Effects of irrigation regimes on the yield and water use of strawberry

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Summary. Strawberry plants (Fragaria × ananassa D. cv Chandler) were grown in field plots and in drainage lysimeters under controlled soil moisture regimes. Four irrigation treatments were established by watering the plants when soil water potential reached −0.01, −0.03, −0.05 and −0.07 MPa. The maximum yield was attained at −0.01 MPa soil water potential. Differences in yield were caused by both changes in the number of fruits per plant and in the fresh weight per fruit. Yield reductions were associated with reductions in total assimilation rate resulting from the decreased assimilatory surface area in plants irrigated at lower soil water potentials. The crop water production function calculated on a fruit fresh weight basis resulted in a yield response factor (K_y) of 1.01.

In mediterranean conditions, where crop growth is not limited by light, crop yield is closely related to water availability (Faust 1986), and therefore dependent upon irrigation.

In Coastal Catalonia, strawberry has been traditionally irrigated mostly by sprinkler irrigation. However, trickle irrigation has been widely adopted in the last few years because many soils are not suitable for sprinkler irrigation due to both low water holding capacity and topography (Marfà et al. 1990). Limited information on crop water requirements has hampered the development of practical irrigation scheduling guidelines and potential yields are not usually reached. Irrigation scheduling errors may result in a serious yield reduction because strawberry plants are sensitive to water stress (Gerhmann 1985). Also, little information is available on the effects of plant water deficits on strawberry physiology (Davies and Albrigo 1983). On the contrary, over-irrigation and prolonged soil saturation can induce Phytophthora root rot and other diseases (Welch et al. 1982). Saving irrigation water is also important in terms of regional water conservation: excessive exploitation of groundwater for agricultural purposes allows the intrusion of sea water and leaching of fertilizers which contaminate the aquifers (Corominas and Custodio 1982).

Crop-water production functions are useful for irrigation scheduling, estimation of water requirements for maximum yield, determination of maximum water use efficiency, allocation of water on a farm and regional level and as an aid to economic analyses (Stewart et al. 1977).

The aims of this study were to determine a) the effects of irrigation regimes on yield and water use efficiency and b) the water production function for fruit yield in response to transpiration that results from different irrigation regimes.

Material and methods

Strawberry plants (Fragaria × ananassa D. cv Chandler) were planted on a Typic Xerorthent soil. Tunnels covered with thermic PE plastic film were used. Experiments were located in the IRTA experimental fields located in coastal Catalonia (41° 25' N, 2° 23' E).

Planting was on November 10, 1989 and cropping continued until July 11, 1990. Strawberries were grown with PE mulch according to conventional cultural practices in the area. Four water treatments were established in four plots of four beds each. Each plot was 6 m long by 4.5 m wide with plants set 30 cm apart within the row. The rows were spaced 32 cm from each other to give an equivalent plant density of 6.41 plants m⁻². Water was supplied by trickle irrigation using turbulent flow emitters spaced every 30 cm, with a flow rate of 2 l h⁻¹. Three laterals per bed were installed.

During the two months after planting, and in order to assure a good plant establishment, water was applied before soil water potential reached −0.02 MPa. Thereafter four irrigation treatments were initiated: fertirrigation was applied in each plot when soil water potential reached −0.01, −0.03, −0.05 and −0.07 MPa respectively. Soil water potentials within each plot were measured by daily readings of paired tensiometers 10 and 20 cm deep (Soil-moisture 2725) and located 15 cm from the emitter. There were three pairs of tensiometers per treatment. Measurements of soil water potential were averaged and the volume fraction of water was assumed to be a close approximation of the soil water contents in the top 30 cm of the soil which was considered to be the maximum root depth (Doorenbos and Pruitt 1984). Amounts of water to be
applied were determined from the water retention curve. Water was applied in a higher volume than the field capacity to ensure drainage in the lysimeters.

