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Effects of Water Deficit and Variations of Fruit Microclimate on Peach Fruit Growth and Quality

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ABSTRACT

This study was carried out to determine the response of peach tree (*Prunus persica* L. Batsch cv 'Alexandra') to water stress and variations of fruit microclimate during the final stage of rapid fruit growth. Two irrigation treatments (standard and deficit irrigations) were applied. Fruit microclimatic conditions were modified by enclosing the fruits in plastic films covered with two types of foil (osmolux and P^+). Fruit and stem potentials showed significant differences between treatments. In the deficit irrigation treatment, tree water potential decreased (-22 bars compared to -15 bars in the case of the treatment with standard irrigation) while at the same time, a fluctuation of the stem diameter was observed. The combined effects of water stress and modified microclimatic conditions affected the fruit water status and, consequently, fruit growth parameters. Water stress slowed the xylem flow into the fruit (-36%) and induced a significant reduction in the fruit diameter, fruit fresh and dry masses and soluble solids content. On the other hand, bagging of the fruits with the two types of plastics did not modify fruit diameter, fruit fresh mass and soluble solids content. However, the osmolux plastic induced a significant reduction in the fruit dry mass. Water stress induced a significant decrease of fruit conductance whereas covering fruits with P^+ plastic induced its increase. This increase is followed by a reduction of the transpiration rate (due to the moisture raised in the film of P^+).

Keywords: film, growth, microclimate, peach, quality, stress

INTRODUCTION

Fruit growth and quality depend essentially on the water and assimilates through phloem and xylem flows, on the phenomenon of sugar dilution or concentration, and on the water and carbon losses via transpiration and respiration, respectively (Van Die and Willemes 1980; Tazuke and Sakiyama 1991; Egea *et al.* 2009). However, the losses of mass by respiration are negligible (Huguet *et al.* 1994; Huguet *et al.* 1998; Wu *et al.* 2007). Fruit sap flow increases as fruit water potential decreases and as tree water potential increases (Lang and Thrope 1986; Chenu *et al.* 2008). Fruit water potential decreases in the same way as its osmotic potential, the latter depending on sugar concentration which increases with both fruit weight and transpiration rate (Génard and Huguet 1996; Li *et al.* 2002; Lechner *et al.* 2008). A number of researches concerning the influence of deficit irrigation on the growth of the fruit and its quality have been carried out. Trees exposed to deficit irrigation during the final stage of fruit rapid growth present fruits which have a higher content of soluble solutes and a longer storage period than those of the well-irrigated trees (Li *et al.* 1989; Mitchell *et al*. 1989; Damla Bender 2008). Such an improvement of fruit quality is often accompanied by a reduction in the fruit size (Li *et al.* 1989; Plaut *et al.* 2004; Yang *et al.* 2010). The effects of water deficit reveals the modification in fruit transpiration rate which influences phloem and xylem flow transporting water, assimilates and minerals into the fruit (Génard and Huguet 1996; Li *et al.* 2002; Najla *et al.* 2010). Similarly, enclosing fruits into plastic films, a common practice after harvest in some countries (Li *et al.* 2002), induces modifications in the microclimate of these fruits; this has a direct effect on the gas exchange and transpiration (Trambouze and Voltz 2001; Shiying *et al.* 2002). Moreover, it decreases light intensity while the relative humidity, and the ambient temperature around the fruit increase (Li *et al.* 2001; Ngouajio *et al.* 2007). Modification of the fruit microclimate can influence physiological processes such as transpiration, respiration and photosynthesis, which are slowed in the fruits covered with plastic film (Li *et al*. 2001). Reductions in the content of soluble solutes and fruit dry mass were also observed. However, no extensive study has yet been carried out on the fruit transpiration in the field. Thus, the objectives of the present study were to determine the effect of water deficit and microclimatic variations on the components of the peach growth and on its water status during the last phase of its growth in the field.

