Original article

Water stress and crop load effects on yield and fruit quality of Elegant Lady Peach [*Prunus persica* (L.) Batch]

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Abstract — Introduction. Fruit production is faced with water shortage, especially in areas with a Mediterranean climate characterized by a very long, dry and hot summer. Thus, the growers under such conditions must manage irrigation carefully by finding new strategies, including water stress management. **Materials and methods**. Effects of water stress (WS) and crop load (CL) on the carbon assimilation rate, fruit growth, crop yield and fruit quality (size and soluble solids content) were evaluated in a 7-year-old 'Elegant Lady' peach orchard (Winters, California, USA). The experimental design consisted of a completely randomized block factorial design with 2 × 3 factors: irrigation with two levels (control and WS trees) and crop load with three levels (light, commercial and heavy). **Results and discussion**. Both CL and WS affected fruit growth during the last stages but not early on. Crop load did not affect trunk water potential (TrWP) which, however, was significantly reduced by WS throughout the day and the season. The stomatal conductance (g_s), transpiration rate (E) and CO_2 assimilation rate (A) were not affected by CL, but they were reduced by WS. There were poor correlations between TrWP and either g_s or A in control trees, indicating relatively poor coordination between leaf functions in peach trees under optimal conditions. Both WS and CL delayed the harvest date through their effect on ripening. Water stress significantly reduced the average crop fresh yield but hardly affected crop dry yield. Both WS and CL affected the distribution of fruit size categories, with the proportion of large fruit decreasing with the increase in crop load and the severity of WS. **Conclusion**. Water stress reduced fruit fresh weight and fruit fresh yield but not fruit dry weight or dry yield. Crop load reduced fruit fresh and dry weights and yields. Crop load had a negative effect on soluble solids content, while WS had a positive effect. Thus, CL reduced fruit size and soluble solids content, while WS reduced size but improved soluble solids concentration.

USA / *Prunus persica* / drought stress / plant water potential / photosynthesis / fruit / growth / yield / sugars

Effets du stress hydrique et de la charge de l'arbre sur le rendement et la qualité des fruits du pêcher Elegant Lady Peach [*Prunus persica (L.)* Batch].

Résumé — Introduction. La production fruitière est confrontée au manque d'eau particulièrement dans les régions méditerranéennes caractérisées par un très long été sec et chaud. Dans de telles conditions, les arboculteurs doivent soigneusement contrôler l'irrigation en trouvant de nouvelles stratégies incluant la gestion du déficit hydrique. **Matériel et méthodes**. Les effets du stress hydrique (SH) et de la charge de l'arbre (C) sur le taux d'assimilation du carbone, la croissance du fruit, le rendement à la récolte et la qualité du fruit (calibre et teneur en solides solubles) ont été évalués en verger de pêchers 'Elegant Lady' âgés de 7 ans (Winters, Californie, USA). Le dispositif expérimental a consisté en un schéma factoriel de blocs complètement randomisés avec 2 × 3 facteurs : facteur irrigation (avec (témoin) ou sans SH) et facteur CR (charge faible, commerciale ou forte). **Résultats et discussion**. Les deux facteurs CR et SH ont affecté la croissance du fruit pendant les derniers stades mais pas au début. La charge de l'arbre n'a pas affecté le potentiel en eau du tronc (PETr) qui, cependant, a été sensiblement réduit par le SH tout au long du jour et de la saison. La conductance stomatique (C_g), le taux de transpiration (T) et le taux de l'assimilation de CO_2 (A) n'ont pas été affectés par la charge, mais ils ont été réduits par le SH. Il y a eu de faibles corrélations entre PETr et C_g ou PETr et A dans des arbres témoins indiquant une coordination relativement faible entre les fonctions de la feuille dans des pêchers placés en conditions optimales. Les deux facteurs CR et SH ont retardé la date de la récolte par leur effet sur la maturation. Le stress hydrique a réduit de manière significative le rendement moyen de la récolte en fruits frais mais il a peu affecté le rendement de récolte en poids sec. Les deux facteurs CR et SH ont affecté la répartition des fruits par catégorie de calibre, la proportion de grands fruits diminuant avec l'augmentation de la charge de l'arbre et la sévérité du stress hydrique. **Conclusion**. Le stress hydrique a réduit le poids frais des fruits et le rendement en fruits frais mais pas le poids sec ou le rendement en poids sec. La charge de l'arbre a réduit le poids frais et secs des fruits ainsi que leur rendement. Elle a eu un effet négatif sur la teneur en solides solubles tandis que le stress hydrique avait un effet positif. Ainsi, la charge de l'arbre a réduit le calibre du fruit et la teneur en solides solubles tandis que le stress hydrique réduisait le calibre mais améliorait la concentration en solides solubles.

États-Unis / *Prunus persica* / stress dû à la sécheresse / potentiel hydrique des plantes / photosynthèse / fruit / croissance / rendement / sucres

1. Introduction

Vegetative and fruit growth in fruit trees are differentially sensitive to water deficit during the season, depending on the stage of fruit growth. Withholding irrigation limited shoot growth and stimulated subsequent fruit growth in 'Golden Queen' peach [1]. Both vegetative and fruit growth declined as irrigation quantity decreased during the period of rapid vegetative growth of 'Golden Queen' peach trees [2].

Water stress significantly reduced the leaf stomatal conductance (g_s) and transpiration rate (E) without affecting the CO_2 assimilation rate (A) in peach [3]. The leaf water potential of the stressed plants was 0.2–0.3 MPa lower than that of the controls from noon on. Similarly, the daily mean leaf water potential was lower in dry than in irrigated peach trees [4].

