Effects of crop load on tree water use in apple (*Malus x domestica* Borkh.)

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Summary: Sap flow rate measurements were carried out during two consecutive ('on' and 'off') years in an apple orchard cv. 'Florina'/M.26 to analyse the effects of various crop load on tree water use. Sap flow rate was measured by thermal dissipation method in trunks of nine trees from June to the harvest. Crop load was between 0.2–9.0 fruits · cm^{-2} of trunk cross section area (equal to 0.5–35.0 fruits·m^{-2} of leaf area), trunk diameter varied between 4.7–8.7 cm.

Total leaf area was estimated by leaf counting or using shoot girth and leaf area relationship. In both years, fruit growth rate was determined by measuring diameter of 280 marked fruits with 7 days frequency. Fruit volume calculated as a function of fruit diameter based on a previously determined relationship.

Total leaf area of trees ranged from 4.4 to 19.5 m^2 and it was closely related to trunk cross section area. At high crop load the fruit growth rate peaked in August with 0.5 l·$tree^{-1}$·day^{-1} and the leaf area specific total fruit volume reched 6 l·m^{-2} before the harvest.

There was a linear relationship between total leaf area and daily water use, while the leaf area specific water use was influenced by crop load rate. The relationship was described by piecewise linear regression with the breakpoint at crop load rate of 12 fruits·m^{-2} of leaf area. At low crop load the slope of the fitted regression line was less than at high crop load rate.

Key words: sap flow rate, leaf area, fruit growth

Introduction

Plant water balance is closely related to mineral nutrition of fruit trees. Plants take up just all the nutrients as water solution, and water flow is essential in the long distance ion transport inside the plants. Both the water balance and nutrition status are in relationship with vegetative growth and crop yield. Furthermore, in the horticultural practice the integrated process of fertilization and irrigation called 'fertigation' is common in high-density orchards.

In commercial orchards (mainly in orchards established with alternate bearing varieties) crop load is the main factor modifying actual growth vigour of trees. Accurate irrigation scheduling is the most important factor to avoid water wasting and injurious environmental impact (nutrient leaching) in irrigated orchards. Many irrigation scheduling models include an 'irrigation threshold' based on the drought sensitivity or water demand of the orchards. Foliage area (or the leaf area index) is the most common factor considered as a 'water demand factor'.

Reliable and detailed information about interactions between plant water use, vegetative and reproductive growth is essential to describe the relationships between these processes and plant nutrition. The aim of this study was to characterize the relationship between crop load and tree water use in apple.

Material and method

The experimental orchard was established by the Research and Extension Centre for Fruit Growing, Újfehértó, in NE Hungary. Trees of apple cv. Florina/M.26 (*Malus* x *domestica* Borkh.) were planted in the spring of 1994 at a spacing 5 by 2 m, into a sandy soil with low humus content (<1 %). Trees were trained as free spindle ones. The average crop load was 15 kg/tree in 1998 and it was only 3 kg/tree in 1999. Irrigation and fertigation were carried out with a drip irrigation system.

Sap flow velocity was determined in trunks of 6 trees by thermal dissipation method after *Granier* (1985) using 3x30 mm probes. Data were recorded continuously with a PC at 5 min intervals. The measurements started on 20th May and ended on 30th September in 1998, and started on 5th May and ended on 5th October in 1999. The data set was not continuous for some trees because of some breakdowns of the instrument, therefore data set of 5 trees from 1998 and 4 trees from 1999 were used to the calculations.

The length of 80 elongated shoots (2–2 shoots in 40 selected trees) was measured in every week between May and September in 1998 and 1999. In 1998 in the first week of July the number of spur-leaves and shoot-leaves was counted in 20 selected trees. At this time the total leaf area of selected elongated shoots and five randomly chosen spurs was measured in the selected 20 trees with a CI-203 Laser Area Meter (CID, Inc.). The total spur-leaf and shoot-leaf area of trees was computed as a product of average leaf area and the number of leaves. In 1999, because of the large tree size there was no more possibility for counting all the leaves of the canopy, therefore the relationship between foliage area of branch and branch girth area was determined in the first week of July, and measuring girth area of all the branch of trees was used for estimating foliage area of trees (*Angelocci & Valancogne*, 1993). The foliage area of trees for other days of the season was estimated using the equation of *Lakatos & Bubán* (2000).

The diameter of 280 selected fruits (7–7 fruits in 40 trees) was measured in every week from June to the harvest in 1998 and 1999. The fruit volume was estimated by the equation of *Assaf* et al. (1982). The growth of fruit volume was described by the expolinear model of *Lakso* et al. (1995):

$$W = \frac{C_m}{R_m} \cdot \ln(1 + e^{R_m \cdot (t - tb)})$$

where W is the fruit volume, C_m is the maximum absolute growth rate (in volume gain per day reached in the linear phase), R_m is the maximum relative growth rate (in volume gain per unit volume per day), t is the time after full bloom in days, tb is the x axis intercept of the linear growth phase.

Results

The relationships between total foliage area and trunk cross-section area was determined on the basis of data set concerning total foliage area of trees during 1998–1999 *(Fig. 1)*.