Available top water was adjusted according to Steiner's method (Steiner 1966) to obtain the following nutrient equilibrium 1:0.5:1.8 and 1:0.7:2.5 (N:P:O₃:K:O) for vegetative and productive periods, respectively. To test for possible fertility effects of irrigation treatments leaves and fruit samples were analyzed for nitrate-N content in spring and summer. No significant differences were found, at 95% confidence level, in fruit and leaf nitrogen content (% dry weight) on both irrigation treatments. Mean leaf N content was 1.98 ± 0.14 and 2.13 ± 0.24 and fruit N content was 1.31 ± 0.16 and 1.29 ± 0.05, for −0.01 MPa and −0.07 MPa treatments, respectively.

Two shallow drainage lysimeters were installed in each treatment to measure the water which had percolated 24 h after irrigation.

Data on maximum and minimum air temperatures and relative humidity and class A evaporation pan were recorded inside the tunnel. These data and wind speed were also recorded in the experiment site (National Agrometeorological Field Station 244-E). Average maximum and minimum temperatures during the growing period were 18.3 °C and 11.0 °C, respectively and the average relative humidity was 80%.

Photosynthetic rates were measured at solar noon in sunny days with a portable photosynthesis system (LI-6000) on 6 fully expanded leaves. The days surveyed were 141, 160, 161, 167, 179, 186, 189 and 202 after planting. Measurement of transpiration rates and stomatal conductances were also taken with a steady state porometer (LI-1600).

Yield and average fruit size were measured on sixteen 0.64 m² subplots per treatment. The harvest period was from March 1 until July 11.

Leaf area index (LAI) was determined by measuring central leaf length in 12 plants of each treatment. Total area was then estimated from the experimentally established relationship: area = 21.49 length − 52.62 (n = 16 and r² = 0.936).

Differences in the parameters studied were evaluated by analysis of variance procedures (F-test) and means were compared using a Tukey’s multiple range test. Data were computed using the statistical program package Statgraphics 4.0 (STSC, INC.).

### Results and discussion

**Effects of irrigation regime on yield**

Significant differences in fruit yield between treatments were obtained. Yield decreased from 8.3 ± 0.28 to 5.6 ± 0.39 kg m⁻² (p < 0.001, ANOVA) from −0.01 to −0.07 MPa treatments (Table 1). Yield was reduced in plants submitted to −0.03, −0.05 and −0.07 MPa regimes due to a decreased mean fruit weight and a diminished fruit number. As has been suggested by Davies and Albrigo (1983), decreased mean fruit weight can be partially due to an accelerated fruit maturation that results in smaller fruits. Diminished fruit number due to mild water deficits has also been reported by Gehrmann (1985) in strawberries cv. Korona.

Irrigation scheduling at −0.01 MPa soil water potential resulted on the highest yields. Goulart and Funt (1986) found a “favourable environment” for strawberry growth between −0.02 and −0.04 MPa of soil water potential, and Renquist (1981) obtained maximum yields with a drip irrigation schedule that maintained soil water potential above −0.03 MPa.

Irrigation treatments had no effects on the length of the harvest period, in agreement with the results obtained by Dwyer et al. (1987).

LAI values (Table 2) were not significantly different for all treatments after 132 days of planting (i.e., after 70 days of differential irrigation treatment), but significant differences (p < 0.007) were measured by day 166. At the end of the cropping cycle values of LAI again did not significantly differ between treatments, probably due to a major variability in plots due to the stages of plant aging. In each plot there were some plants that were beginning to lose their leaves and to develop runners and some others that were not. This behaviour can be related to competition with other plants for light and other resources (Zammit and Westoby 1987).

No significant differences in photosynthetic rates, stomatal conductance and transpiration rates were observed. Midday photosynthetic rates for treatments −0.01 and −0.07 MPa were 12.6 ± 1.26 and 11.6 ± 0.75 μmol m⁻² s⁻¹. Midday stomatal conductance and transpiration rates were 1.7 ± 0.20 cm s⁻¹ and 11.4 ± 0.60 μmol cm⁻² min⁻¹ for −0.01 MPa treatment and 1.2 ± 0.09 cm s⁻¹ and 11.6 ± 0.75 μmol cm⁻² min⁻¹ for −0.07 MPa treatment. Thus, reduced leaf area in the low irrigation regimes is what allows water losses to be regul-