Regulated deficit irrigation reduced soil and predawn leaf water potential, stomatal conductance, net CO_2 assimilation and trunk growth in 'Cal Red' peach trees [5]. Blanco *et al.* [6] reported that shoot length, fresh and dry weight, and the relative increment in trunk girth were reduced as the level of crop load increased in 'Catherine' peach trees.

Water deficit during the first phase of rapid fruit growth significantly increased fruit size at harvest in peach [7]. Similarly, stress applied in the first stage of fruit growth induced an increase in fruit size if normal water supply was insured during the remaining stages of fruit growth in peach [8]. However, smaller fruits were produced when water deficit was imposed throughout the fruit development period, or during the final accelerated fruit growth phase. The last stage of very active fruit growth prior to harvest is very critical and remains sensitive to water shortage, which leads to a reduction in fruit size and yield.

The water status of well-watered 'Elegant Lady' peach trees was independent of crop load [9]. In trees receiving reduced irrigation, the degree of water stress increased with increasing crop load. Water stress reduced fruit fresh weight at all crop loads, but did not affect dry fruit weight in trees with light to moderate crop loads in peach. However, water stress significantly reduced fruit dry weight in trees with heavy crop loads (unthinned). CO_2 uptake and stomatal conductance in peach leaves increased during June and July when fruit dry weight accumulation was high [10]. However, there were no significant differences in leaf gas exchange characteristics between fruiting and defruited 'O'Henry' peach trees during the early stages of fruit growth. During the last stage of fruit growth, CO_2 assimilation rates were slightly higher in fruiting than in defruited trees, and they were associated with an increase in leaf conductance [10]. The deficit irrigation treatment induced a higher fruit soluble solids concentration and lower fruit weight in 'O'Henry' peach [11].

In most reports, extreme cases of fruiting and defruited trees were studied, whereas only a few dealt with varied fruit levels. Since both irrigation and crop load affect fruit size and since, in addition, they interact, it is important to study the combined effect of these two factors. Fruit size is a major quality factor of peach production for the fresh market. Since fruit size is affected by crop load and water deficit, it is of economic interest to optimize crop load and water deficit to maximize the number of large fruit.

The objectives of our study were to:

- evaluate the relative influence of cropping (fruit sink demand) on leaf function (A, g_s and E) under fully irrigated and water-stressed conditions,
- use fruit growth potential measurement techniques to assess the influence of water stress on the relative ability of the tree to meet fruit growth demands,
- determine the effects of water stress and crop load on yield and fruit quality in peach.

2. Materials and methods

2.1. Plant material

One hundred and twenty trees, in eight rows, of 7-year-old 'Elegant Lady' peach [*Prunus persica* (L.) Batsch] grafted on 'Lovell' rootstock were selected for uniformity, in a block at the UC Davis Wolfskill experimental orchard, Winters, California. The orchard was planted in a high-density formation [(5.5 × 2) m spacing] and trained to a perpendicular V [12]. Trees received standard commercial dormant pruning and care in terms of fertilization and pest management.

2.2. Irrigation treatments

The experiment was set up in a completely randomized block design with four blocks (half-rows). Eight pairs of adjacent half-rows were selected as blocks. Four half-rows received the control irrigation treatment (CT) and the other four received the water stress (WS) treatment. In order to prevent surface water movement between treatments, the water-stressed treatments were isolated by a border half-row on each side.

Reference evaporation (ET_0) data for Winters, CA, were obtained from the California Irrigation Management System (CIMIS). Irrigation was withheld until mid-June during the first stages of fruit growth, because of the very cool and wet spring. During May alone, the rainfall was 87 mm, of which 56 mm fell during the last four days of the month. The management of irrigation was adapted to the wet conditions and the time necessary, after imposition of water stress, for observable effects on plant water status (*table I*).

2.3. Thinning treatments

Within each irrigation level, the control and water-stressed treatment rows were divided into five sub-plots, consisting of pairs of adjacent trees. Sub-plots were randomly assigned one of three thinning treatments : light crop load (LC), minimum 10 cm between fruit, commercial crop load (MC), minimum 5 cm between fruit (standard commercial fruit spacing and crop load), or heavy crop load (HC), no fruit thinned. Fruit were thinned during the third week of May, 5 weeks after full bloom.

The experimental design consisted of a completely randomized factorial design with 2 × 3 factors: factor A being irrigation with two levels (control and water stress) and factor B being crop load with three levels (light, commercial and heavy).

Table I.
Irrigation (mm) applied for control and water-stressed trees in an experiment carried out in an Elegant Lady peach orchard (Winters, Ca, USA).

Date		Control trees	Water-stressed trees	Evapotranspiration
June	15	33	–	36
	20	–	–	55
	27	47	–	43
July	06	47	–	46
	13	47	–	47
	20	47	12	50
	24	–	12	47
	27	47	12	44
August	03	47	16	47
	10	47	12	–

2.4. Water potential measurements

Water potential was measured with a Scholander Pressure Chamber (Soil Moisture Equipment Co., Santa Barbara, CA, USA). To measure whole-tree water status, weekly measurements of stem water potentials were made in the morning (0830 to 0930 h), at midday (1130 to 1230 h) and in the afternoon (1430 to 1530 h) on shaded leaves, close to the main trunk. The leaves were bagged, with plastic sheaths covered with aluminum foil, for at least half an hour before measurement. This method of water potential measurement eliminates the leaf-to-leaf variability encountered using exposed leaves by measuring a leaf in which water potential has equilibrated with that of the main trunk [13]. Measurements were made at weekly intervals during the last 5 weeks of the fruit growth period.

