall.

The experiment was conducted with four different irrigation water strategies and a completely randomized block design with four replications. Treatments were rainfed (RF), full irrigation (FI; irrigated at sowing, tillering, grain filling, and heading periods), moderate irrigation (MI; irrigated at tillering and grain filling periods), and deficit irrigation (DI; irrigated only at heading period). Each plot area was 17.5 m<sup>2</sup> (Figure 1). The wheat was cultivated in the 2009–2010 and 2010–2011 growing seasons. The sowing and harvest dates were respectively in late October and on 15 July in both study periods.

Commercial N fertilizers were divided into two; half was applied at planting and the other half was applied at

the early tillering stage (110 kg N ha<sup>-1</sup>). Approximately 50 kg P ha<sup>-1</sup> was applied to ensure adequate phosphorous nutrition. Meteorological data were measured on an hourly basis from an automatic meteorological station at the field site. Irrigation water was applied by the basin method. Soil moisture contents were monitored using a neutron probe (CPN) from soil surface to 90 cm of soil depth with 20-cm intervals twice a week.

Ten to 20 stem samples were taken from the very lowest part of the plant near the soil surface for analyzing oxygen isotopic compositions of plant xylem water during the preanthesis and anthesis stages (on 5, 15, and 26 May). Approximately 2–3 g of fresh stem tissue was placed in a screw-cap glass vial, and the top of the cap was wrapped with Parafilm. The samples were transported to the Seibersdorf Stable Isotope Laboratory of the International Atomic Energy Agency (Vienna, Austria) and were analyzed using a standard mass spectrometer. Isotopic concentrations are expressed as the difference between the measured ratios of the sample and an international

