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The Response of Nectarine Fruit Size and Midday Stem Water Potential to Irrigation Level in Stage III and Crop Load

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ABSTRACT. **The interactions between irrigation and crop level with respect to fruit size distribution and midday stem water potential were investigated for 3 years in a nectarine (*Prunus persica* L. 'Fairlane') orchard located in a semi-arid zone. Wide ranges of crop loads and irrigation rates in stage III were employed, extending from practically nonlimiting to severely limiting levels. Irrigation during stage III of fruit growth ranged from 0.63 to 1.29 of potential evapotranspiration (ETp). Fruit were hand thinned to a wide range of fruit levels (300 to 2000) fruit/tree in the 555-tree/ha orchard. The yields and stem water potentials from 1996, 1997 and 1998 were combined together and the interrelations among yield, crop load and stem water potential were examined. Fruit <55 mm in diameter growing at 400 fruit per tree were the only ones not affected by irrigation level. The yield of fruit of 60 to 75 mm in diameter increased with irrigation level, but only a slight increase was observed when the irrigation rate rose above 1.01 ETp. A significant decrease in the yields of 60 to 65, 65 to 70, and 70 to 75-mm size grades occurred at crop levels greater than 1000, 800, and 400 fruit per tree, respectively. Midday stem water potential decreased with increasing crop level, and it is suggested that midday stem water potential responds to crop load rather than crop level. Relative yields of the various size grades were highly correlated with midday stem water potential. It was suggested that the midday stem water potential integrates the combined effects of water stress and crop load on nectarine fruit size.**

Fruit size is a major criterion of nectarine fruit quality. Since fruit thinning and irrigation are the two agricultural practices that affect fruit size the most (Berman and DeJong, 1996; Naor et al., 1997a), it is of interest to optimize crop level and water availability to maximize the number of large fruit.

Tree response to deficit irrigation depends on the fruit growth stage (Behboudian and Mills, 1997). Deficit irrigation in stages I and II of fruit growth, did not affect yield (Li et al., 1989), whereas deficit irrigation in stage III decreased fruit size (Berman and DeJong, 1996; Naor et al., 1999) and changed some quality attributes (Chalmers and Wilson, 1978; Li et al., 1989). Crop water consumption in stage III was much higher than that in stage II (Boland et al., 1993; Olsson, 1977) and has reached 120% of the Class A pan evaporation rate. However, fruit size did not respond to irrigation above 100% of Class A pan evaporation (Mitchell and Chalmers, 1982) or above 0.92 of potential evapotranspiration (Naor et al., 1999) in stage III. Irrigation level affects soil water availability (Li et al., 1989; Naor et al., 1999) and, consequently, plant water status (Berman and DeJong, 1996; Naor et al., 1999), shoot growth (Chalmers et al., 1981), stomatal conductance (Naor, 1998) and fruit size (Berman and DeJong, 1996; Boland et al., 1993; Naor et al., 1999).

Peach crop yield can account for 65% to 70% of total tree annual dry matter production (Chalmers and van den Ende, 1975). Peach and nectarine size decreases with increasing crop load (Berman and DeJong, 1996; Blanco et al., 1995; Naor et al., 1999; Rowe and Johnson, 1992; Tukey and Einset, 1938), probably because of source limitation (DeJong and Grossman, 1995). Compared with nonfruiting trees, fruiting nectarine trees often have greater stomatal conductance (Chalmers et al., 1983; DeJong, 1986a, 1986b) and higher assimilation rates (Chalmers et al., 1975; Crews et al., 1975; DeJong, 1986b), probably partially to compensate for the increased assimilate demand.

Assimilation rate and midday stem water potential of stressed peach trees, decreased with increasing crop level, probably because new root tip production decreased in the heavily crop-loaded trees (Berman and DeJong, 1996), but Naor et al., (1999) reported no decrease in midday stem water potential at similar crop levels to those studied by Berman and DeJong (1996). Differing canopy sizes and, therefore, different crop loads were hypothesized as accounting for the contradictory results.

The objectives of the present investigation were to study how the yield, fruit size and stem water potential are affected by irrigation rates in stage III of fruit development and by crop load, both of them over ranges extending from practically nonlimiting to severely limiting levels.

Materials and Methods

The first 2 years of this experiment have already been reported (Naor et al., 1999).