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**Table 1. Effects of irrigation treatment on yield, mean fruit weight and number of fruits per plant. Values indicated are the mean ± s.e.m. (n = 16). Significant differences (p < 0.05) are separated by Tukey’s multiple range test**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg m⁻²)</th>
<th>Weight/fruit (g)</th>
<th>Fruits/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>−0.01 MPa</td>
<td>8.3 ± 0.28 a</td>
<td>16.8 ± 0.23 a</td>
<td>76.8 ± 2.36 a</td>
</tr>
<tr>
<td>−0.03 MPa</td>
<td>7.3 ± 0.32 ab</td>
<td>15.4 ± 0.26 b</td>
<td>70.2 ± 3.05 ab</td>
</tr>
<tr>
<td>−0.05 MPa</td>
<td>6.2 ± 0.44 bc</td>
<td>15.2 ± 0.47 b</td>
<td>59.7 ± 2.90 bc</td>
</tr>
<tr>
<td>−0.07 MPa</td>
<td>5.6 ± 0.39 c</td>
<td>13.9 ± 0.36 c</td>
<td>63.4 ± 3.91 bc</td>
</tr>
</tbody>
</table>

**Table 2. Leaf area index at 73, 96, 111, 132, 166, 199 and 231 days after planting (DAP) for each irrigation treatment. Values indicated are the mean ± s.e.m. (n = 12). Means differing significantly are separated within columns by Tukey’s test (p < 0.05)**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>73</th>
<th>96</th>
<th>111</th>
</tr>
</thead>
<tbody>
<tr>
<td>132</td>
<td>166</td>
<td>199</td>
<td>213</td>
</tr>
<tr>
<td>−0.01 MPa</td>
<td>0.71 ± 0.093</td>
<td>1.22 ± 0.156</td>
<td>1.87 ± 0.193</td>
</tr>
<tr>
<td>−0.03 MPa</td>
<td>0.49 ± 0.049</td>
<td>0.97 ± 0.072</td>
<td>1.37 ± 0.108</td>
</tr>
<tr>
<td>−0.05 MPa</td>
<td>0.77 ± 0.066</td>
<td>1.09 ± 0.105</td>
<td>1.58 ± 0.158</td>
</tr>
<tr>
<td>−0.07 MPa</td>
<td>0.67 ± 0.060</td>
<td>1.04 ± 0.123</td>
<td>1.33 ± 0.148</td>
</tr>
<tr>
<td>2.61 ± 0.255</td>
<td>3.96 ± 0.297 a</td>
<td>5.10 ± 0.602 a</td>
<td>4.78 ± 0.515</td>
</tr>
<tr>
<td>1.79 ± 0.139</td>
<td>2.84 ± 0.241 b</td>
<td>3.65 ± 0.291 ab</td>
<td>4.99 ± 0.513</td>
</tr>
<tr>
<td>2.18 ± 0.176</td>
<td>3.07 ± 0.245 ab</td>
<td>4.47 ± 0.459 a</td>
<td>4.28 ± 0.543</td>
</tr>
<tr>
<td>1.98 ± 0.232</td>
<td>2.62 ± 0.305 b</td>
<td>2.55 ± 0.315 b</td>
<td>3.30 ± 0.318</td>
</tr>
</tbody>
</table>
lated by means of reduced radiation interception and a smaller transpiration surface (Jones 1980; Levitt 1980; Nobel 1984; Pruit et al. 1980).

Reduced leaf area in the low irrigation regimes could be explained as a consequence of the sensitivity of cell enlargement to water deficits (Bradford and Hsiao 1982). Strawberry plants cv. Chandler have been shown to use different mechanisms of drought tolerance according to water availability. For example, plants from −0.07 MPa treatment have been shown to use a mechanism of osmotic adjustment, whereas with plants from −0.01 MPa drought tolerance was based on increased tissue elasticity (Pémeulas et al. 1991). High tissue elasticity allows a greater utilization of assimilates and nutrients for growth (Munns 1988), and turgor mediated processes, such as elongation growth or photosynthesis (Bradford and Hsiao 1982), are less affected than under lower elasticities.

