Irrigation scheduling under water shortage: investigation of scion-rootstock of peach and water deficit combinations
Mohamed Ghrab, Mohamed Moncef Masmoudi, Mehdi Ben Mimoun and Netij Ben Mechlia

ABSTRACT
Adequate choice of variety, rootstock and irrigation techniques could be, together, sources of improvement of water use. A field experiment was carried out in northern Tunisia on two drip irrigated peach varieties grafted on two rootstocks. Two deficit levels, mild DI1 and severe DI2, were applied. Phenological survey allowed determination of the crop growth stages: initial, development, mid- and late-season. The average lengths of these crop stages were 32, 43, 49 and 136 days for early variety and 33, 49, 63, and 105 days for mid-season variety, respectively. Mean value of crop evapotranspiration (ETc) for the four growth stages was respectively 31, 115, 211 and 420 mm for early variety and 40, 128, 311 and 300 mm for mid-season variety. ETc was restricted with low ground cover to 25, 85, 150 and 280 mm. Tree development, yield and water needs were affected by water status, rootstock and climatic conditions. Threshold values of Ψstem of –1.5 and –2.0 MPa could be considered for mild and severe deficit irrigation. The water use of the soil water seemed to be more efficient with vigorous rootstock under mild deficit. Under extreme watering conditions, rootstock effects were negligible. Lack of chilling affected tree growth inducing reduced water requirements.

Key words | deficit irrigation, development, Prunus persica, rootstock, variety

INTRODUCTION
Peach is highly valued as a table fruit. A gradual extension of the production season of peach has been occurring in Tunisia, which extends from April to September. Consequently, significant differences in tree growth stages have been identified depending on variety, which had a direct impact on farming operations including irrigation (Pavel & DeJong 1993; Allen et al. 1998). Furthermore, the water requirements of peach depended on development stage. It was generally expressed as a function of the reference evapotranspiration (ET0) and crop coefficient (Kc). Various approaches have been used to estimate Kc for peach (Tan & Layne 1981; Worthington et al. 1984). The findings led to a succession of Kc values that describe the changing of transpiration conditions at different growth stages. A new approach was developed by Food and Agriculture Organization (FAO) and based on the identification of crop growth stages with respective Kc (Allen et al. 1998). The high variability of rainfall in space and time is observed and severe climatic deficits affected fruit crops. Moreover, global warming with abnormal temperature variations resulted in contrasting chilling accumulations, which influenced the development of fruit species (Luedeling et al. 2011; Campoy et al. 2012). Consequently, fruit tree training must adapt to chronic water deficit conditions and cyclic severe drought initiated by global warming. In the context of increasing water scarcity, irrigation scheduling seeks optimum water supply for better productivity. Effective use management is the only way to save water for the increasingly irrigated agriculture (Chalmers et al. 1981; Johnson et al. 1992; Boland et al. 1995; Pérez-Pérez et al. 2010). Under the

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semi-arid conditions of Tunisia, irrigation deprivation at different stages of fruit growth of a late variety of peach was investigated in field experiments (Ghrab et al. 1998). The deficit irrigation strategy seemed to be a relevant choice (Ben Mechlia & Masmoudi 2003; Ghrab et al. 2003a, b).

Tree water status was affected by soil water availability and hydraulic conductance of roots. In irrigated orchards, fruit trees are formed by a combination of two different genotypes, the scion and the rootstock which could markedly affect vegetative growth and water status of the scion (DeJong et al. 2005). The combination of rootstock type and irrigation restrictions may offer beneficial results. Differing behaviors of citrus rootstocks in response to water cut-off suggested some physiologically better ones for long-term deficit irrigation under semi-arid conditions (Pérez-Pérez et al. 2008). The valuable findings on water saving techniques in the peach orchard with a late variety revealed interesting ways for better use of irrigation water (Ben Mechlia & Masmoudi 2003). The combinations of maturing season of peach variety, rootstocks and deficit irrigation levels under water shortage may offer beneficial results.