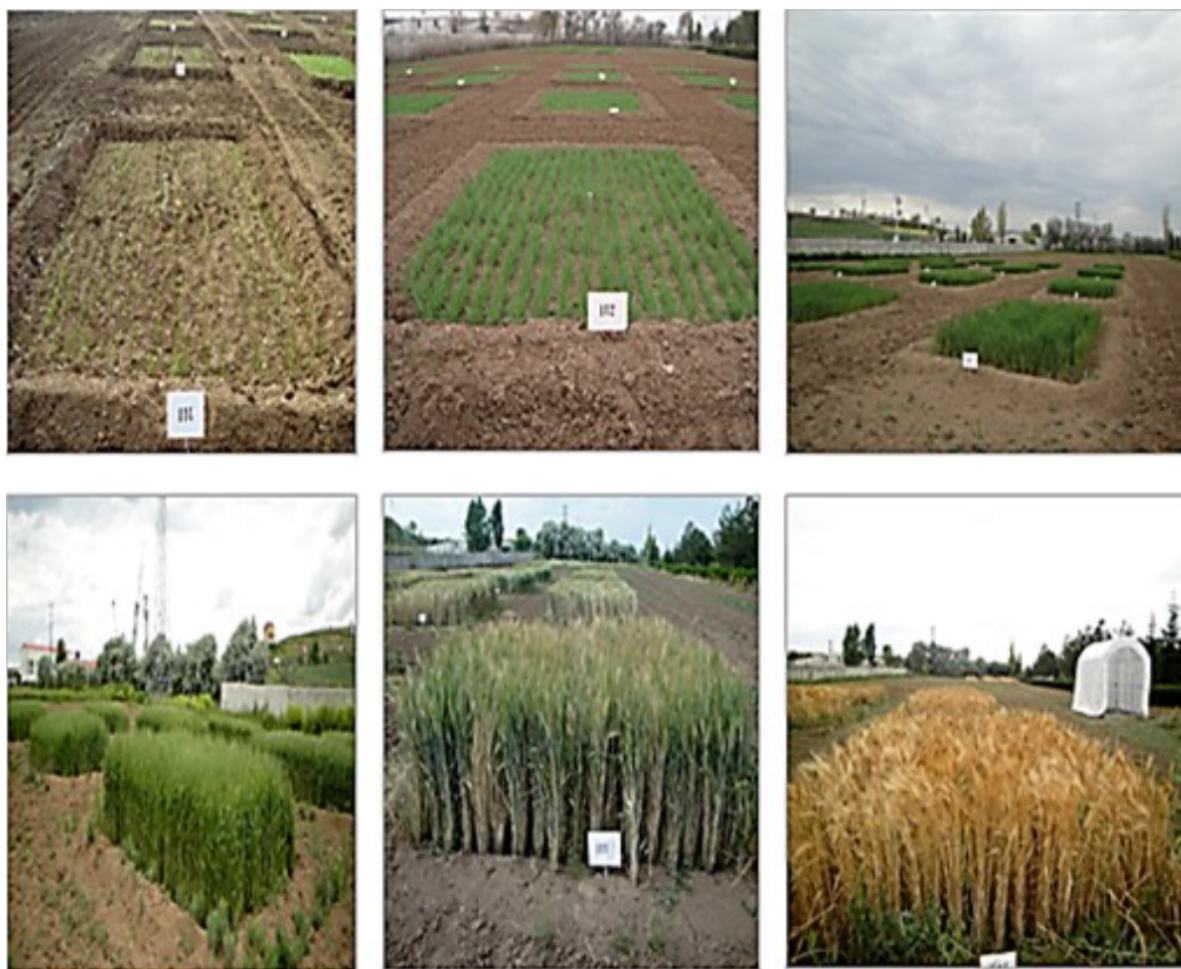


Figure 1. Field experiment design.

standard (Vienna Standard Mean Ocean Water, V-SMOW) over the measured ratio of the standard (Yepez et al., 2003). This is expressed using delta ( $\delta$ ) notation in per mil (‰), as shown in Eq. (1) (Ehleringer et al., 2000):

$$\delta(\text{‰}) = \left( \frac{R_{\text{sample}}}{R_{\text{standard}}} - 1 \right) \times 1000 \quad (1)$$

Here, R is the molar ratio of the heavy to light isotopes in the sample and the appropriate standard. The oxygen isotope discrimination ( $\Delta^{18}\text{O}_{\text{stem}}$ ) of stem parts was calculated using Eq. (2) (Cabrera-Bosquet et al., 2009):

$$\Delta^{18}\text{O}_s = \frac{\delta_{\text{sw}} - \delta_{\text{iw}}}{1 + \delta_{\text{iw}}} \quad (2)$$

Here  $\delta^{18}\text{O}_{\text{sw}}$  and  $\delta^{18}\text{O}_{\text{iw}}$  (approximately  $-6.7$ ) are the oxygen isotope compositions of stem water and irrigation water.

### 3. Results and discussion

#### 3.1. Soil water content

The average irrigation water amount applied was approximately 237 mm, 115 mm, and 61 mm for FI, MI, and DI treatments, respectively. The changes in soil profile moistures (Figure 2) showed compatible change depending on the rainfall and irrigation treatments. Irrigation significantly affected soil water content. Irrigation water was applied until field capacity level for each irrigation event.

#### 3.2. Crop grain yields and biomass

The highest grain yield (GY) and aboveground biomass (BM) ( $4.55 \text{ t ha}^{-1}$  and  $14.49 \text{ t ha}^{-1}$ ) were obtained from the FI treatment. Average GY values of the FI treatment were 26.37%, 3.30%, and 8.79% higher than the RF, DI, and MI treatments, respectively. Harvest index (HI) values of the plots were calculated using the grain yield and biomass