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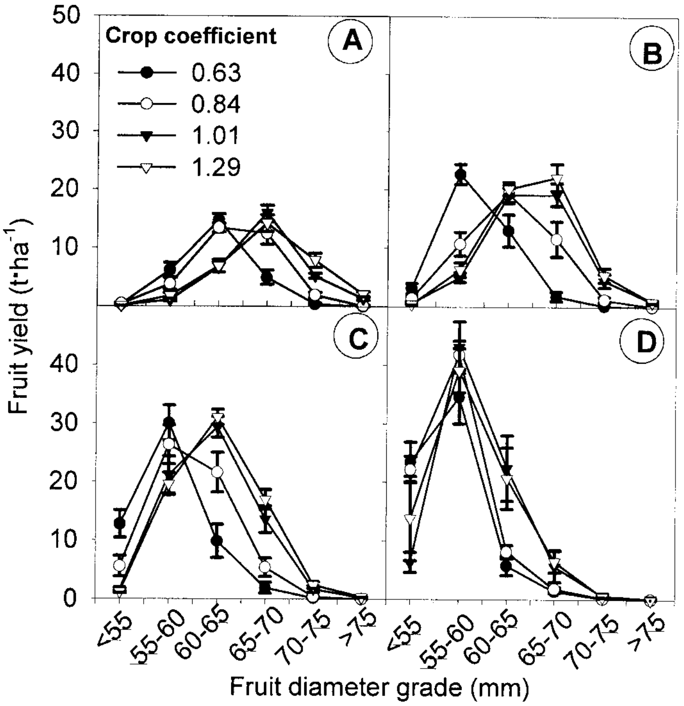

Fig. 1. Fruit size distribution of Fairlane nectarine in the four crop coefficients (fraction of ETp) in the years 1996–98. The four graphs represent crop levels of 399 (**A**), 697 (**B**), 1070 (**C**), and 1490 fruit per tree (**D**). Bars denote standard error.

Climatic conditions. The experimental site was in the northern Galilee, Israel (33°N, 36°E), 350 m above mean sea level, which is a semi-arid zone with no summer rain. The average annual precipitation (October–April) in this area is about 550 mm.

Experimental orchard. The experimental plot was an 8-year-old, drip-irrigated, commercial orchard of 'Fairlane' nectarine on *Prunus persica* seedling rootstock spaced at 4 × 4.5 m. The soil fraction comprised of 57% clay, 35% silt, and 8% sand. The irrigation system consisted of two lateral lines per row, separated by 1.0 m apart, with 2.3-L·h^{-1} pressure-compensated in-line drippers (Netafim, Israel), spaced at 1.0 m.

Statistical design. The experiment was a split-plot factorial design, with four irrigation levels as main plots and crop level as subplots. The treatments were replicated randomly five times. Each main plot (irrigation treatment) consisted of six adjacent rows with three trees each. The four inner trees were used for the crop-level treatments.

Treatments. The experimental plot was irrigated until the end of stage II, according to commercial practice: irrigation was started by the end of April at 0.33 of potential evapotranspiration (ETp), and was gradually increased to 0.55 ETp at the end of stage I (beginning of June). Irrigation during stage II (beginning of June until mid-July) was 0.62 ETp. Differential treatments were applied in stage III. Irrigation rates after harvest were reduced to 0.55 ETp. The experimental plot was irrigated daily in stage III except for weekends, when there was a 2-d interval. Four irrigation levels were implemented in stage III in 1998: 0.63, 0.86, 1.00, and 1.31 of ETp. The fruit on the four inner trees in each irrigation (main) plot were counted in the first week of June and hand-thinned to four fruit levels: 200 to 500, 500 to 800, 800 to 1100, and 1100 to 1500 fruit/tree. Fruit thinning was found not to have been sufficiently accurate; therefore, the actual fruit levels (200 to 2000) measured at harvest were used for data analysis.

Crop measurements. The fruit from the experimental plots were harvested at the beginning of September 1998 (two selective pickings, according to size (>60 mm in diameter), and color). The fruit of each tree were weighed, and their size distribution was determined by means of a commercial grading machine (50 to 85 mm in diameter).