MATERIALS AND METHODS

Experimental site and materials

The experiments were carried out during the summer of 2005 in the Avignon Centre of the Institut National de la Recherche Agronomique (INRA) on peach trees (*Prunus persica* L. cv. 'Alexandra') grafted on GF 677 and grown in containers. Peach trees at the last phase of fruit development were considered. The fruit growing conditions differed in regard to irrigation regimes and plastic films. Trees received routine horticultural care including winter pruning, thinning weekly drip irrigation, and pest control.

Treatments

Water restriction was imposed during the last phase of peach growth on 10 trees by reducing irrigation to 50% approximately for two months. Fruits were individually covered with two types of plastic films of different permeability: osmolux (film ELF ATOCHEM, thickness 25 µm, permeability for H_2O at 23°C is 3500 g/m²/24h, P.A.T.I.S.p.A Thermoplastic films agriculture and

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industry, Italy) and P^+ (poly propylene, thickness 35 µm, its permeability for H_2O at 23°C is very weak, P.A.T.I.S.p.A Thermoplastic films agriculture and industry, Italy). Cages covered with the plastics were positioned around the fruit, and small aluminium boxes were fixed to the top of the cage to limit direct radiation (**Fig. 1**). The plastics were placed on 10 trees with 10 fruits per type of plastic. One uncovered fruit was associated to each treatment and placed under similar conditions (height, direction and leaf area). The treatments were: (IP^+) irrigated treatment covered with P^+; (IO) irrigated treatment covered with osmolux; (SP^+) stressed treatment covered with P^+; (SO) stressed treatment covered with osmolux; (IN) irrigated uncovered treatment; (SN) stressed uncovered treatment.

Measurements

In order to measure the stem water potential (Ψ_{stem}), which is a more stable parameter than the leaf water potential (Ψ_{leaf}); leaves were shaded for 1 day before being cut from the tree. Ψ_{stem} was measured using a Scholander-Hammel pressure room on mature leaves selected from the middle of shoots at different periods. 25 leaves per treatment were used. Variations of stem diameter were measured using Linear Variable Differential Transducers (Solartron, USA). Fruit growth parameters (fruit diameter as well as fruit fresh mass, dry mass and soluble solids content) were measured twice a week during the period of experimentation. For each measurement, 7 fruits per treatment were used. A psychrometer (Wescor C-52 sample chamber, 2% ± 0.1 bar, Washington, USA) was used to measure the fruit water potential (Ψ_h) from fine sections of fruit pulp; the osmotic potential ($\Psi\pi$) is measured by plunging the fruit pulp in liquid nitrogen (-196°C) during 10 seconds. Turgor pressure was estimated indirectly by measuring the water potential and the osmotic pressure:

$$\Psi_h = \Psi_\pi + P \qquad (1)$$

Fruit conductance was estimated at weekly intervals, during the period of rapid fruit growth. Six fruits per treatment were used, the diameters (cheek, suture and height) of these fruits were measured to calculate fruit surface area. The fruit surface area was computed with MAPLE Software (Waterloo Maple Inc., Canada), assuming that a fruit has an ellipsoidal shape. After sealing the pedicel, fruits were weighed and placed in a ventilated chamber under controlled conditions of temperature and humidity. Temperature and relative humidity of the chamber were minutely measured (Sefram log 1520, St Etienne, France). Each fruit was weighed at hourly intervals for 8 h. Hourly surface conductance g_h ($cm.h^{-1}$), of each fruit was calculated according to Gibert *et al.* (2005):

$$g(h) = \frac{T_f(h)}{S_f \times \frac{M_w}{R \times Temp} \times P^* \times (H_f - H_a)} \qquad (2)$$

where h is time since sampling (h), T_f is the transpiration per unit time ($g\ h^{-1}$), which is equal to the weight loss, S_f is the fruit surface area at $h = 0$, M_w is the molecular mass of water (18 g mol^{-1}), R is the gas constant (83 cm^3 bar mol^{-1} K^{-1}), $Temp$ is the temperature (°K), P^* is the saturation vapour pressure (bar), which depends on temperature following the equation of Fishman and Génard (1998): $P^* = 0{\cdot}008048 \ast \exp(0{\cdot}0547 \ast (Temp - 273{\cdot}15))$, H_f is the relative humidity within the fruit (assumed to be equal to 100%), and H_a is the relative humidity of the atmosphere.

