Evaluation of ET-HS model for estimating water demand and water use efficiency of sugar beet in semi-arid condition of Isfahan, Iran

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ABSTRACT

Hargraves-Samani method is one of the methods for calculating plant evapotranspiration that needs minimum meteorological data. In order to evaluate ET-HS model in determining sugar beet crop water demand in Isfahan, an experiment was conducted at research field of Department of Agriculture, Khorasgan Branch, Islamic Azad University, Isfahan, Iran in 2005. The study was based a Randomized Complete Block Design with three replications and six irrigation treatments. Irrigation treatments included irrigation to supply 50, 75, 100, 125 and 150% of crop water demand on the basis of ET-HS model and control on the basis of 90 mm evaporation from Class A evaporation pan during growing season. Results showed that the effect of irrigation treatment was significant on total dry matter and root yield. In addition, root yield increased in the treatment of irrigation to supply 150% of crop water demand. But, sugar percentage increased up to irrigation to supply 100% of crop water demand albeit insignificantly, and then started to decrease. White sugar yield significantly increased to 8.7 t.ha⁻¹ up to irrigation to supply 100% of crop water demand and then, started to decrease with further increase in irrigation level. The highest water use efficiency for root yield was obtained from the irrigation to supply 50% of crop water demand. Given the precision of ET-HS model in control treatment, it can be used for irrigating sugar beet in such regions as Isfahan and sugar beet water demand can be determined only on the basis of the daily temperature data without using the data of evapotranspiration or soil water depletion, so that the yield does not decrease and the appropriate white sugar yield is obtained by the application of minimum irrigation level.

Keywords: ET-HS model, Semi-arid regions, Sugar beet, Water demand

INTRODUCTION

Sugar beet global cultivation area was 6.218 million hectares in 2001 (FAO, 2002). Sugar beet can grow in a wide range of climatic conditions (Sakellariou-Makrantonaki et al., 2002; Tognetti et al., 2003; Hassani et al., 2010). Under irrigated farming, sugar beet is known as a crop with a high water use and so, it is not widely cultivated in regions with limited water resources (Fabeiro et al., 2003) and drought is the main cause of its yield loss (Pidgeon et al., 2001; Tognetti et al., 2003). This fact accompanied with the increased water demand raises the essential question that how the increasing agricultural production can be maintained along with sustained utilization of water resources (Ober et al., 2004). Nonetheless, sugar beet is regarded as a drought-resistant crop under water deficit conditions owing to its long vegetative growth period, the lack of sensitive flowering stage, deep root system and high osmotic adjustment ability (Amaducci et al., 1976). In a study in soil with low permeability on 14, 21 and 28-day irrigation intervals under semi-arid conditions, decreasing irrigation frequency by three during sugar beet growing season did not result in significant loss of its root yield (Winter, 1988). In sugar beets grown under stress conditions, sugar percentage increases more rapidly and it can be 5% higher in plants grown in severe stress than in normal conditions (Hang and Miller, 1986). However, it was reported that total yield and industrial quality index (IQI) of sugar

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beet were influenced by the total volume of irrigation water (Fabeiro et al., 2003). The general effect of irrigation is usually reflected in higher nutrient absorption, but it is not necessarily accompanied with an increase in the concentrations of the nutrients in plants which can be related to irrigation-induced excessive growth (Winter, 1990). In total, environmental conditions can deeply affect sugar yield and root yield (Hoffmann et al., 2009). An important example of these environmental conditions is water stress (Shrestha et al., 2010).