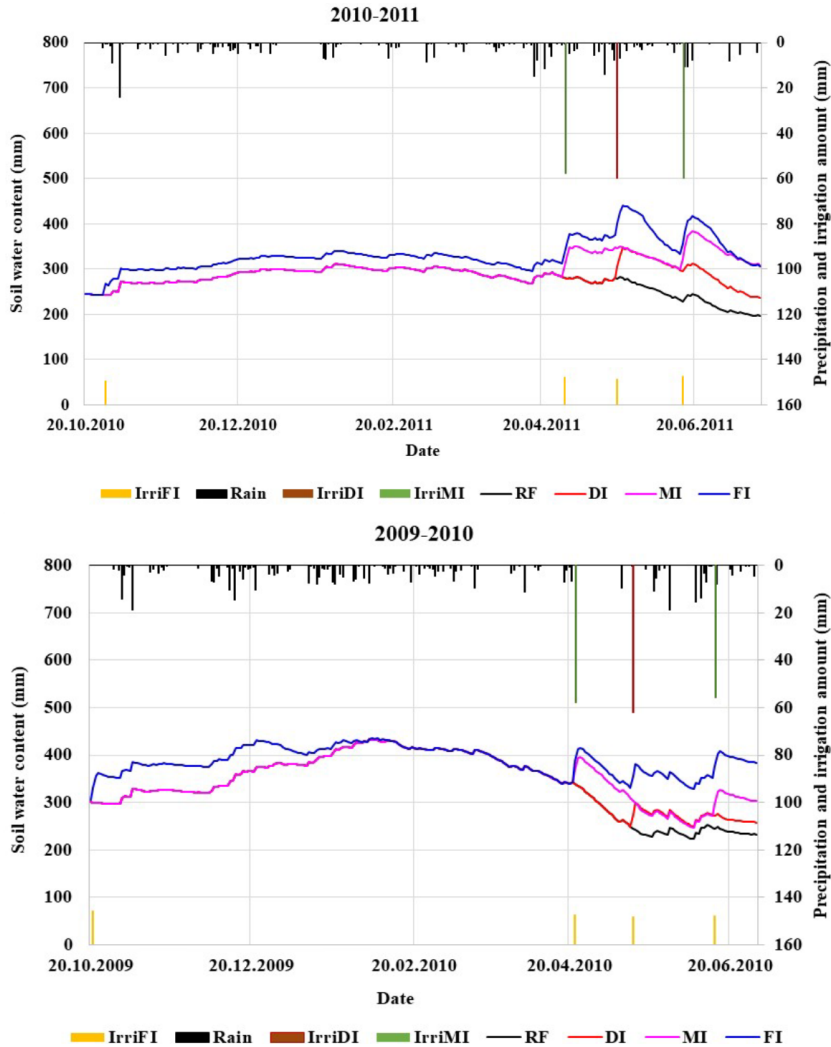


Figure 2. Soil water content data (for the growth periods of 2009–2010 and 2010–2011).

values ( $HI = GY/BM$ ). The highest average HI was found in FI, as 31.4%. Average GY, BM, and HI values of treatments are given in Figure 3. Results of variance analysis showed that the difference between GY and BM of treatments was statistically significant ( $P < 0.05$ ). Additionally, GY and BM and HI were also positively correlated (Yağbasanlar et al., 1995; Villagas et al., 2001). The determination coefficient ( $R^2$ ) was 0.88 for the relationship between GY and BM and 0.66 for the relationship between GY and HI, as given in Figure 4.

### 3.3. Isotopic signal of plant transpiration

Under isotopic steady-state conditions, the isotope ratio value of water taken up by plant roots and transported to leaves is equal to that of the water leaving the leaf surface during transpiration, such that a measure of the value of plant water collected from stems or root crowns is sufficient to represent  $\delta_T$  (Flanagan et al., 1991; Heng et al., 2014).

The isotopic composition of stem water samples was used to predict the isotopic rate of water vapor from