Stem water potential measurements. Midday stem water potential was measured with a pressure chamber. Two shoot tips per tree were sampled from the inner part of the canopy; they were enclosed, while still attached, in plastic bags covered with aluminum foil. After an equilibrating period of 90 min, the shoot tips were detached from the shoot, and stem water potential was determined immediately in the field with a pressure chamber (Ari-Mad, Kfar Charuv, Golan Heights, Israel). The two measurements were averaged for statistical analysis. Stem water potential measurements were usually taken from the trees near to the installed tensiometers. Midday stem water potential measurements were taken on three, four, and seven dates in 1996, 1997, and 1998, respectively. On two occasions in 1996 and 1998, measurements were taken in all crop levels of the highest and the lowest irrigation level treatments.

Statistical analysis. The average midday stem water potentials from August 1 to harvest each year were analyzed by Analysis of Variance followed by Duncan's multiple range test, by means of the SAS GLM (SAS Institute, Cary, N.C.) procedure.

The crop yield data and average midday stem water potential from 1 Aug. to harvest of 1996, 1997 (Naor et al., 1999), and those of 1998 (current year) were pooled together. The pooled data set of the 3 years comprised of 232 out of 240 possible records, because of missing data. The range of fruit was divided into six subgroups, and averages and standard errors of the yield were calculated for each subgroup. These calculations were used for the analysis of the relationships between the yields of the various sizes, and crop level.

The range of midday stem water potential was divided into seven subgroups, and averages and standard errors of midday stem water potential and the crop yield were calculated for each subgroup. These calculations were used for the analysis of the relationships between yields of different sizes and midday stem water potential.

Results

Irrigation. Cumulative irrigation during stage III of fruit growth in 1998 ranged from 197 to 411 mm and daily irrigation rates ranged from 4.6 to 9.6 mm. The average crop coefficients in

Table 1. Average midday stem water potential from Aug. 1 to harvest in 1996–98 in the four crop coefficient treatments (fraction of potential evapotranspiration), and average fruit per tree in those trees that weren used for stem water potential measurements.

Crop coefficient	1996	1997	1998
0.63	–2.06 c^{z}	–2.07 c	–2.36 b
0.84	–1.55 b	–1.69 b	–2.16 b
1.01	–1.42 ab	–1.29 a	–1.84 a
1.29	–1.26 a	–1.21 a	–1.62 a
Fruit per tree	654	664	1217

^{z}Results followed by different letters differ significantly, $p = 0.05$

the three years of the experiment were 0.63, 0.84, 1.01, 1.29 in the four irrigation treatments. Those crop coefficients are used in the Discussion, to designate the irrigation treatment when the data from the three years were discussed.

Fruit size distribution. The fruit size distributions of the two highest irrigation treatments were similar at all crop levels (Fig. 1). Almost no fruit larger than 75 mm in diameter were apparent, even at the lowest crop level. The 0.63 and 0.84 treatments, at 399 fruit per tree (Fig. 1A) had similar fruit size distribution except for larger yield in the 0.84 treatment at the 65 to 70-mm size grade. Fruit size of all treatments was shifted toward smaller fruit with increasing crop level to 697 fruit per tree (Fig. 1B), where it was more pronounced in the lowest irrigation treatment. All irrigation treatments had practically no fruit >70 mm at 1070 (Fig. 1C) and 1490 fruit per tree (Fig. 1D). The maximum yield frequency in the two highest irrigation treatments was in the 65 to 70 mm, 60 to 70 mm, 60 to 65 mm, and 55 to 60 mm size grades at the 399, 697, 1070 and 1490 fruit per tree. All irrigation treatments had similar maximum yield frequency at 1490 fruit per tree (Fig. 1D) where the distribution of 0.63 and 0.84 treatments was tended toward smaller fruit size, and that of the 1.01 and the 1.29 treatments was tended toward larger fruit size (Fig. 1D).

Stem water potentials. The midday stem water potential decreased with decreasing irrigation level in all three years (Table 1); The midday stem water potential, within each treatment, were similar in 1996 and 1997 and that in 1998 were lower (Table 1).

The effect of irrigation and crop level on midday stem water potential. The midday stem water potential (SWP) was highly correlated with crop coefficient (K_C) and crop level (N_{TOT}) (Fig. 2) in a multiple regression (SWP = $-4.12 - 0.000000233 \times N_{TOT}^2 + 4.71 \times K_C - 1.91 \times K_C^2$; $r^2 = 0.82$), where all the parameters were highly significant ($P = 0.0001$).