The fruit could be considered as a compartment that receives the phloem and xylem flows by its peduncle (Najla *et al.* 2010). Each vegetable portion is characterized by a conductance (L) or a resistance (R) to the sap transfer. Thus, the water flow entering the fruit can be described using the equation of Van Den Honert (1948):

$$d_v/d_t = L\left(\Delta\Psi_h\right) = \left(\Psi_{hp} - \Psi_{hf}\right)/R \qquad (3)$$

where d_v/d_t : xylem water flow (m s^{-1}); L: hydraulic conductance (m^3 m^2 s^{-1}) = (1/R) inverse of the hydraulic resistance (m s^{-1}); Ψ_{hp}: water potential of the peduncle (MPa); Ψ_{hf}: fruit water potential (MPa).

Fig. 1 Fruits in cages surrounded by plastic films of P+ (A) and osmolux (B) with the sensors of humidity and temperature. The aluminium boxes were fixed to the top of the cage to limit direct radiation.

Parameters of the fruit microclimate

Ambient temperature and air relative humidity in the films around seven fruits of each treatment were measured from 25 May until harvest, using a thermal sensor (Thermocouple cuivre -constant) and a sensor of moisture (HIH-3610 series Honywell, RH ±5%, USA). These sensors were connected to a power acquisition station (CR7 Campbell Scientific, France).

Experimental design and statistical analysis

The experiment was designed as random sectors. Each treatment consisted of 10 replicates (trees) and each duplicate consisted of 10 fruits. Analysis of variance and parameters estimation were performed using the R. 2.5.1 statistical software (The R Project for Statistical Computing, http://www.r-project.org/). The means and standard deviations were calculated. The data shown are the averages of all repetitions. Significant differences were assessed by the LSD test at the 5% level (Little and Hills 1968).

RESULTS

Variations of microclimate conditions around the fruit

Bagging fruits significantly influences their microclimate (**Fig. 2**). Nocturnal temperature was not affected by covering,

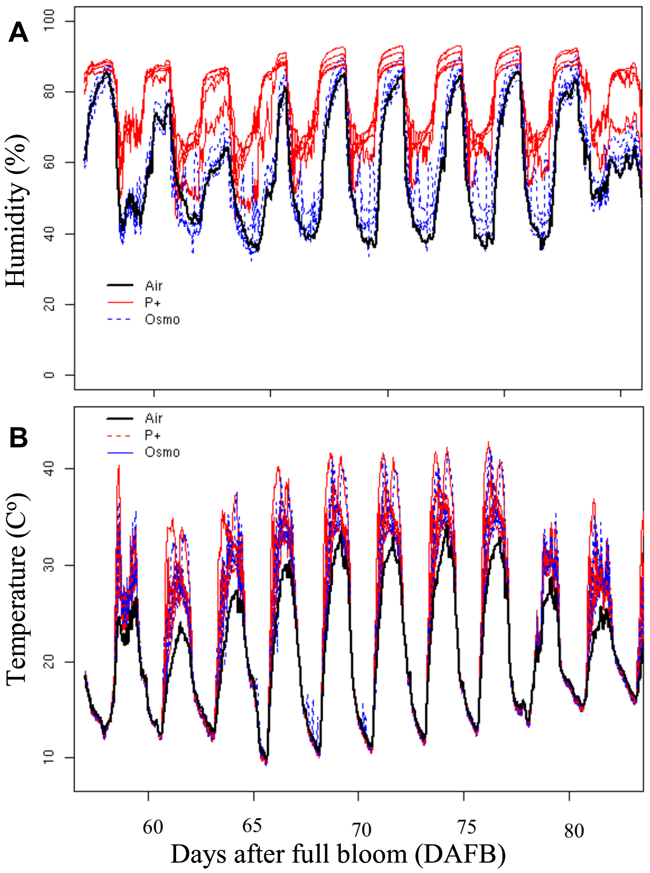

Fig. 2 Humidity (A) and temperature (B) variations in plastic films ($P+$ and osmolux) and external air as a function of day after full bloom.