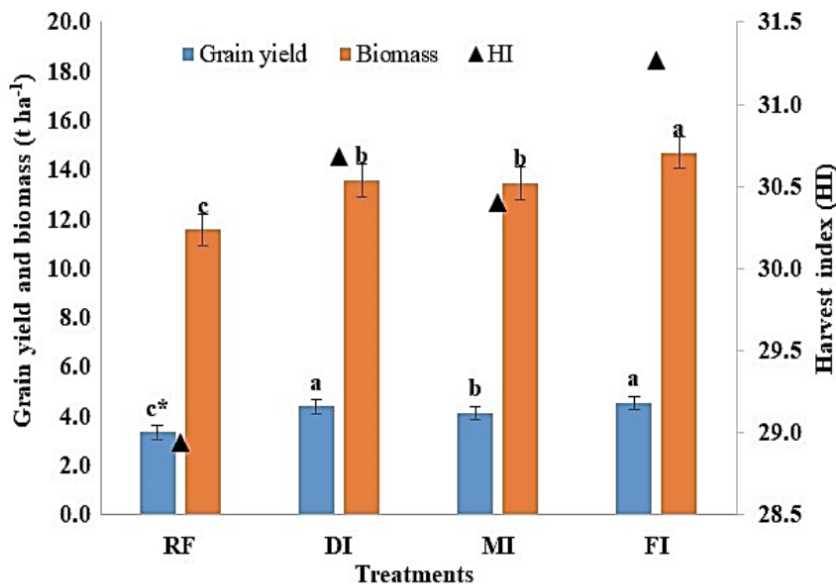


Figure 3. Average GY, BM, and HI where \* indicates Duncan classes.

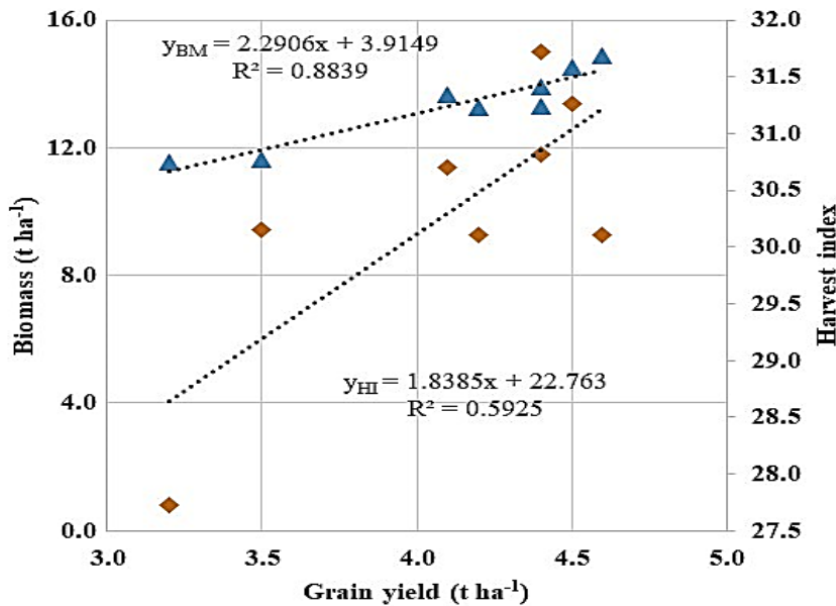


Figure 4. Relationships between GY, BM, and HI.

transpiration ( $\delta_T^{18}\text{O}$ ). Average  $\delta_T^{18}\text{O}$  values were obtained as  $-8.44\text{‰}$ ,  $-8.42\text{‰}$ ,  $-8.40\text{‰}$ , and  $-8.28\text{‰}$  for RF, DI, MI, and FI treatments, respectively. It is shown in Figure 5 that the calculated stem oxygen isotope discrimination ( $\Delta^{18}\text{O}_s$ ) was negatively correlated with applied irrigation water. This can be explained by the fact that  $\square^{18}\text{O}$  enrichment of the stem is increased in plants under water deficient conditions as a result of a decrease in transpiration (Barbour and Farquhar, 2000; Cabrera-Bosquet et al., 2009). According to irrigation treatments the determination coefficient for different sampling dates was found to be 0.83, 0.86, and 0.86.

### 3.4. Stomatal conductance

Stomatal conductivity ( $g_s$ ,  $\text{mol m}^{-2} \text{s}^{-1}$ ) measurements are presented in Figures 6a and 6b. The lowest  $g_s$  values were

observed for the RF treatment. In the other treatments,  $g_s$  values increased depending on increased in soil water content. The observed data, especially after irrigation, show that the pores get closed under deficit soil water conditions. Several researchers such as Zhao et al. (2001), Liang et al. (2002), and Zhang et al. (2003) reported similar results. A significant very strong positive relationship was found between applied irrigation water and average  $g_s$  values with  $R^2 = 0.96$ .