Better use of irrigation water relies on sound planning (Stegman and Bauer, 1977). A technique for efficient management of irrigation water is to use new models for determining water demand and scheduling irrigation along with decreasing the susceptibility of sugar beets to water deficiency and improving their tolerance to drought by breeding (Pidgeon et al., 2001; Jones et al., 2003). Some of these models estimate the yield under water stress conditions (Geerts and Raes, 2009) and others are related to climatic changes and evaluate the yearly variations of the yield during drought periods (Jones et al., 2003). These models mostly need a wide range of data and information about climate which are mainly gathered in research centers and need to be calibrated before use (Brisson et al., 2003; Stockle et al., 2003; Eitzinger et al., 2004; Shrestha et al., 2010). Also, these models are used for determining water use efficiency (WUE) whose direct evaluation is very time-consuming and expensive (Rajabi et al., 2009). FAO method (Penman-Monteith) was introduced as a standard method that evaluates potential evapotranspiration (ET₀) by software CropWat (Allen et al., 1998). On the other hand, studies in arid and semi-arid regions have shown that temperature and radiation-based equations are highly precise (Allen et al., 1998) among which Hargraves-Samani method has been accepted as an authentic method throughout the world (Hargraves and Samani, 1985). Accordingly, modified Hargraves-Samani equation is more precise than FAO equation for arid and semi-arid regions of Iran (Hargraves and Samani, 1985). Furthermore, given the global validity of Hargraves-Samani model among other models, it can evaluate ET₀ more precisely in arid and semi-arid regions. Najafi and Tabatabaei (2004) used the following modified Hargraves-Samani equation in ET-HS model for evaluating evapotranspiration:

$$ET_{(p)} = \alpha(T_{\text{max}} - T_{\text{min}}) \left[ \frac{T_{\text{max}} + T_{\text{min}}}{2} + 17.8 \right]$$

where, $ET$ is crop evapotranspiration, $\alpha$ is calibration coefficient (which depends on regional climate and soil conditions) and $T_{\text{max}}$ and $T_{\text{min}}$ are daily maximum and minimum temperature. Indeed, ET-HS model is used to determine irrigation water quantity and irrigation schedule for different crops (Najafi and Tabatabaei, 2007). After calibration for a certain region, ET-HS model needs a few simple climatic variables, i.e. minimum and maximum daily temperatures, which are readily available to farmers. In addition, in their studies on tomato and eggplant, Najafi and Tabatabaei (2007) concluded that ET-HS model is quite useful for estimating water demand and for scheduling irrigation.

Since sound determination of sugar beet water demand is very important in planning irrigation management, sugar beet evapotranspiration models need to be evaluated and if water use is accurately managed, especially during sensitive growth stages, WUE will be improved. The objectives of the current study were to determine sound management of water use during sensitive growth stages of sugar beet and to minimize water use per sugar beet root dry matter production.

**Materials and Methods**

In order to evaluate ET-HS model in determining sugar beet crop water demand in Isfahan, an experiment was conducted at research field of Department of Agriculture, Khorasgan Branch, Islamic Azad University, Isfahan, Iran in 2005. It was located in Khatounabad Region with the latitude of 32°40’ N., longitude of 51°48’ E. and altitude of 1555 m from sea level. The regional climate is classified as arid and very hot with arid summers on the basis of Köppen climate classification, but the recommended classification for Iran ranks it as a region with arid and hot climate with relatively cold winters. Long-term average yearly precipitation and temperature of the region are 120 mm and 16°C, respectively. The soil of the research field was composed of 38.5% sand, 10.5% silt and 51% clay with a clay texture which is a sort of Isfahan soils (Table 1). The study was based on a Randomized Complete Block Design with three replications and six treatments. The irrigation treatments included irrigation to supply 50, 75, 100, 125 and 150% of crop water demand on the basis of ET-HS model during growing sea-
The seeds of multigerm cv. IC 2 were used. They were sown in a dense planting pattern on May 14, 2005. Before sowing, the field was fertilized with 200 kg.ha\(^{-1}\) Ammonium phosphate + 100 kg.ha\(^{-1}\) Urea on the basis of soil test. The experimental treatments equally received 417 m\(^3\) water in the first and second irrigation. To acquire the density of 80000 plants.ha\(^{-1}\), the seedlings were thinned at 4-6-leaf stage on sowing rows with 25 cm spacing and each experimental treatment was fertilized with 50 kg.ha\(^{-1}\) Urea. To control narrow-leaf and broad-leaf weeds, 5 kg.ha\(^{-1}\) Piramin and 5 l.ha\(^{-1}\) Betanal were mixed and applied after 2-leaf stage of sugar beets. The insecticide Subsidin (2:1000) was used for controlling Conorrhynchus brevirostris (Gyll.). In addition, leaf-feeding pests were controlled by Ekatin (2:1000). Powdery mildew was also controlled during early-summer by the fungicide Calixin (2:1000). The plots were separately irrigated during growth period in accordance with the experimental plan at the desired time. The amount of applied water was measured by a water contour according to ET-HS model. In control treatment, the amount of applied water was precisely measured by a volume contour, too.