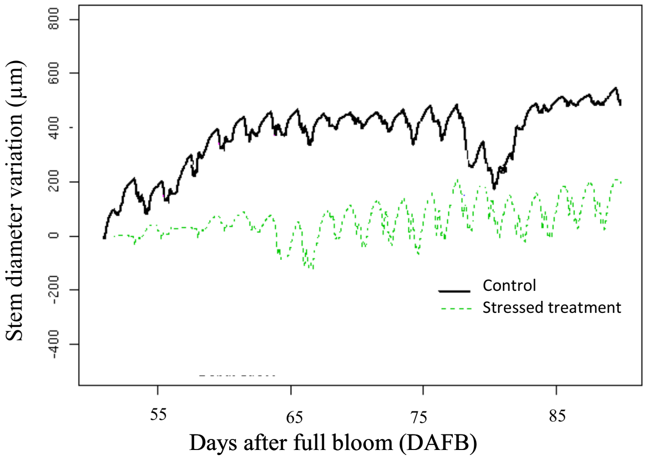

Fig. 3 Evolution of the stem diameter micro-variations of control (solid line) and stressed treatment (dotted line) during the III phase of fruit growth.

while the diurnal temperature of the fruit increased in approximately 8°C in the two plastics when compared to the control ($P < 0.005$). Air relative humidity increased significantly under the P^+ plastic (up to 85% during the night and 50% during the day) while the fruit moisture in osmolux plastic has comparable values with the control (60% during the night and 40% during the day).

Microvariations of shoot diameter

Stem diurnal contractions were regular in the course of time (between 50 and 100 µm) in the irrigated treatment (**Fig. 3**) while in the water stressed treatment, it was clearly amplified (between 150 and 200 µm).

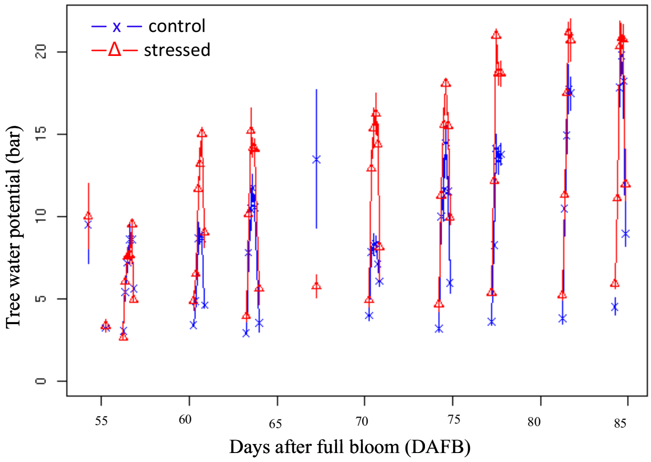

Fig. 4 Evolution of the stem water potential of control (— x —) and stressed treatment (—Δ—) during the III phase of fruit growth. Values are means (± S.D.) of measurements from twenty five leaves for each treatment (n = 25). Lines represent daily measurements of stem water potential (predawn and minimum).

Predawn and minimum water potential of tree

The differences in tree water potential between the treatments reflect the importance of irrigation on the tree water status during phase III of fruit growth (**Fig. 4**). Tree predawn water potential was lower in stressed trees at after 57 days after full bloom (DAFB) (-5 ± 1 bars against -3 ± 1 bars for the control). On the other hand, the difference in the minimal water potential of tree between the treatments appeared to be very significant at 77 DAFB (-22 and -15 bars for the stressed and the control treatment, respectively).