### 3.5. The relationships between stem oxygen isotope discrimination and yield and stomatal conductance

The average final GY and aboveground BM were found negatively correlated with average  $\square^{18}\text{O}_s$  for the two growing seasons (Figure 7a). Effects of water regime on yield were probably reflective of the correlation between

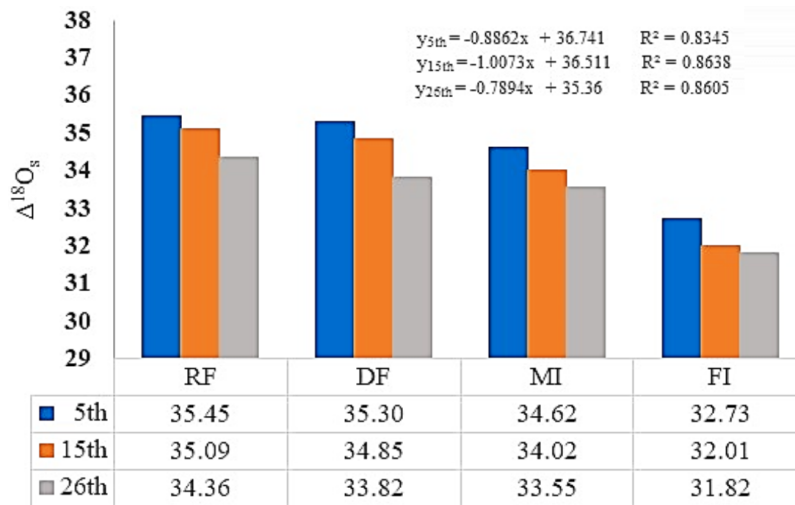


**Figure 5.** The stem oxygen isotope discrimination for different irrigation treatments on 5, 15, and 26 May.

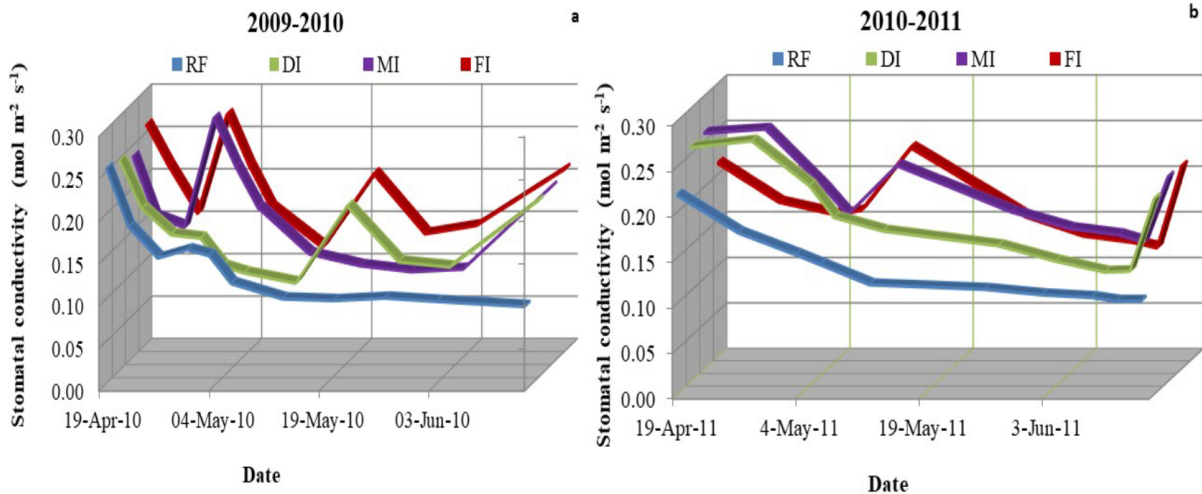


**Figure 6.** Stomatal conductance of treatments for 2000–2010 (a) and 2010–2011 (b) growing seasons.

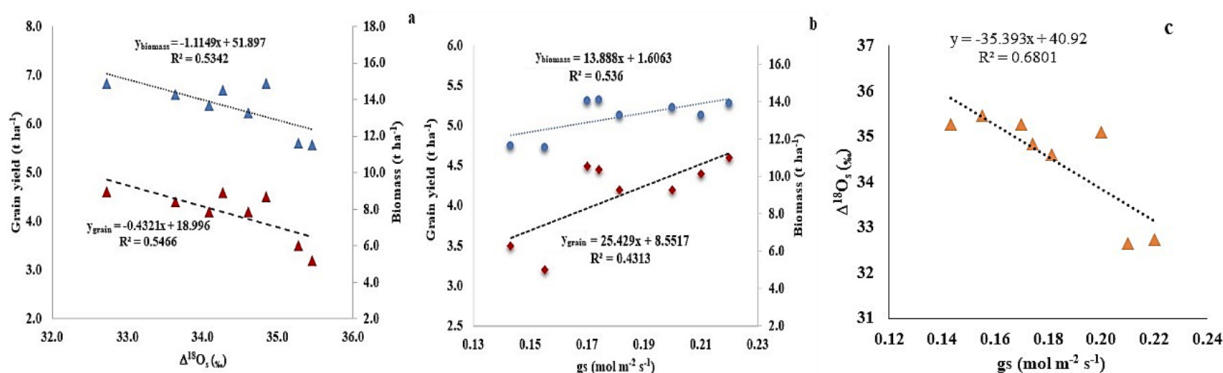


**Figure 7.** The relationships between stem oxygen isotope discrimination, grain yield, biomass, and stomatal conductance (a-  $\Delta^{18}\text{O}_s$  vs. GY and BM, b-  $g_s$  vs. GY and BM, c-  $g_s$  vs.  $\Delta^{18}\text{O}_s$ ).

the isotopic composition of transpiration and yield (Fischer et al. 1998; Barbour et al., 2000).

The relationship between grain yield and  $g_s$  was significantly positive (Figure 7b), as reported by Rees et al. (1993), Delgado et al. (1994), and Bahar et al. (2009). The determination coefficient of the relationship between biomass and  $g_s$  was low ( $R^2 = 0.43$ ). It can be said that the final aboveground biomass is not a good indicator to estimate stomatal closure.