To measure the yield and some important qualitative traits of sugar beet roots, the first and sixth rows and 0.5 m from both ends of the rows were removed from the experimental plots at the end of the season and the remaining plants were taken as the statistical population of the study. Root yield of each plot was determined in a 3-m\(^2\) area. In addition, dry matter, sugar percentage and some qualitative characteristics were measured by Betalyser. White sugar percentage was regarded as the difference of sugar content and molasses sugar percentage, and white sugar yield (t.ha\(^{-1}\)) was regarded as white sugar percentage multiplied by root yield (Emsaki, 1996).

The data were statistically analyzed by software MSTAT-C and the means were compared by LSD test at 5% probability level.

### Table 1. Some physical and chemical attributes of the study field soil at the depths of 0-30 and 30-60 cm

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>EC (ds.m(^{-1}))</th>
<th>Organic C (%)</th>
<th>Total N (%)</th>
<th>Absorbable P (ppm)</th>
<th>Absorbable K (ppm)</th>
<th>pH</th>
<th>Cation exchange capacity (Meq/100 g)</th>
<th>Sand (%)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>3.90</td>
<td>1.60</td>
<td>0.16</td>
<td>28</td>
<td>450</td>
<td>7.80</td>
<td>16.30</td>
<td>39</td>
<td>50</td>
<td>11</td>
<td>Clay</td>
</tr>
<tr>
<td>30-60</td>
<td>3.70</td>
<td>1.40</td>
<td>0.14</td>
<td>22</td>
<td>410</td>
<td>7.80</td>
<td>16.40</td>
<td>38</td>
<td>52</td>
<td>10</td>
<td>Clay</td>
</tr>
</tbody>
</table>

*The initial irrigations up to the emergence stage have not been taken into account in calculation of water use.*

### Table 2. The amount of water applied during growing season and the number of irrigations at different treatments (m\(^3\).ha\(^{-1}\))

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of applied water (m(^3).ha(^{-1}))</th>
<th>Number of irrigations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I(_1)</td>
<td>I(_2)</td>
</tr>
<tr>
<td></td>
<td>6800</td>
<td>8800</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>23</td>
</tr>
</tbody>
</table>

The initial irrigations up to the emergence stage have not been taken into account in calculation of water use.
RESULTS AND DISCUSSION

Total dry matter

Irrigation treatment affected total dry matter (TDM) significantly at 1% probability level (Table 3). The highest TDM (1496.67 g.m⁻²) was produced by plants irrigated to supply 150% of their water demand. As the water demand percentage was increased, TDM increased (Table 4) which shows that the more water was available to plants, the higher the TDM they produced. However, it resulted in the loss of final TDM in the current study caused by the loss of shoot dry matter due to such factors as cold weather and the impossibility of calculating shoot dry matter due to leaf yellowing and shattering. This response has been confirmed in some studies (Rafiee, 1995; Jahadakbar and Ebrahimiyan, 1998).