The relative growth rate of total foliage area in 1998 and 1999 was similar, but the vegetative growth in 1999 was more intensive due to the low crop load, so the absolute value of foliage area was threefold more than a year before *(Fig. 2)*. The correlation between crop load and foliage area was –0.82 ($p<0.05$) in trees selected to the sap flow measurements.

Close relationship was proved between total foliage area and daily tree water use. The relationship was described by

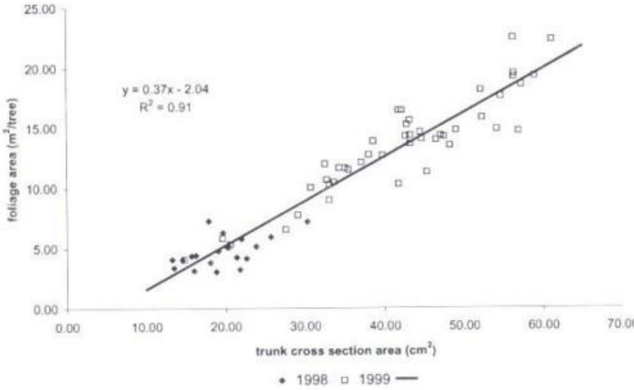

Figure 1 Total leaf area of 'Florina'/M.26 apple trees plotted against trunk cross-section area. Újfehértó, 1998–1999

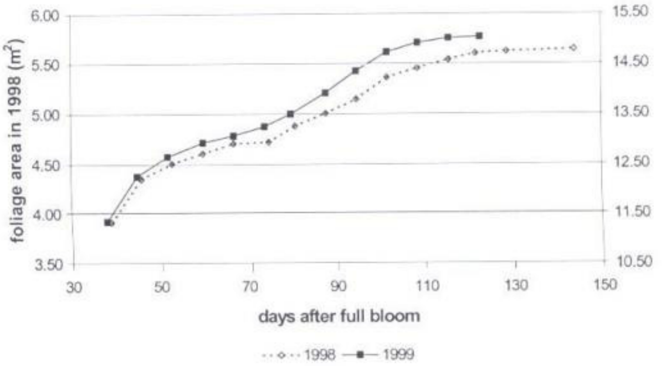

Figure 2 Total foliage area of trees 'Florina'/M.26 (in 1998 n=20; in 1999 n=40). Újfehértó, 1998–1999

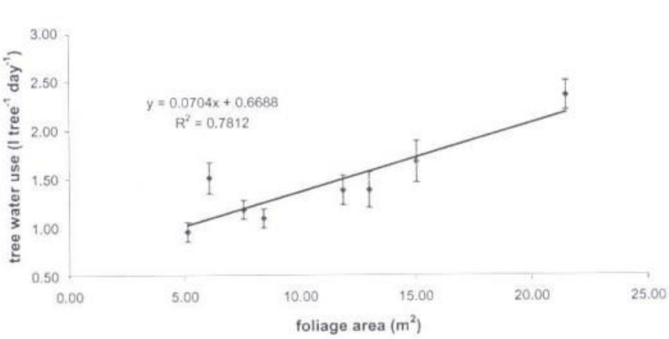

Figure 3 Daily tree water use plotted against leaf area on Florina/M.26. Újfehértó, 1998–1999

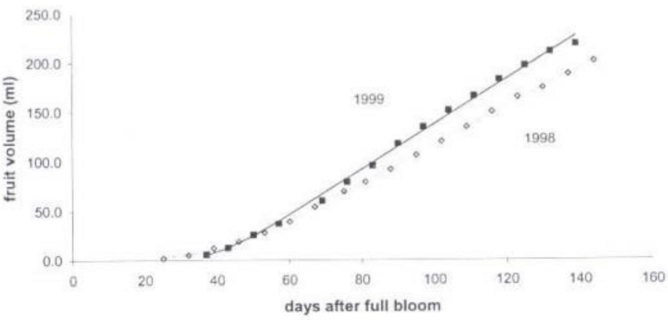

Figure 4 Fruit volume fo apple cv. 'Florina'/M.26 as a funkction of time after full bloom (n=280 in both year). R^2 value of fitted lines $y_{1998}=(1.9449/0.1165) \cdot \ln(1+e^{(x-40)\,0.1165})$ and $y_{1999} = (2.2932/0.1902) \cdot \ln(1+e^{(x-40)\,0.1902})$ are 0.9996 and 0.9972, respectively. Újfehértó, 1998–1999

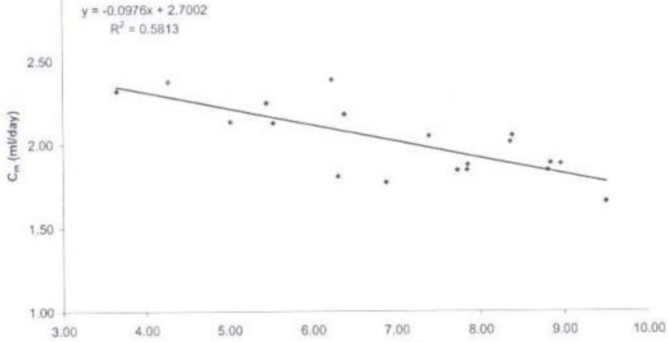

Figure 5 Maximum absolute fruit growth rate (C_m) plotted against crop load (fruits per cm^2 of frunk cross section area). Újfehértó, 1998

a linear model *(Fig. 3)*. The slope of fitted line (which is equal to daily water use of unit leaf area) was 0.070 $l \cdot m^{-2}$ in September, while it was 0.085 $l \cdot m^{-2}$ in June, 0.091 $l \cdot m^{-2}$ in July and 0.102 $l \cdot m^{-2}$ in August.