A negative relationship was obtained between average  $\Delta^{18}\text{O}_s$  and  $g_s$  at a significant level for which the correlation coefficient was 0.68 (Figure 7c). According to some researchers such as Sternberg et al. (1986), Farquhar et al. (1988), Fischer et al. (1998), Barbour et al. (2000), and Ripullone et al. (2007), the oxygen isotope composition of the plant materials is a sign of the evaporation conditions caused by material situations; consequently, the  $\delta^{18}\text{O}$  changes in the plant should indicate the changes of the stomatal conductance. These study results show similar trends and support the theory of Barbour and Farquhar (2000), which indicated that plants with more open stomata should have less enriched organic oxygen.

### 3.6. Conclusions

The highest GY and BM ( $4.5 \text{ t ha}^{-1}$  and  $14.5 \text{ t ha}^{-1}$ ) were measured from the FI treatment. However, the

difference between the yield of DI and FI treatments was insignificant. It might be recommended that DI treatment can be used for wheat irrigation to increase water-use efficiency for semiarid climate conditions. Although the highest grain yield, biomass, and  $g_s$  value were observed under well-irrigated conditions, the highest  $\Delta^{18}\text{O}_s$  was obtained under water stress conditions. GY was found to be strongly negatively related to  $\Delta^{18}\text{O}_s$ , so it may be a useful predictor of yield in irrigation programs. Effects of water regime on yield were probably reflective of the correlation with the isotopic composition of transpiration. The relationship between GY and  $g_s$  was positive. A negative relationship was obtained between the average  $\Delta^{18}\text{O}_s$  and  $g_s$  at a significant level for which the correlation coefficient was 0.68.

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