2.5. Gas exchange measurements

Photosynthetic measurements were made at weekly intervals. Gas exchange was measured three times (morning: 0830 to 0930 h, noon: 1130 to 1230 h and afternoon: 1430 to 1530 h) during the day on intact mature leaves of approximately the same age located in outer, well-exposed portions of the canopy of four trees from each of the six irrigation-thinning treatment combinations. All measurements were made with leaves exposed to direct sunlight above the level required for light saturation of the photosynthetic system. Gas exchange and water potential measurements were taken simultaneously. Gas exchange measurements were made with a CIRAS-1 PP system (619 Primrose Street Haverhill, MA, 01830 USA).

2.6. Fruit growth

Fruit growth was assessed by making weekly measurements of fruit diameter, using a digital caliper, of six fruits per tree of four trees per irrigation-thinning treatment combination. Six fruits (three for each side of the perpendicular V) were randomly selected and tagged on each tree after thinning. At weekly intervals, maximum fruit diameter was measured on each tagged fruit. A sample of 30 fruits from similar trees in the same orchard block was collected at each measurement time to determine the relationship between fruit diameter and fresh and dry weights. Dry weight of fruits was taken following drying of the fruits in a forced-air draft oven at 65 °C until there was no weight decrease. This relationship between fruit diameter and fruit weights was used to convert fruit diameter measurements on the experimental trees into fruit fresh and dry weights.

2.7. Fruit harvest

Fruit were harvested at true maturity in order to evaluate the specific effects of water stress and crop load on the ripening date, fruit development period and fresh and dry yield. The fruits were picked on three harvest dates: July 29, August 5 and August 12. Harvest dates were calculated using a weighted average of the relative number of fruits picked on each of the three harvest dates. On each picking date, all fruits removed from each tree were weighed to obtain the total crop fresh weight for each tree. The total number of fruits harvested per date were counted and sorted per size category. The number of fruits per size category was recorded and a sample of 20 fruits was collected. A sub-sample of 10 of the 20 fruits was weighed to determine average fruit fresh weight per size category prior to drying at 65 °C in a forced-air draft oven. The fresh weight/dry weight ratio of the sub-samples was used to calculate the total dry crop yield for each tree. The average fresh and dry weight per fruit was calculated by dividing total crop fresh weight and total dry weight by total fruit number. The remaining 10 fruits per size category were used to measure soluble solids content (SSC), with three replicates for each measurement, using a digital refractometer. For each fruit a sample wedge was cut from stem to blossom end and to the center of the fruit to account for variability in SSC from the top to bottom and inside to outside of the fruit. Wedges were then juiced with a juice extractor using cheesecloth to remove pulp from the juice.

2.8. Data analysis

The data were analyzed by a two-way analysis of variance as a 2 × 3 factor factorial design in a randomized complete block design for general variance. The mean separation was performed using Duncan's multiple range test at a significant level of $P < 0.05$.

3. Results and discussion

3.1. Fruit growth

The growth curve of the fruit on stressed trees lagged behind that of the control. The effect of water deficit on fruit growth could be explained by insufficient water for cell elongation, through which the fruit insures its growth during the last stages and/or limited photosynthesis, leading to a shortage in photosynthates. The trees with heavy crop were source-limiting (high fruit competition) and could not provide enough photosynthates to insure the appropriate growth required to obtain good fruit size. Thus, the trees with increasing crop load and exposed to water stress were source-limiting, which led to a reduction in fruit growth [14].

3.2. Water potential

No interaction was detected between irrigation and crop load concerning trunk water potential (TrWP) for the entire season, regardless of the time of measurement. TrWP of water-stressed trees was significantly lower than that of control trees beginning in the morning, and remained so throughout the day and the season. The TrWP of water-stressed trees was lower than that of control trees in the morning, noon and afternoon and remained so for all dates of measurement [14]. The seasonal pattern of midday TrWP showed a clear distinction in the trend between water-stressed and control trees, independent of crop load.

3.3. Stomatal conductance

Stomatal conductance (g_s) of water-stressed trees became significantly lower than that of control trees during the late stage of fruit growth, as the season progressed and the severity of stress increased [14].

3.4. Transpiration rate

The transpiration rate showed a similar trend to stomatal conductance by decreasing as the season progressed and the severity of stress increased [14].

3.5. Photosynthesis

Starting July 9, the assimilation rate in water-stressed trees was significantly lower than that of control trees [14]. The magnitude of the difference existing between the two irrigation regimes increased as the season progressed. The assimilation rate of the water-stressed trees decreased from 80% of the control on July 9 to 56% on the following dates of measurement of July 16 and 23. Crop load did not affect the assimilation rate in either irrigation regime [14].

3.6. Relationship between TrWP, g_s and photosynthesis

There were very poor correlations between TrWP and either g_s or photosynthesis (P_n) in control trees. This indicates that under optimal conditions there is very poor coordination of the different functions taking place in a peach tree. In contrast, the relationships were of a better type when the trees were experiencing a water shortage [14].

Regarding the TrWP and P_n relationship, similarly to that for TrWP and g_s, it was of the opposite trend in control and water-stressed trees. Thus, in well-watered trees, TrWP is high and is enclosed in a narrow range and so is the assimilation rate, while in water-stressed trees both TrWP and P_n are low, and as TrWP continues to decrease so does P_n in response to stress.

On the other hand, there was a close relation between g_s and P_n in both control and water-stressed trees. However, the correlation between the two parameters was much better in trees submitted to water deficit, indicating once again the poor coordination between stomatal conductance and the carbon assimilation rate in peach grown under optimal conditions. This relation tends to be improved as the trees experience some water stress. A better correlation between P_n and g_s in water-stressed trees suggests that, under limiting conditions, the trees would coordinate various functions better, allowing a more efficient use of limited resources and a better adaptation to a harsh environment.