Root yield

The effect of irrigation treatment on root yield was significant at 1% probability level (Table 3). Root yield significantly increased as plants water demand percentage was increased. The highest root yield (57.02 t.ha⁻¹) was obtained in the treatment of irrigation to supply 150% of crop water demand which had significant differences with the treatments of irrigation to supply 50, 75 and 100% of crop water demand. Control treatment did not show significant differences with the treatments of irrigation to supply 100 and 125% of crop water demand, but its difference with other treatments was significant. Treatments of irrigation to supply 50 and 75% of crop water demand which had the lowest root yield did not show significant difference with each other. Therefore, low-irrigation resulted in significant loss of root yield in both treatments (Table 4). A positive, significant correlation ($r = 0.95^{* *}$) was observed between root yield and TDM which reveals that plant TDM increased with root yield. The correlation between root yield and white sugar percentage was negative and significant ($r = -0.57^{* *}$). Root yield was not significantly correlated with root impurities including Na ($r = 0.24^{ns}$), K ($r = 0.31^{ns}$) and $\alpha$-amino nitrogen ($r = 0.07^{ns}$). It was not significantly correlated with molasses sugar percentage, too ($r = 0.09^{ns}$). The correlation between root yield and white sugar yield (WSY) was positive and significant ($r = 0.89^{**}$). It means that the effect of root yield on WSY was positive and significant. Campel (2002) concluded that the effect of the increase in root weight on sugar yield was greater than that of the increase in sugar content alone. Schneider et al. (2002) showed that sugar yield was strongly correlated with root yield and less strongly with sugar concentration.

Sugar percentage

Irrigation treatment did not significantly impact sugar percentage (Table 5). Nonetheless, the highest sugar percentage (17.48%) was obtained from the treatment of irrigation to supply 100% of crop water demand and the lowest one (15.12%)
was obtained from control treatment followed by the treatment of irrigation to supply 150% of crop water demand (15.48%) (Table 6). Sugar percentage was negatively and significantly correlated only with Na ($r = -0.43^{**}$) and molasses sugar percentage ($r = -0.56^{**}$), i.e. the higher the sugar percentage was, the significantly lower the Na and molasses sugar percentage were. This finding was in agreement with the findings of Jahadakbar and Ebrahimiyan (1998), too.

**Sodium**

Irrigation treatment did not significantly affect Na content (Table 5). Although the lowest Na content (3.45 Meq g per 100 g root) was obtained from the treatment of irrigation to supply 100% of crop water demand, the highest one (4.86 Meq g per 100 g root) was obtained from the treatment of irrigation to supply 125% of crop water demand (Table 6). The correlation between Na and white sugar percentage was negative and significant ($r = 0.77^{**}$), i.e. white sugar percentage significantly decreased with the increase in Na content. Other researchers have introduced Na as one of the most important impurities of sugar beet roots, too and have stated that its content in root has a negative correlation with white sugar percentage (Cook and Scott, 1993).

**Potassium**

Irrigation treatment did not significantly influence K content of roots (Table 5). However, the highest and lowest K contents were obtained from the control treatment and the treatment of irrigation to supply 150% of crop water demand, respectively. K content was 5.82 Meq g per 100 g root in the treatment of irrigation to supply 75% of crop water demand which had the highest K content followed by control treatment (Table 6). K had a positive correlation with other studied impurities and a negative correlation with white sugar percentage. Also, Cooke and Scott (1993) stated that the impurities of juice extract had mostly positive correlation with each other and a negative correlation with white sugar percentage.

**α-amino nitrogen**

The effect of irrigation treatment was not significant on α-amino nitrogen (Table 5). On the basis of ET-HS model, the highest α-amino nitrogen (7.20 Meq per 100 g) was obtained from the treatment of irrigation to supply 150% of crop water demand and the lowest one (3.35 Meq g per 100 g) from the treatment of irrigation to supply 100% of crop water demand (Table 6). As one of the important impurities of sugar beet, α-amino nitrogen has a close relationship with technological merit of sugar beet. Technological merit of sugar beet, in turn, is linked with N management and commits toll by either lessening sugar purity and crystallization coefficient in factory or by inducing regrowth and depleting sucrose stored in roots (Cook and Scott, 1993).