Total yields of the highest irrigation level in 1996 and 1998 and that of the well irrigated trees studied by Berman and DeJong (1996) were plotted together (Fig. 3). The planting densities in the two studies were different, therefore the data was presented on a per hectare basis. Total yield in both 1998 and that of Berman and DeJong, (1996) deviated markedly from linearity at high crop level where that in 1996 was linear.

The relative yields at different size grades were highly correlated with midday stem water potentials (Fig. 4). The relative yield curve for fruit larger than 55 mm leveled off at midday stem water potentials higher than –1.7 MPa; that for fruit larger than 60 mm started leveling off at midday stem water potentials higher than –1.3 MPa, and its maximum extrapolated value (from the regression analysis) was 93%; the relative yield of fruit larger than 65 mm did not start leveling off, but its maximum extrapolated value was 72%. Fifty percent of the total yield comprised fruit larger than 55, 60, and 65 mm, at midday stem water potentials of –2.56, –1.99, and –1.54 MPa, respectively.

Discussion

Yield and irrigation-level interactions. The decrease in fruit size with decreasing irrigation rate (Fig. 1) indicates source limitation (DeJong and Grossman, 1995) caused by water stress, which could be explained in terms of reduced assimilation rate (Berman and DeJong, 1996) due to lower stomatal conductance (Naor, 1998). Also the possibility of a decrease in fruit turgor because of water stress could not be excluded. The two highest irrigation rates had similar yields. This may indicate that an additional increase in irrigation rate, in this particular orchard, would not be expected to increase fruit size dramatically.

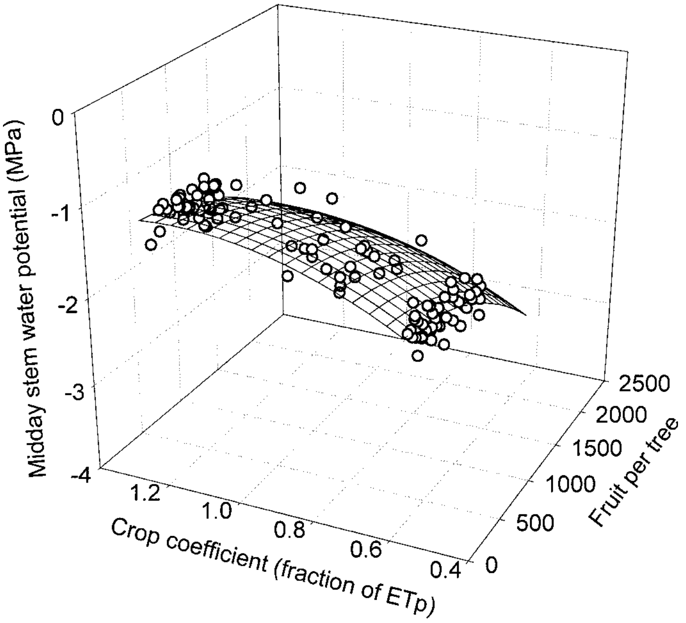

Fig. 2. Midday stem water potential in 1996, 1997, and 1998 as a function of the number of fruit per tree and crop coefficient (fraction of ETp). Both the data and the predicted values by a multiple quadratic regression analysis ($r^2 = 0.82$; n = 122) are presented.

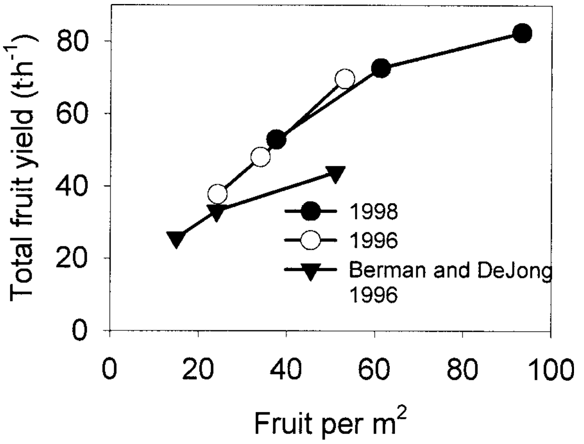

Fig. 3. Total yield in the highest irrigation level in 1996 and 1998, and total yield of well-irrigated trees (Berman and DeJong, 1996), as a function of the number of fruit per unit area of soil.