3.7. Harvest date

Both water stress and crop load delayed harvest through their effect on ripening, which was delayed as a consequence of the effect of the two factors on fruit growth, thus reducing its rate and prolonging its duration. The fruit growth on water-stressed trees was slowed down because of high competition among fruit for carbohydrate supply, which was negatively affected by water deficit on unthinned trees. The harvest date did not differ between light and commercial crops,

Table II.
Effects of water regime and crop load on fresh and dry crop yield, and on average fresh and dry fruit weight of Elegant Lady peach (Winters, Ca, USA).

Water regime	Crop load	Crop fresh yield (kg per tree)	Crop dry yield (kg per tree)	Fresh fruit weight (g)	Dry fruit weight (g)
Control	Light	40 c	6.1	185 a	28.2
	Commercial	49 b	7.5	153 b	23.3
	Heavy	67 a	10.2	102 e	15.3
Water stress	Light	29 d	5.4	128 c	23.7
	Commercial	37 c	6.9	115 d	21.1
	Heavy	47 b	8.6	72 f	13.2

Values with different letters in the columns are significantly different according to Duncan's multiple range test at $P < 0.05$.

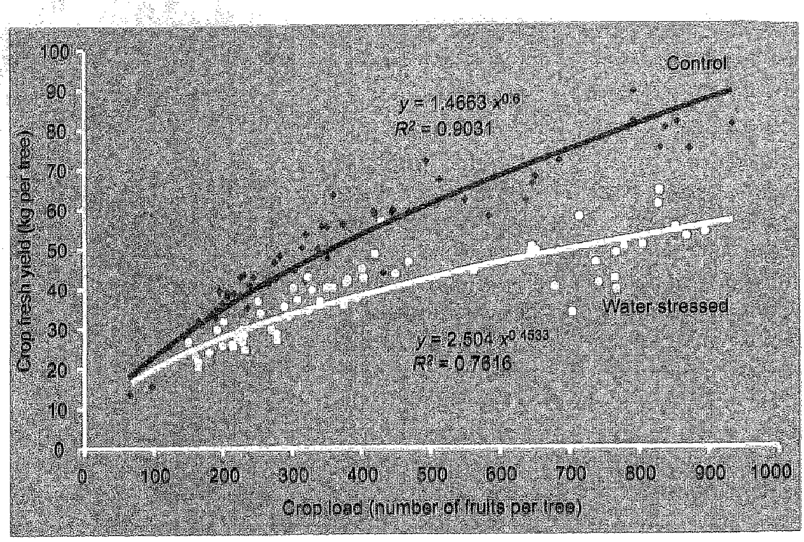

Figure 1.
Relationship between crop fresh yield and crop load for control and water-stressed Elegant Lady peach trees.

while heavy crop load significantly delayed harvest. Thus, trees with light and commercial crop loads were able to insure appropriate fruit growth and carry fruit through the ripening process. In contrast, on unthinned trees and because of high competition, fruit growth was slowed down and ripening delayed.

3.8. Crop yield

There was an interaction between crop load and water stress regarding crop fresh yield (*table II*). There was a significant main effect of water stress, which reduced the average crop fresh yield from 52 kg·tree^{-1} for control trees to 32 kg·tree^{-1} for water-stressed trees, resulting in a reduction of 39% or 12 t·ha^{-1}. Similarly, average crop fresh yield was improved as crop load increased and reached (35, 43 and 57) kg·tree^{-1} or (31, 40 and 52) t·ha^{-1}, respectively, for light, commercial and heavy (unthinned) crops. Thus, total fresh yield increased, as did the fruit number per tree.

For both control and water-stressed trees, the relationship of either crop fresh/dry yield or fruit fresh/dry weight to crop load is best predicted by the logarithmic transformation $y = ax^b$. The relationship of crop fresh yield (kg per tree) to crop load expressed as number of fruits per tree is described by the equations: $y = 1.47\ x^{0.6}$ ($R^2 = 0.90$) for control and $y = 2.54\,x^{0.45}$ ($R^2 = 0.76$) for water-stressed trees (*figure 1*). The accuracy of prediction of this relationship was not improved when crop load was expressed as fruit number per cm^2 and crop fresh yield as g·cm^{-2} of the trunk sectional area, as the equations became $y = 248.84\ x^{0.56}$ ($R^2 = 0.86$) for control and $y = 240.24\ x^{0.38}$ ($R^2 = 0.75$) for water-stressed trees.

In contrast to fresh yield, there was no interaction between water stress and crop load in regard to dry yield. Thus, for a given crop load level, water stress reduced fresh yield through the reduction of hydration but had no significant effect on dry yield. This suggests that the inhibitory effect of water stress on photosynthesis did not affect total dry yield, which was similar for control and water-stressed trees. This suggests that the fruit remained a very strong sink, even under stress conditions, and reduced photosynthesis, which continued to drive most of the carbohydrates synthesized in the leaves. In fact, crop dry yield was 8 kg per tree or 7.23 $t \cdot ha^{-1}$ for the control and 7 kg per tree or 6.36 $t \cdot ha^{-1}$ for water-stressed trees, showing a reduction of only 12% or 1 $t \cdot ha^{-1}$. This limited effect of water stress on dry yield contrasts very much with its significant effect on fresh yield, which was reduced by 38.5% or 18 $t \cdot ha^{-1}$. The relationship of dry yield to crop load is of exponential type and is described by the equations: $y = 0.22\ x^{0.6}$ (R^2 = 0.90) for control and $y = 0.47\ x^{0.45}$ (R^2 = 0.76) for water-stressed trees (*figure 2*). At a low range of crop load (less than 200 fruits per tree), there was no difference between the control and water-stressed trees, suggesting that at low load the crop dry yield is similar for both the control trees and those submitted to restricted irrigation. However, as the crop load per tree increases, the dry yield tends to be higher for control trees than for stressed ones. When crop load is expressed as number of fruits per cm^2 and crop dry yield as $g \cdot cm^{-2}$ the relationship between the two parameters is predicted by the equations: $y = 37.95\ x^{0.56}$ (R^2 = 0.86) for control and $y = 44.15\ x^{0.38}$ (R^2 = 0.75) for water-stressed trees. As can be seen from R^2, the prediction equations were not improved, which indicates that the variability among trees is very small and shows the good homogeneity of the experimental units.