This study seeks to explore possibilities of improving the water use through varietal choice that determines water requirements and the choice of rootstock, which determines the capacity and dynamic use of soil water. In the first step, an estimation of water requirements under standard conditions of the region of Mornag was done based on crop growth stages for early and mid-season varieties. In the second step the behavior of these two varieties was studied in fields under deficit irrigation depending on rootstock type. The experiment explores the possibility of a better use of soil water reserves resulting from rainfall and a substantial reduction in irrigation water supply during the summer. It looks for reliable tools to adjust deficit levels via tree water status and to state to which extent rootstock affects plant water relations under various levels of water deficit conditions.

**MATERIAL AND METHODS**

**Experimental trial**

This work has been conducted in an experimental orchard located in the plain of Mornag, 15 km south-east of Tunis (36°41'N, 10°15'E) during three growing seasons (2006–2008). The drip-irrigated orchard consisted of 4-year-old trees of early and mid-season maturing peach varieties (Early May Crest and Royal Glory, respectively) grafted on GF677 and Cadaman. The trees were planted with a density of 416 trees ha⁻¹ (4 m × 6 m apart) and trained to an open vase system.

The experimental orchard is characterized by a loamy-clay soil. Its physical properties were 32% clay, 49.4% silt and 18.6% sand and its water related properties are 36.1 and 21.5% at field capacity and wilting point, respectively. The fruit production area is subjected to Mediterranean climate with a long dry season and high evaporative demand. The mean values of precipitation and reference evapotranspiration (ET₀) are 450 and 1,250 mm, respectively.

**Watering conditions**

Water requirement of mature peach trees of early and mid-season maturing varieties was estimated under standard conditions of irrigated orchards in the main production zone of northern Tunisia. Crop evapotranspiration (ETₜ) was determined using the single crop coefficient (Kc) and daily Penman-Monteith reference evapotranspiration (ET₀) as ETₜ = Kc * ET₀ and based on observed duration of tree growth stages: initial, development, mid-season and late-season (Allen et al. 1998). Crop coefficient values of 0.5, 0.9 and 0.65 were respectively adopted for initial, mid- and late seasons.

Water scarcity generated limited water availability for irrigation. Deficit irrigation levels were applied to better manage limited water availability. Two deficit irrigation levels DI₁ and DI₂ as mild and severe were applied to blocks of 15 trees for each scion-rootstock combination during the growing season. Irrigation consisted of regular supply from fruit set to harvest and less frequent supply during post harvest. Trees were irrigated with two dripper lines and four emitters per tree providing 4 and 21 l h⁻¹ for mild and severe deficit irrigation treatments, respectively. Total water applied during the dry season was in the range of 100–300 mm for mild level DI₁ and 50–200 mm for severe level DI₂ of deficit irrigation. Consequently, for the non-standard conditions, reduction coefficient for deficit irrigation strategies Kc was determined as a correction for
low ground cover resulting from the age and spacing of trees. ETc was determined as: $\text{ETc} = K_c \times K_r \times \text{ETo}$, with a $K_c$ value of 0.7, considered depending on the ground cover (Masmoudi-Charfi et al. 2004).

**Agronomic survey**

Phenological stages and vegetative and fruit growth were monitored and used to identify the four crop growth stages: (i) initial, from blooming to flowering; (ii) development, from flowering until 70% of canopy cover; (iii) mid-season, covering full canopy-harvest period; and finally (iv) late season, which ends at senescence.

Deficit irrigation treatments DI1 and DI2 were applied on blocs of 15 trees (three adjacent rows of five trees) for each scion-rootstock combination. Measurements were made on the five trees of the central row. Six shoots per tree and five trees per scion-rootstock and deficit level combination were selected for monitoring. At harvest, fruit yield per tree was computed on five trees per combination plot (scion, rootstock, DI).

Predawn leaf water potential ($\Psi_{PD}$) and stem water potential ($\Psi_{stem}$) were measured on two trees per scion-rootstock and deficit level plot. $\Psi_{PD}$ was performed early in the morning before sunrise (03h 30), while $\Psi_{stem}$ was determined at midday (12h 30–14h 00) on covered leaves with black plastic and aluminum foil (Shackel et al. 1997). Measurements were carried out on four leaves per tree for each tree water status method.

**Statistical analysis**

A one-way analysis of variance was performed using the SPSS 13.0 statistical package for Windows and the treatment means were compared using the Duncan test calculated at 5% level.