Fruit measurements

A significant reduction ($P < 0.005$) in the diameter of the stressed fruits appears from 63 DAFB (**Fig. 5A**) until harvest, where diameter of the stressed fruits was 50 mm as compared with 58 mm for the control. While the effect of bagging appears significant from 77 DAFB within the irrigation treatment (52, 53 and 56 mm for IN, IO and IP$^+$, respectively) and the stressed treatment (43, 41 and 47 mm for SN, SO and SP$^+$, respectively) (**Fig. 5A**).

The effect of water deficit on fruit fresh mass (**Fig. 5B**) was significant ($P < 0.005$) from the 67 DAFB. At harvest, a decrease of 20% in fruit diameter was observed between the irrigated and the stressed treatments. The effect of bagging was significant at different periods. At harvest, the IO plastic film induced a reduction of fruit fresh mass within the irrigated treatments (100, 101 and 90 g for IN, IP$^+$ and IO, respectively). No significant effect was observed within the stressed treatments at harvest.

Water stress had a significant effect ($P < 0.005$) on the fruit dry mass (data not shown). At harvest, the fruit dry mass decreased from 16 g to less than 10g due to water stress. Regardless of irrigation conditions, a significant difference ($P < 0.01$) in fruit dry mass was observed in the treatment with osmolux film.

A significant increase of soluble solids content (**Fig. 6**) in stressed fruits was observed during fruit development, regardless the plastic film treatment. At harvest, this increment was 14% for SN, 13% for SO and 15% for SP$^+$ compared with IN, IO and IP$^+$, respectively. Moreover, the bagging of the fruit affected significantly their soluble solids content at 80 DAFB. The fruits bagged with osmolux film had higher soluble solids contents as compared to the fruits bagged with P^+ ($P < 0.01$).

Fig. 7 shows the pattern of fruit water potential. At harvest, the stressed fruits had a water potential significantly lower than that of irrigated fruits (-13 and -10.5 bars, respectively). Regarding the impact of plastic covers, an effect much more marginal and delayed was noted on fruit water

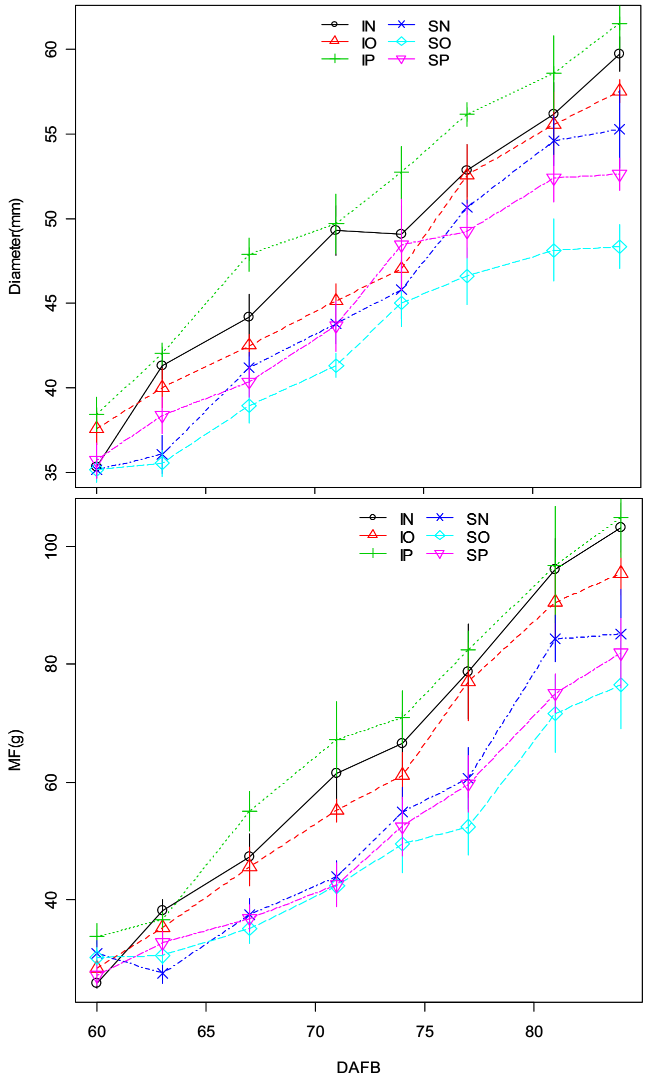

Fig. 5 Evolution of fruit diameter (A) and fresh mass (B) during phase III of fruit growth. Values are means (± S.D.) of measurements from 7 fruits for each treatment (n = 7).