Whether crop load and yield were expressed in relation to the tree or to the trunk cross-sectional area, it appears that, at a low range of crop load (less than 200 fruits per tree or 2.5 fruits per cm^2), the two curves cross each other. This suggests that at this level crop dry yield is not yet affected by water deficit (*figure 2*).

3.9. Fruit weight

Regarding fruit fresh weight, there was an interaction between water stress and crop load. Thus, water stress significantly reduced average fresh weight and so did crop load (*table II*). The relationship of fruit fresh weight to crop load is of exponential type and is described by $y = 218.41\ e^{-0.0011x}$ (R^2 = 0.84) for control and $y = 173.08\ e^{-0.0013x}$ (R^2 = 0.85) for water-stressed trees (*figure 3*). The relationship between the two parameters is very similar in control and stressed trees in terms of the curve shape and R^2. When crop load is expressed as number of fruits per cm^2, the equations become $y = 230.78\ e^{-0.1186x}$ (R^2 = 0.85) for control and $y = 184.4\ e^{-0.131x}$ (R^2 = 0.92) for water-stressed trees, thus showing an improvement in the accuracy of the prediction equation for water-stressed trees but not for the control, reflecting a better use efficiency.

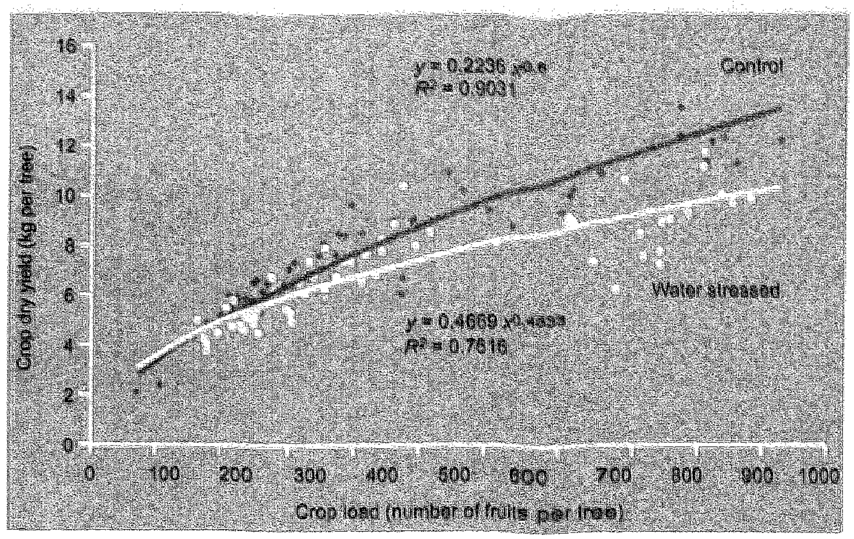

Figure 2.
Relationship between crop dry yield and crop load for control and water-stressed Elegant Lady peach trees.

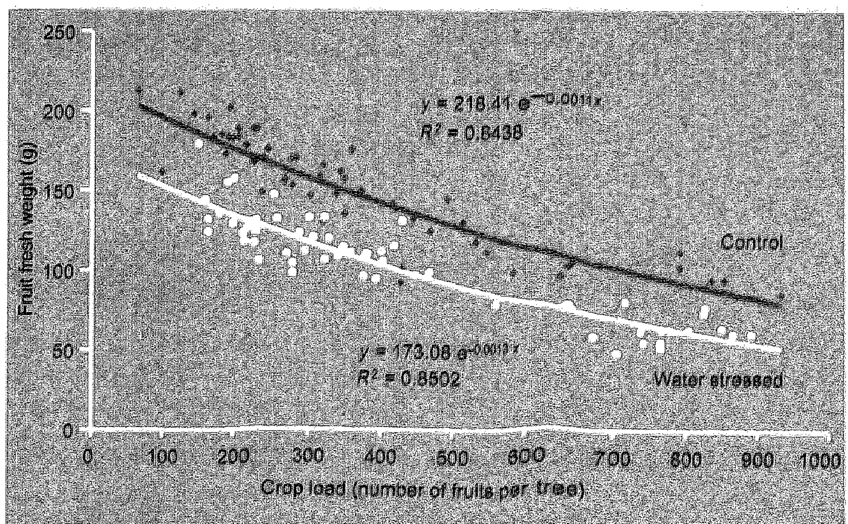

Figure 3.
Relationship between fruit fresh weight and crop load for control and water-stressed Elegant Lady peach trees.