**Molasses sugar percentage**

Irrigation treatments did not have significant impact on molasses sugar percentage (Table 5). However, as can be seen in Table 6, the highest molasses sugar percentage was obtained from the treatment of irrigation to supply 150% of crop water demand and the lowest one from the treatment of irrigation to supply 100% of crop water demand on the basis of ET-HS model. Molasses sugar percentage is the difference of total and white sugar percentage and determines the sweetness of molasses. Molasses sugar percentage increases as the amount of sugar which becomes unavailable in factory increases (Emsaki, 1996).

**White sugar percentage**

Irrigation treatment did not significantly affect

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**Table 6.** Means comparison for some measured quantitative and qualitative traits as affected by the treatments in 2005

<table>
<thead>
<tr>
<th>Treatment (percent of crop water demand supplied on the basis of ET-HS model)</th>
<th>Sugar content (%)</th>
<th>Na (Meq/100 g)</th>
<th>K (Meq/100 g)</th>
<th>α-amino N (Meq/100 g)</th>
<th>Molasses sugar (%)</th>
<th>Extractable sugar (%)</th>
<th>White sugar yield (t.ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>16.23 a</td>
<td>4.65 a</td>
<td>5.43 a</td>
<td>5.25 a</td>
<td>4.24 a</td>
<td>11.99 a</td>
<td>4.55 a</td>
</tr>
<tr>
<td>75</td>
<td>16.91 a</td>
<td>4.39 a</td>
<td>5.82 a</td>
<td>6.74 a</td>
<td>4.43 a</td>
<td>12.47 a</td>
<td>4.76 a</td>
</tr>
<tr>
<td>100</td>
<td>17.48 a</td>
<td>3.45 a</td>
<td>5.55 a</td>
<td>3.35 a</td>
<td>3.32 a</td>
<td>13.59 a</td>
<td>6.12 a</td>
</tr>
<tr>
<td>125</td>
<td>16.19 a</td>
<td>4.86 a</td>
<td>5.50 a</td>
<td>5.04 a</td>
<td>3.90 a</td>
<td>11.87 a</td>
<td>6.55 a</td>
</tr>
<tr>
<td>150</td>
<td>15.48 a</td>
<td>4.68 a</td>
<td>5.25 a</td>
<td>7.20 a</td>
<td>4.72 a</td>
<td>10.76 a</td>
<td>6.11 a</td>
</tr>
<tr>
<td>Control</td>
<td>15.12 a</td>
<td>2.54 a</td>
<td>5.93 a</td>
<td>5.18 a</td>
<td>4.25 a</td>
<td>11.55 a</td>
<td>5.87 a</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>3.54</td>
<td>3.45</td>
<td>0.872</td>
<td>3.92</td>
<td>1.523</td>
<td>4.586</td>
<td>2.457</td>
</tr>
</tbody>
</table>

Figures with similar letter(s) in each column were not significantly different.

Ebrahimiyan (1998). **Technological merit of sugar beet.**

Soleymani A, Najafi P, Dehnavi M, Shaherjabiyan MH | Evaluation of ET-HS model for estimating water demand and ... 33
Table 7. Comparison of WUE based on root yield, total sugar yield and extractable sugar yield in 2005

<table>
<thead>
<tr>
<th>Treatment (percent of crop water demand supplied on the basis of ET-HS model)</th>
<th>WUE (kg.m$^{-3}$) based on*</th>
<th>Root yield</th>
<th>Total sugar yield</th>
<th>Extractable sugar yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>5.91 a</td>
<td>0.96 a</td>
<td>0.71 a</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>4.36 c</td>
<td>0.73 b</td>
<td>0.54 ab</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>4.21 c</td>
<td>0.74 b</td>
<td>0.57 ab</td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>4.31 c</td>
<td>0.70 b</td>
<td>0.51 ab</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>4.22 c</td>
<td>0.65 b</td>
<td>0.45 c</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>5.35 b</td>
<td>0.85 ab</td>
<td>0.62 ab</td>
<td></td>
</tr>
</tbody>
</table>

LSD 5% 0.53 0.20 0.23

Figures with similar letter(s) in each column were not significantly different.