Stem water potential and yield interactions. The combined data from 1996, 1997 and 1998 shows that midday stem water potential decreases with increasing crop level (Fig. 2). However, the quadratic relationships (Fig. 2) shows that the effect of crop level on midday stem water potential decreases with decreasing crop level, and it explains why the 1996 data (Naor et al, 1999) was found not to be sensitive to crop level.

The midday stem water potential of stressed trees was reported to be sensitive to crop level (Berman and DeJong, 1996) at similar crop loads (on a per hectare basis) where no correlation was apparent in the present study in 1996 (Naor et al, 1999). The yield curve in the current study in 1998 and in the findings of Berman and DeJong (1996) deviated from linearity (Fig. 3), indicating a higher crop load, which means that there was a source limitation

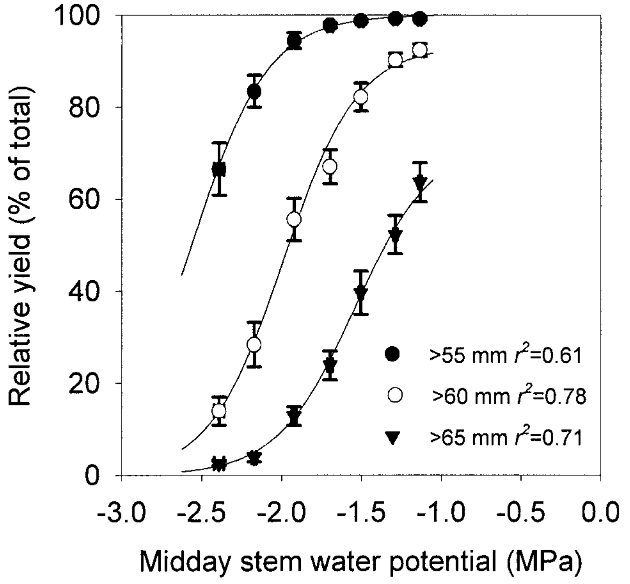

Fig. 4. Relative yields of fruit greater than 55, 60, and 65 mm in diameter as a function of average midday stem water potential from Aug. 1 to harvest. Bars denote standard error. The data include all three years (1996–98). The lines are sigmoids that were fitted to the raw data (n = 122).

(DeJong and Grossman, 1995). The decrease in midday stem water potential in the present study in 1998 (not shown) and data from Berman and DeJong (1996) were associated with high crop load, where it did not respond to the number of fruit per tree when the crop load was lower (Fig. 3). These may suggest that the midday stem water potential decreases with increasing the number of fruit per tree once the tree experience a source limitation (Fig. 3).

The effect of crop level on midday stem water potential (Fig. 2) may explain most of the differences between midday stem water potential between years (Table 1). Maximum daily vapor pressure deficits in the measurement days in 1998 were consistently higher by 0.5 kPa than that in the former two years. It may also account in a small part for the lower midday stem water potential in 1998 than in the former years (McCutchaan and Shackel, 1992).

Our data show a combined effect of irrigation and crop load on midday stem water potential, with the latter being highly correlated with relative yield (Fig. 4). It seems that midday stem water potential integrates the effects of irrigation and crop load on fruit size.

STEM WATER POTENTIAL AND IRRIGATION SCHEDULING. The lower midday stem water potentials in 1998 (Table 1) were associated with crop levels that are much higher than common crop levels in commercial orchards. Therefore, the consistent midday stem water potentials in 1996 and 1997, which represent common commercial crop levels, indicate that midday stem water potential may serve as an indicator for irrigation scheduling.

The midday stem water potential under the highest irrigation rate in the present study was much lower than those reported for well-irrigated nectarine (Berman and DeJong, 1996) and other deciduous trees (Shackel et al, 1997). The lower midday stem water potential in the present study is associated with soil profiles high in clay mineral contents (57%), and with high soil moisture content in the root zone (Naor et al, 1999). The same was apparent in pear trees growing in a deep, high in clay soil profile (Naor et al, 2000). This suggests that there may be some limitation in the water absorption capacity of the root system in this soil, which could be related to lower oxygen fluxes into the root zone, or to mechanical resistance to root growth. It may well be that the rootstocks also play a role in determining water absorption capacity. A severe water stress in stage II of fruit growth (not shown) due to low irrigation rate (0.55 Kc) might have harmed the roots, which might have resulted in a decreased water absorption capacity.

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