**RESULTS AND DISCUSSION**

**Crop growth stages**

The lengths of crop growth stages are necessary to estimate water requirements of varieties within species. The respective durations of the four growth stages for the two varieties of peach are given in Table 1. During the 3 years, the lengths of the four stages were respectively about 28–34, 37–50, 46–51 and 133–138 days for early-maturing variety early May Crest and 29–39, 47–50, 61–66 and 103–108 days for mid-season variety Royal Glory. Both early and mid-season varieties presented a short initial stage of 1 month. The late-season stage was the longest one and it extended to more than 50% of total crop growth for the early variety.

The length of the four crop growth stages coincided with previous data reported in the same production area (Ben Mechlia & Masmoudi 2005) and integrated the reference lengths adopted by FAO 56 manual (Allen et al. 1998). Zapata et al. (2013) reported an average length of 25, 65, 45 and 127 days for early-maturing peach varieties and 29, 67, 76 and 90 days for mid-season maturing peach varieties, respectively. These differences could be related to differences in phenological stages between varieties within each maturing season (early, mid-season or late). Moreover, these crop growth stages seemed to be affected by the lack of chilling in 2007 resulting in elongated initial and development crop stages.

**Watering references under standard conditions**

Trend evolution of ETo, $K_c$ and ETc for early and mid-season peach varieties during 2006, 2007 and 2008 were established (Figure 1). It appears that mid-season crop stage with active vegetative and fruit growth may precede or coincide, depending on variety, with the period of high evaporative demand (peak of ETo). Development and mid-season growth stages of early-maturing variety Early May Crest occurred before the period of high evaporative

<table>
<thead>
<tr>
<th>Crop growth stages</th>
<th>cv. Early May Crest</th>
<th>cv. Royal Glory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>28</td>
<td>34</td>
</tr>
<tr>
<td>Development</td>
<td>41</td>
<td>50</td>
</tr>
<tr>
<td>Mid-season</td>
<td>51</td>
<td>46</td>
</tr>
<tr>
<td>Late-season</td>
<td>138</td>
<td>133</td>
</tr>
<tr>
<td>Total</td>
<td>258</td>
<td>263</td>
</tr>
</tbody>
</table>
demand while covering a large part of this period for the mid-season maturing variety Royal Glory. Inter-annual variation occurs in the trends of three parameters considered. A delay of crop growth stages occurred in 2007 related to delayed flowering and vegetative growth. Consequently, mid-season growth stage largely coincided with the period of high evaporative demand for both early and mid-season maturing varieties of peach.

Total water needs of both varieties were 800 mm during 2006 and 2008 and 740 mm in 2007. The late-season crop stage required more than 50% of the water needs of early peach varieties, whereas mid-season varieties had important needs (75%) during mid- and late-season crop growth stages (Table 2). Similar crop water requirement (733–741 mm) was estimated for early-maturing peach Flordastar in South Eastern Spain (Abrisqueta et al. 2010). In North
Eastern Spain, average crop evapotranspiration of a 6-year period of 823 and 895 mm was reported for early and mid-season maturing peach, respectively (Zapata et al. 2013). Average water needs of 890 mm were estimated for both early (Flordastar) and mid-season (Royal Glory) maturing peach using datasets of 20 years under standard conditions of irrigated orchards in the production area of Mornag (Ben Mechlia & Masmoudi 2003). Moreover, the lack of chilling induced restriction of water requirements (730–740 mm in 2007) subsequent elongation of initial and development growth stages duration.

Irrigation water requirements ranged between 500–670 mm and 500–680 mm for early-maturing Early May Crest and mid-season maturing Royal Glory, respectively, with an average of 600 mm in the production zone of northern Tunisia. Conejero et al. (2011) estimated crop irrigation requirements for an early-maturing variety as 504–797 mm over 3 years according to daily ET0, Kc and the percentage of ground area shaded by tree canopy. Zapata et al. (2013) indicated net irrigation requirements for early and mid-season maturing peach varieties in North Eastern Spain of 682 and 754 mm, respectively. However, these needs are often unfulfilled under our conditions because of severe water shortage and increased competition from other sectors. Consequently, achieving standard conditions with full irrigation is somewhat difficult and deficit irrigation management must be adopted.