* Water use efficiency has been considered for post-emergence period and initial irrigations for emergence have not been taken into account.

White sugar yield

The effect of irrigation treatment was not significant on white sugar yield (Table 5). Nonetheless, the highest white sugar percentage (13.59%) was obtained from the treatment of irrigation to supply 100% of crop water demand and the lowest one (10.76%) from the treatment of irrigation to supply 150% of crop water demand on the basis of ET-HS model (Table 6) which can be related to bigger plants in the latter treatment compared to the former one. Also, Fabeiro et al. (2003) reported that white sugar percentage decreased with the increase in single plant size and that lower quantity of irrigation water resulted in lower sugar percentage which is in agreement with the results of the current study. In the current study, white sugar percentage had a negative, significant correlation with Na ($r = -0.34^{**}$) and molasses sugar percentage ($r = -0.73^{**}$). It means that as white sugar percentage was increased, Na and molasses sugar percentage were decreased significantly. This is in agreement with the findings of Jahadakbar and Ebrahimiyan (1998). Pakniyat (1999) reported that the ideal conditions were when sugar yield and white sugar yield were equal.

Water use efficiency in terms of root yield

The study of the quantity of water used in different water use management treatments on the basis of ET-HS model showed that the highest quantity was applied in the treatment of irrigation to supply 150% of crop water demand, whereas the amount of water used in control treatment was between the amounts used in the treatments of irrigation to supply 100 and 75% of crop water demand. The highest WUE for root yield was obtained from the treatment of irrigation to supply 50% of plant water demand which produced 5.91 kg root per m$^{3}$ applied water. As the amount of irrigation water was increased, WUE for root yield significantly decreased (Table 7). It shows that the increase in root yield was not able to compensate the increase in the amount of applied water. Also, it shows that as water becomes more expensive, producers cannot use more water to produce more roots and should seriously take WUE for root yield into consideration (Najafi and Tabatabaei, 2007; Najafi and Tabatabaei, 2009).

Water use efficiency in terms of total sugar yield

Total sugar yield is crucially important for producers since it is the criterion for sugar beet purchase and plays the main role in sugar yield (Pakniyat, 1999). The highest WUE for sugar yield was 0.96 kg.m$^{-3}$ which was obtained from the treatment of irrigation to supply 50% of crop water demand; that is, 0.96 kg gross sugar was produced for each m$^{3}$ applied water in this treatment. It exhibited statistically significant differences with all treatments except control. The lowest WUE was obtained from the treatment of irrigation to supply 150% of crop water demand. This response means that in this treatment, applied water was more than the water demand of the plants and so, it became unavailable to plants. The irrigation treatments did not show significant differences in...
their WUE for total sugar yield unless the treatment of irrigation to supply 50% of crop water demand (Table 7).

**Water use efficiency in terms of white sugar yield**

The pattern of the variation of WUE for white sugar yield shows how much white sugar is produced for how much applied water. The highest WUE for white sugar yield was obtained from the treatment of irrigation to supply 50% of crop water demand which did not have significant difference with the irrigation treatments of control and irrigation to supply 75, 100 and 125% of crop water demand. It had significant difference only with the treatment of irrigation to supply 150% of crop water demand. It reveals that only in the treatment of irrigation to supply 150% of crop water demand, the applied water amount was more than required.

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