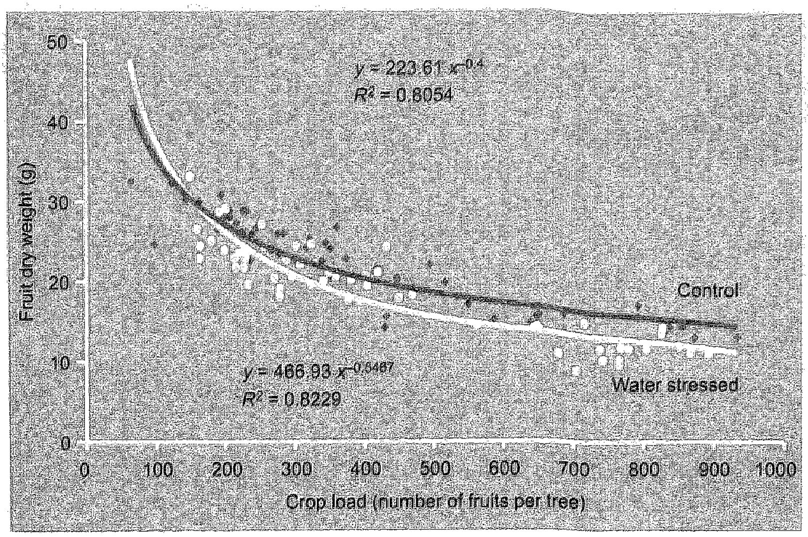

Figure 4.
Relationship between fruit dry weight and crop load for control and water-stressed Elegant Lady peach trees.

The average fruit dry weight was only slightly affected by water stress but was significantly reduced by crop load. In fact, as the crop load (fruit number per tree) increased, the average fruit dry weight decreased. The relationship of fruit dry weight to crop load expressed in kg per tree is of exponential type and is described by the equations: $y = 223.61\ x^{-0.4}$ ($R^2 = 0.81$) for control and $y = 466.93\ x^{-0.55}$ ($R^2 = 0.82$) for water-stressed trees (*figure 4*). At less than 200 fruits per tree, there was no difference in fruit dry weight between dry and wet treatments. Actually, at a very low range of crop load, there may even be an improvement in dry weight in water-stressed trees. This could be associated with fruit strength, which would be improved because of the suppressing effect of water deficit on photosynthesis, which would limit vegetative growth. This would indicate higher water-use efficiency under limited irrigation. In fact, when fruit dry weight and crop load are brought to the unit of the trunk cross-sectional area, the equations describing the relationship between the two parameters become $y = 35.19\ e^{-0.12x}$ ($R^2 = 0.85$) for control and $y = 33.89\ e^{-0.13x}$ ($R^2 = 0.92$) for water-stressed trees, showing an improvement, especially for the dry treatment.

Water deficit reduced photosynthesis but its effects on fruit dry weight and on total dry yield were limited. This suggests that the fruit remained a strong sink capable of deriving most of the carbohydrates elaborated. The effect of water stress is certainly more pronounced on other sinks, mainly shoot and, to a lesser extent, root growth. Since most of the shoot growth in peach occurs during stages I (rapid growth with active cell division) and II (growth deceleration corresponding to the pit hardening), it is expected that water stress imposed during stage III (fruit enlargement characterized by cell enlargement) would affect mainly shoot growth in girth.

Table III.
Fruit percentage per size category presented to analyze the effects of water regime and crop load on fruit size distribution of Elegant Lady peach crops (Winters, Ca, USA).

Water regime	Crop load	40[1] (75 mm)[2]	50[1] (70 mm)[2]	64[1] (65 mm)[2]	72[1] (60 mm)[2]	88[1] (55 mm)[2]
Control	Light	35	39	17	8	1
	Commercial	16	35	27	15	7
	Heavy	2	5	16	23	54
Water stress	Light	1	16	32	38	13
	Commercial	1	8	29	39	23
	Heavy	0	1	4	14	81

[1] Number of fruits in a 16-pound packing box.
[2] Fruit diameter.

3.10. Fruit size

Both water stress and crop load affected the distribution of the fruit size categories (*table III*). The proportion of large fruit decreased as the fruit number per tree increased for both control and stressed trees. For control trees, the proportion of small fruit (categories 72 and 88) did not exceed 9% for light crop load, and it reached 22% for commercial crop load, but it jumped to a very high level of 77% for heavy crop load, meaning that more than three-quarters of the fruit borne by unthinned control trees was of a small size. For the same trees, the proportion of large fruit (categories 40 and 50) was 74% for light crop and 51% for commercial crop, but only 7% for heavy crop. This shows the negative effect of crop load on fruit size, even on trees grown under optimal conditions. The negative effect of crop load on fruit size was even more pronounced on water-stressed trees, where the proportion of small fruit was 51% for the light crop, and reached 62% for commercial crop and 95% for heavy crop.

3.11. Soluble solids concentration

As for fruit size, water stress and crop load affected fruit soluble solids concentration (*table IV*). As was expected, crop load had a negative effect on soluble solids concentration, which decreased as the fruit number per tree increased. In contrast, water stress had a positive effect on soluble solids contents, which were higher in fruits from water-stressed trees than in those from control trees for all three crop levels. On the other hand, soluble solids concentration depended on the size of the fruit in both control and trees submitted to water deficit (*table V*). Thus, soluble solids content of the fruit increased as the fruit size increased and there was a positive correlation between fruit diameter and soluble solids concentration of the fruit in both control and water-stressed trees. This indicates that the largest fruit have higher soluble solids concentrations than the smaller ones. The relationship between fruit size and soluble solids concentration is described by the equations: $y = 0.14\,x + 1.93$ ($R^2 = 0.96$) for fruits on control trees and $y = 0.12\,x + 6.74$ ($R^2 = 0.96$) for those on water-stressed trees (*figure 5*).

Table IV.
Effects of water regime and crop load on fruit soluble solids concentration (%) of Elegant Lady peach (Winters, Ca, USA).