Watering conditions under deficit irrigation

Annual values of ET0 and precipitations were respectively 1,170 and 566 mm in 2006, 1,096 and 539 mm in 2007 and 1,188 and 204 mm in 2008. Consequently, the rainfall deficit developed from the end of spring covered active vegetative and fruit growth stages. With low ground cover in peach orchards, ETc was restricted. The total amount of ETc estimated after adjusting Kc for low ground cover was 566, 520 and 557 mm for early-maturing varieties and 564, 509 and 562 mm for mid-season maturing varieties, respectively in 2006, 2007 and 2008 (Table 3). ETc values during mid- and late-season crop stages represented more than 75% of the total amount.

Irrigation water comes from the public irrigation network, which is characterized by poor reliability of supply. Under this constraint, irrigation management failed in some periods to meet the needs. It was applied daily and regularly from fruit set to harvest followed by frequent withhold of water supply depending on water availability. The total amount of irrigation applied on the early variety was 100–50 mm, 200–100 mm and 200–100 mm for the mild–severe deficit regimes in 2006, 2007 and 2008, respectively (Table 3). Royal Glory as mid-season maturing received 120–60 mm, 200–100 mm and 300–200 mm under DI1 and DI2 during the respective 3 years.

Responses of scion-rootstock combinations to deficit irrigation

An improvement of tree water status with irrigation was observed until harvest (Figure 2). ΨPD and Ψstem decreased with deficit irrigation levels. Trees grafted on less vigorous rootstock Cadaman had unfavorable water status with a significant decline of ΨPD and Ψstem. Under severe deficit (ΨPD and Ψstem below −1.0 and −2.0 MPa respectively) during

<table>
<thead>
<tr>
<th>Variety</th>
<th>Growth stage</th>
<th>2006 ETc (mm)</th>
<th>2007 ETc (mm)</th>
<th>2008 ETc (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early May Crest</td>
<td>Initial</td>
<td>17</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Development</td>
<td>70</td>
<td>109</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Mid-season</td>
<td>158</td>
<td>141</td>
<td>148</td>
</tr>
<tr>
<td></td>
<td>Late-season</td>
<td>315</td>
<td>239</td>
<td>294</td>
</tr>
<tr>
<td></td>
<td>Total (mm)</td>
<td>566</td>
<td>520</td>
<td>557</td>
</tr>
<tr>
<td>Royal Glory</td>
<td>Initial</td>
<td>25</td>
<td>35</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Development</td>
<td>100</td>
<td>80</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>Mid-season</td>
<td>220</td>
<td>219</td>
<td>217</td>
</tr>
<tr>
<td></td>
<td>Late-season</td>
<td>219</td>
<td>175</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>Total (mm)</td>
<td>564</td>
<td>509</td>
<td>562</td>
</tr>
</tbody>
</table>

Table 3 | ETc and irrigation water supplied (mm) under mild deficit DI1 over the four growth stages of early and mid-season peach varieties
postharvest, differences in tree water status became insignificant between rootstocks. Less vigorous rootstock showed more negative tree water status under similar conditions, which suggests higher resistance to water transport (Li et al. 2023). Similar findings reported that the lowest water potential corresponded to the lowest hydraulic conductivity along the stem for nectarine (Motisi et al. 2007). Under mild deficit level (300 mm), vigorous rootstock showed a greater capacity for water uptake, which could be related to its higher hydraulic conductance (Solari et al. 2009). Differences in tree vigor induced by rootstock were explained by differences in water status (Basile et al. 2005) and had significant effects on total vegetative growth (Solari & DeJong 2013).