Thus, differences in yield between treatments manifested by both the reduction in the number of fruits per plant and the reduction in total assimilation rates were a consequence of a reduction in assimilatory surface area (Pruit et al. 1980; Jones 1980) at lower irrigation regimes, which has been defined as drought stress avoidance mechanism (Levitt 1980).

Water use efficiency

Water use efficiency, WUE, (Hillel and Guron 1975) is defined as the ratio between dry matter production and transpired water. In this study WUE is expressed as fruit fresh yield per water transpired. Water use efficiency was 14.67, 17.23, 20.76 and 17.90 g l⁻¹ from −0.01 to −0.07 MPa treatments, respectively.

The lysimeter system used was protected from ground-water intrusion, mulch avoided direct evaporation from soil, and there was no variation of soil water content because the amount of water applied at the last irrigation recharged the soil profile to reach the initial conditions. Thus the water added to the lysimeters minus drainage provided a valid estimate of transpiration (T).

Transpiration was greater when irrigating at higher soil matric tensions probably due to a greater leaf area index. Water use by strawberry irrigated during the entire growing season at soil water tension of −0.01 MPa was 566 mm. Transpired water in treatments −0.03, −0.05 and −0.07 MPa was 424, 299 and 313 mm, respectively.

The maximum water consumption found was greater than the 368 mm reported by Giovanardi and Testolin (1984) for strawberry cv. Gorella irrigated at −0.04 MPa giving a total yield of 28.2 t ha⁻¹. Yields in our experiment were also higher. Differences can be attributed to different water use efficiencies of those cultivars.

Crop water production functions

To evaluate the sensitivity of the strawberry crop to soil moisture deficit, yield (Y) response factors were calculated as the ratio between relative yield decrease (1 − Y/YN) and relative transpiration (T) deficit (1 − T/TN).

Subindices a and m indicate the actual and the maximum value observed. The relative basis is used to allow comparison with production functions developed in other years or climate conditions (Doorenbos and Kassam 1979). As strawberries were grown under plastic mulch, evaporation from soil could be considered zero. Crop water function was developed from combined data of the eight lysimeters and describe the response of total fruit fresh yield per m² to relative T. K_y, the slope of the linear relationship:

\( 1 - \frac{Y}{YN} = K_y \cdot (1 - \frac{T}{TN}) \)

was

\[ K_y = 1.01 \pm SE 0.083 \quad (r^2 = 0.77, n = 7, p < 0.05) \]

Lysimeter conditions were different from the whole crop ones. Fruit yield was depressed in lysimeters. The percentual reduction of yield when compared to the respective treatment for the soil grown plant was 93, 77, 57 and 76%, for treatments −0.01, −0.03, −0.05 and −0.07 MPa, respectively. Confined conditions reducing soil aeration might have caused these reductions in yield. Also the disturbed soil structure and diminished suction in lysimeters may have affected strawberry growth, thus making suspect the results based on lysimeter data.

Giovanardi and Testolin (1984) reported K_y values of 1.38 for cv. Gorella and Belrubi, also using the fruit fresh yield. Differences can be attributed to different responses of cultivars to water shortage, Gorella and Belrubi being some 38% more sensitive than Chandler to water deficits. In a previous study on water relations of three strawberry cultivars, Chandler showed a higher drought resistance (Savé et al. 1987) than Fern and Pajaro cultivars.

Conclusions

Correct irrigation management can improve strawberry yields as strawberry plants show large responses to water stress, even if it is mild. The experimental yields obtained were 150 to 250% larger than those obtained by strawberry growers in Coastal Catalonia. In the reported study, irrigation scheduling at −0.01 MPa was the most productive treatment. Differences in yield were manifested in a reduction in the number of fruits and their weight due to a reduced total assimilation rate under lower soil water potentials. The use of tensiometers to schedule irrigation is recommended as a means of improving yields in the area, even at the highest range in soil water potentials. Strawberry cv. Chandler showed large yield responses to water shortage even to a mild water stress.

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References