Water regime	Crop load		
	Light	Commercial	Heavy
Control	12.38 bc	11.88 cd	11.08 d
Water stress	14.87 a	14.28 a	12.94 b

Values with different letters are significantly different according to Duncan's multiple range test at $P < 0.05$.

Table V.
Effects of water regime and crop load on fruit soluble solids concentration (%) in relation to fruit size of Elegant Lady peach (Winters, Ca, USA).

Water regime	Crop load	40[1] (75 mm)[2]	50[1] (70 mm)[2]	64[1] (65 mm)[2]	72[1] (60 mm)[2]	88[1] (55 mm)[2]
Control	Light	13.14	12.20	11.93	10.85	-
	Commercial	12.61	11.88	11.58	10.71	-
	Heavy	11.98	11.37	11.15	10.43	9.68
Water stress	Light	15.60	15.38	15.00	14.63	13.74
	Commercial	15.73	14.68	14.40	14.09	13.54
	Heavy	-	13.85	12.89	12.75	12.27

[1] Number of fruits in a 16-pound packing box.

[2] Fruit diameter.

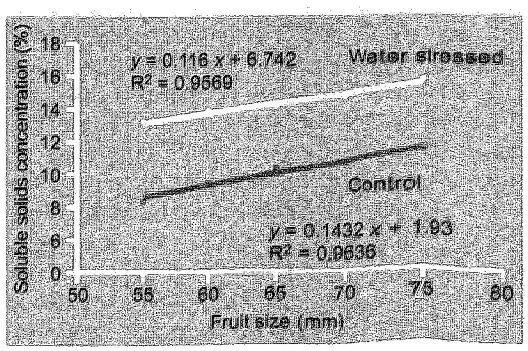

Figure 5.
Relationship between soluble solids concentration and fruit size concentration for control and water-stressed Elegant Lady peach trees.

4. Discussion

Fruit growth curves showed similar trends for both control and water-stressed trees during the early stages of fruit growth in the season. However, as the season progressed (intensive fruit growth, increase in severity of stress and high climatic demand), the fruit on stressed trees showed a slower growth rate. Both water stress and crop load reduced fruit growth. The effect of water stress on fruit growth could be explained by insufficient water for cell elongation, through which the fruit insures its growth during the last stages and/or through photosynthesis, leading to a shortage in photosynthates preventing the fruit from satisfying its demand. The crop load effect on growth could be attributed to high competition existing among fruit toward a limited source (photosynthates) which resulted from water deficit.

Water stress significantly reduced the trunk water potential (TrWP), which was not affected by crop load [14]. The seasonal pattern of midday TrWP showed a clear distinction in the trend followed by water status in control and water-stressed trees, independent of crop load. Water deficit also significantly reduced stomatal conductance and the transpiration rate during the last stage of fruit growth, while crop load did not. The difference in the transpiration rate (E) between water-stressed and control trees appeared first at noon and in the afternoon, indicating that the trees were still at this point able to recover overnight and maintain a decent transpiration rate the following morning. However, at later stages of the season, the transpiration rate of water-stressed trees was lower than that of control trees throughout the day, starting in the morning. At this point, the stress had reached a level where the trees could no longer recover overnight and thus continuously maintained a lower transpiration rate. Water stress significantly reduced stomatal conductance and the transpiration rate in peach trees [3, 4].

Regarding photosynthesis (P_n), there was no crop load effect throughout the season. However, water stress reduced P_n as the season progressed and the fruit demand became high. Thus, the negative effect of water stress observed on fruit growth could be explained in part by its effect on photosynthesis. Crop load did not affect the assimilation rate in either irrigation regime. Similar P_n in trees with varying crop loads indicates the existence of alternate sinks, all competing for the same source. The existence of such alternate sinks continues to drive the photosynthesis at its maximum rate even on trees with light crop loads. During the late stage of fruit growth, the negative effect of water deficit on P_n appeared, starting in the morning and persisting throughout the day. At this stage, the trees had reached a point where they could no longer recover overnight in order to maintain a decent CO_2 assimilation rate level, even in the morning.

There is a close relationship between stomatal conductance and P_n in both control and water-stressed trees. This correlation is better in trees exposed to water deficit.

Both water stress and crop load delayed the harvest date through their effect on ripening. Thus, water deficit delayed harvest. Similarly, the harvest date was delayed as crop load increased. Both factors delayed harvest through their effect on ripening because of the effect of water stress and crop load on fruit growth, which reduced its rate and prolonged its duration. The fruit growth on water-stressed trees was slowed down because of high competition among fruit for carbohydrate supply, which was negatively affected by water deficit on unthinned trees. The harvest date did not differ between light and commercial crops, while heavy crop load significantly delayed harvest. Thus, trees with light and commercial crop loads were able to insure appropriate fruit growth and carry fruit through the ripening process. In contrast, on unthinned trees and because of high competition, fruit growth was slowed down and ripening delayed.

Water stress reduced the average crop fresh yield, which was improved as crop load increased. On the other hand, water stress slightly reduced dry yield whatever the crop load was. However, the difference between the wet and dry treatment for the same crop load was not significant. Thus, for a given crop load, water stress reduced fresh yield through the reduction of hydration but had no significant effect on dry yield. This suggests that the inhibitory effect of water stress on photosynthesis did not affect total dry yield, which was similar for control and water-stressed trees. This indicates that the fruit remained a very strong sink, even under stress conditions and reduced photosynthesis, which continued to drive most of the carbohydrates synthesized in the leaves. This limited effect of water stress on dry yield contrasts very much with its significant effect on fresh yield. In contrast to water stress, crop load had a positive effect on total crop dry yield, which increased as the fruit number per tree increased. At a low range of crop load (less than 200 fruits per tree), there was no difference between the control and water-stressed trees, suggesting that at low load the crop dry yield is similar for both the control trees and those submitted to restricted irrigation. However, as the crop load per tree increases, the dry yield tends to be higher for control trees than for stressed ones.