For early and mid-season varieties, deficit irrigation strategies should be adjusted to limit water deficits during the long postharvest phase. Our results proved that a threshold value of $\Psi_{\text{stem}}$ of $-1.5$ and $-2.0$ MPa could be adopted for moderate and severe deficit irrigation as previously found for late peach cultivar (Ben Mechlia et al. 2002). Postharvest severe deficits were obtained for $\Psi_{\text{PD}}$ and $\Psi_{\text{stem}}$ below $-1.0$ and $-2.0$ MPa respectively. Reliable tools for irrigation scheduling in peach orchards under water stress conditions were investigated. A valid approach estimating relative transpiration from $\Psi_{\text{PD}}$ was reported for practical uses for irrigation scheduling under moderate stress conditions (do Paço et al. 2016). Furthermore, Vera et al. (2015) indicated that irrigation scheduling could be managed by plant water status and a threshold $\Psi_{\text{stem}}$ value of $-0.9$ MPa was proposed for the summer period in early-maturing peach orchards. The regular use of plant water stress indicator seems to be a valuable method to succeed in scheduling regulated deficit irrigation (Zapata et al. 2013). Some findings pointed out that the threshold limits of $\Psi_{\text{stem}}$ are variable between crops, crop development stages, soil characteristics and fruit loads. A threshold value of $-1.5$ MPa was proposed as a limit of

![Figure 2](https://iwaponline.com/ws/article-pdf/14/2/312/415460/312.pdf)
water stress for stone fruit trees (Zapata et al. 2013) as previously reported for peach trees (Marsal et al. 2005; Dichio et al. 2007), cherry (Marsal et al. 2009) and prune (Shackel et al. 2000). Vegetative growth and yield were affected by water status. Globally, trees grafted on GF677 showed higher shoot growth for both cultivars (Table 4) and higher yield only with Royal Glory (Figure 3) under mild deficit irrigation (DI1). For Early May Crest, there is no clear effect of rootstock on yield, or probably a small advantage for Cadaman. Under severe water conditions (DI2: 50–200 mm), differences between rootstocks were not measurable and vegetative growth and yield were affected at similar degrees for all trees. A yield reduction of 14 to 22% is observed for both cultivars compared to DI1. When using data from all treatments, it can be noticed that best performances are obtained for the combinations EMC-Cadaman and RG-GF677. In 2007, similar vegetative growth and yield were performed for all combinations (variety, rootstock, DI). Lack of chilling occurring this year seemed to have harmful effects on scion-rootstock combinations of peach.

Deficit irrigation reduced total vegetative growth of early and mid-season varieties, leading to smaller trees. Previous works widely documented the high sensitivity of peach tree growth to different irrigation strategies (Chalmers et al. 1981; Johnson et al. 1992; Boland et al. 1993; Girona et al. 2005; Abrisqueta et al. 2010; Vera et al. 2013). However, early-maturing cultivar was more affected by postharvest deficit and rootstock seems to have a key role on tree vigor. Girona et al. (2005) indicated that deficit levels are variety, soil and fruit load dependent. Successful deficit irrigation practices depended on peach variety. The most-sensitive growth stage is the final stage of rapid growth of fruit and water restriction during the first two stages reduced vegetative growth without harmful effect on yield of late-maturing variety (Chalmers et al. 1981; Ghrab et al. 1998). For early maturing varieties, deficit irrigation was mainly applied in post-harvest (Johnson et al. 1992). However, tree growth and yield seemed to be affected at different levels depending on deficit severity and rootstock as observed for early and mid-season maturing peach varieties. Drought-resistant rootstocks could pass resistance to cultivar under different irrigation strategies and reduced the negative effect of water stress (Qi et al. 2007; Pérez-Pérez et al. 2008). Recent results reported that the yield of early maturing varieties are more affected by post-harvest irrigation (Vera et al. 2013). The expected increase in water prices in agriculture production regions and an increase in the demand for water for other uses indicate that applying deficit irrigation is an efficient alternative as much in agronomic terms as in real economic terms (Pérez-Pérez et al. 2010).

**CONCLUSIONS**

During the 3-year monitoring period, crop growth stages and water requirements of early and mid-season maturing
varieties of peach were determined. Water requirements and irrigation water needs of the two peach varieties were determined under standard conditions in the main production zone in northern Tunisia. Under poor reliability of supply from the public irrigation network, tree development and water needs were severely affected and better water management is needed. Postharvest deficit irrigation was considered in peach orchards at mild and severe levels. With water scarcity, deficit irrigation levels must be adjusted and tree water status seems to be a reliable tool for irrigation scheduling. Threshold values of $\Psi_{stem}$ of −1.5 and −2.0 MPa could be considered for mild and severe deficit irrigation. Rootstock seems to have a major role in the valorization of soil water conditions, rootstock effects were insignificantly.

References


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