The maximum fruit growth rate on the Fig. 4 was 1.9 $ml \cdot day^{-1}$ in 1998 and it was 2.3 $ml \cdot day^{-1}$ in 1999 (where the curve of '1998' and '1999' are the average growth curve of all the fruits measured in the given years). The correlation between fruit volume at harvest and crop load was –0.81 in 1998 and it was –0.06 in 1999 ($p<0.001$ and n.s., resp.). Similarly, close correlation could be demonstrated between the maximum absolute growth rate of fruits, C_m and the crop load in 1998 *(Fig. 5*, where C_m values were computed from average fruit growth curves of individual trees). The leaf area unit specific fruit surface area (assuming spherical fruit form) was 0.5 $m^2 \cdot m^{-2}$ on the trees of highest crop load before harvest *(Fig. 6)*.

The relationship between leaf area specific water use and crop load could be described by piecewise linear regression *(Fig. 7)*. At low crop load the slope of fitted line was low, while at high crop load was high. The breakpoint of the model was at 12 $fruits \cdot m^{-2}$ i.e. below this threshold the crop load did not have any influence on leaf area specific water use. When the crop load is higher than this critical value, the slope of fitted line was 5.9 ml • $fruit^{-1}$ • day^{-1}, so every fruit increased the leaf area specific water use with 5.9 ml a day.

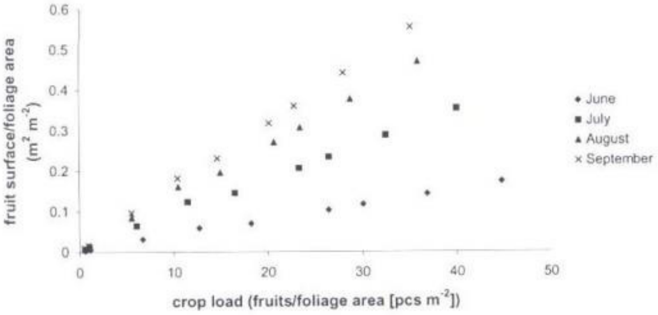

Figure 6 Leaf area specifiv fruit surface area on apple 'Florina'/M.26. Újfehértó, 1998–1999

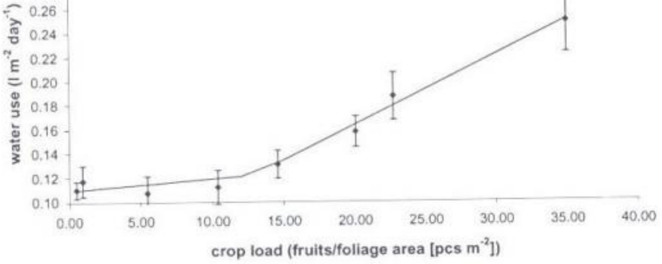

Figure 7 Leaf area specific water use of trees cv. 'Flirina'/M.26 plotted against crop load. Cumulative R2 of fitted lines = 0.9821 (Y=0.1092 + 0.0009 • x and y = 0.0469 + 0.0058 • x). Újfehértó, 1998–1999

Discussion

In a five years old orchard of 'Braeburn'/M.26 *Wünsche* et al. (2000) proved a negative correlation between foliage area and crop load, and a non-linear relationship between tree water use and crop load. Similarly, *Naor* et al. (1997) could not demonstrate any relationships between crop load and fruit size or water supply and fruit size below the crop load value of 200 fruits per tree. Corresponding to these results, our data suggest a combined effects of crop load on tree water use. At higher level of crop load the vegetative growth and total foliage area was low *(Fig. 2)*, i.e. water consumption of trees is low, because there is a close linear relationship between foliage area and tree water use *(Fig. 3)*. On the other hand, heavier crop load corresponds to larger total fruit volume and surface *(Fig. 6)* in spite of lower growth rate of fruits *(Fig. 4–5)*. The resultant of these two contrary effects is a non-linear relationship between tree water use and crop load in a wider range *(Fig 7)*.

The water demand of apple trees depends on crop load above a critical value. In the case of our experimental orchard with density of 1000 trees/ha this critical value was 12 fruits/m^2 of foliage area (which equal to ~120 fruits/tree). The sensitivity of the orchard to drought and water shortage is lower below this critical value or it is affected by other factors. In the range of crop load below the critical value there is a possibility to save irrigation water without any effect of fruit size.

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