Fruit fresh weight was reduced by water stress and crop load. However, the average fruit dry weight was only slightly affected by water stress but significantly reduced by crop load. In fact, as the crop load (fruit number per tree) increased, the average fruit dry weight decreased. At less than 200 fruits per tree, there was no difference in fruit dry weight between dry and wet treatments. Actually, at a very low range of crop load, there may even be an improvement in dry weight in water-stressed trees. This could be associated with fruit strength, which would be improved because of the suppressing effect of water deficit on photosynthesis, which would limit mainly vegetative growth. This would be an indication of a higher water-use efficiency under limited irrigation. Water deficit reduced photosynthesis but its effects on fruit dry weight and on total dry yield were limited. This suggests that the fruit remained a strong sink capable of deriving most of the carbohydrates elaborated. The effect of water stress is certainly more pronounced on other sinks; mainly, shoot growth in girth. Neither shoot growth nor root growth were measured in our experiment; however, other experiments have shown that water stress affects first primarily shoot growth by reducing photosynthesis [2, 5, 6, 7, 10]. Therefore, the limited effect of water stress on dry yield would have been achieved at the expense of shoot growth. In fact, the control of vegetative growth has been the reason behind the use of regulated deficit irrigation in fruit production.

Both water stress and crop load had a negative effect on fruit size. The proportion of large fruit decreased as the fruit number per tree increased for both control and stressed trees. This shows the negative effect of crop load on fruit size even on trees grown under optimal conditions. This indicates that, even under normal irrigation, unthinned trees had a load exceeding their capacity to respond to the demand of the fruit to reach normal (commercial) size. The negative effect of crop load on fruit size was even more pronounced in water-stressed trees.

As for fruit size, both water stress and crop load affected fruit soluble solids concentration, but in a different manner. Crop load reduced soluble solids content, which decreased as the fruit number per tree increased. In contrast, water stress had a positive effect on soluble solids concentrations, which were higher in fruits from water-stressed trees than in those from control trees, regardless of crop load. Thus, crop load had a negative effect on both fruit size and soluble solids, while water stress reduced size but improved soluble solids concentration. On the other hand, soluble solids concentration depended on the size of the fruit in both control and trees submitted to water deficit. Thus, soluble solids content of the fruit decreased as the fruit size decreased and there was a positive correlation between fruit diameter and soluble solids concentration of the fruit in both control and water-stressed trees. Similarly, the deficit irrigation induced a higher fruit soluble solids concentration and lower fruit weight in 'O'Henry' peach [11].

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Efectos del estrés hídrico y de la carga del árbol sobre el rendimiento y la calidad de los frutos del melocotonero Elegant Lady Peach [*Prunus persica (L.)* Batch].

Resumen — Introducción. La producción fructífera se ve enfrentada a la falta de agua, en particular, en las regiones mediterráneas caracterizadas por un verano muy largo, seco y cálido. En tales condiciones, los cultivadores deben controlar el riego rigurosamente, procurando hallar nuevas estrategias que incluyan el control del agua. **Material y métodos**. Se evaluaron en vergel de melocotoneros 'Elegant Lady' de 7 años de edad (Winters, Californie, USA) los efectos tanto del estrés hídrico (EH) como de la carga del árbol en la cosecha (CA) sobre la tasa de asimilación de carbono, el crecimiento del fruto, el rendimiento en la cosecha, y la calidad del fruto (tamaño y contenido en sólidos solubles). El dispositivo experimental consistió en un esquema factorial de bloques completamente aleatorizados con 2 × 3 factores: factor riego (con o sin EH) y factor CA (carga ligera, comercial o pesada). **Resultados y discusión**. Ambos factores CA y EH afectaron al crecimiento del fruto durante las últimas fases, pero no lo hicieron al principio. La carga del árbol no afectó el potencial en agua del tronco (PETr); el cual, no obstante, se redujo notablemente por EH a lo largo de todo el día y de la temporada. La conductancia estomática (Cs), la tasa de transpiración (T) y la tasa de la asimilación de CO_2 (A) no fueron afectadas por CA, pero fueron reducidas por EH. Hubieron ligeras correlaciones entre PETr y Cs o PETr y A en árboles testigo, lo que indica una correlación relativamente ligera entre las funciones de la hoja en los melocotoneros situados bajo condiciones óptimas. Ambos factores CA y EH retrasaron la fecha de la cosecha, debido a su efecto sobre la maduración. El estrés hídrico redujo de manera significativa el rendimiento medio de la cosecha en frutos frescos, pero afectó poco al rendimiento de cosecha en peso seco. Ambos factores CA y EH afectaron al reparto de los frutos por categorías de calibres, la proporción de frutos grandes disminuyó de acuerdo con el aumento de la carga del árbol y la intensidad del estrés hídrico. **Conclusión**. El estrés hídrico redujo el peso fresco de los frutos, pero no lo hizo con el peso seco, ni tampoco con el rendimiento en peso seco. La carga del árbol redujo el peso fresco y seco de los frutos así como su rendimiento. Ésta tuvo un efecto negativo sobre el contenido en sólidos solubles, mientras que el estrés hídrico tuvo un efecto positivo. De este modo, la carga del árbol redujo la dimensión del fruto y el contenido en sólidos solubles, mientras que el estrés hídrico reducía el tamaño, pero mejoraba la concentración en sólidos solubles.

EUA / *Prunus persica* / estrés de sequia / potencial hídrico de las plantas / fotosíntesis / fruto / crecimiento / rendimiento / azucares