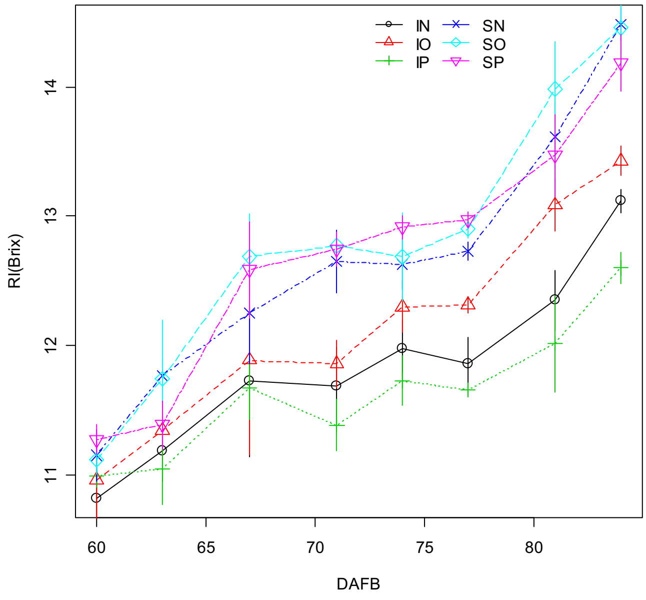

Fig. 6 Evolution of fruit soluble solutes content during phase III of fruit growth. Values are means (± S.D.) of measurements from 7 fruits for each treatment (n = 7).

potential at harvest, whereas P^+ induced a less negative water potential (-9.5 and -12.5 bars for IP^+ and SP^+, respectively, against -13.5 and -11.5 bars for SO and IO, respectively). The water deficit decreased significantly ($P < 0.01$) the fruit osmotic pressure to -18 bars as compared to -13 bars for the control (**Fig. 8**). The bagging effect was only significant when using P^+ plastic with the stress treatment (**Fig. 8**).

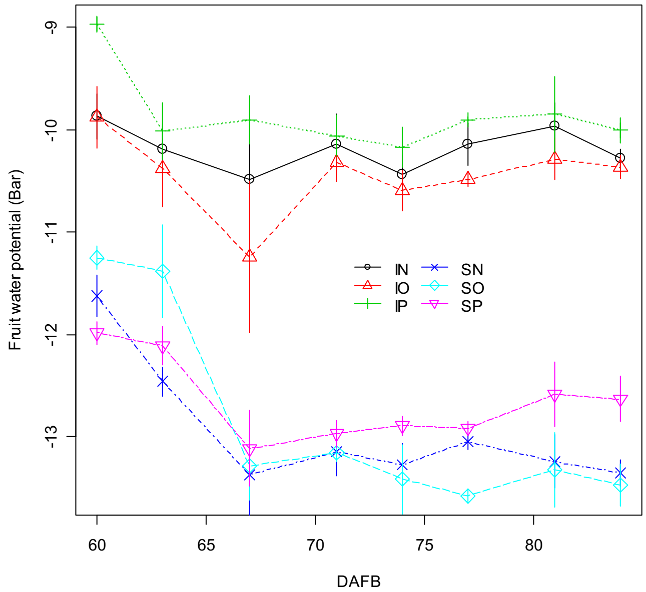

Fig. 7 Evolution of fruit water potential during phase III of fruit growth. Values are means (± S.D.) of measurements from 7 fruits for each treatment (n = 7).

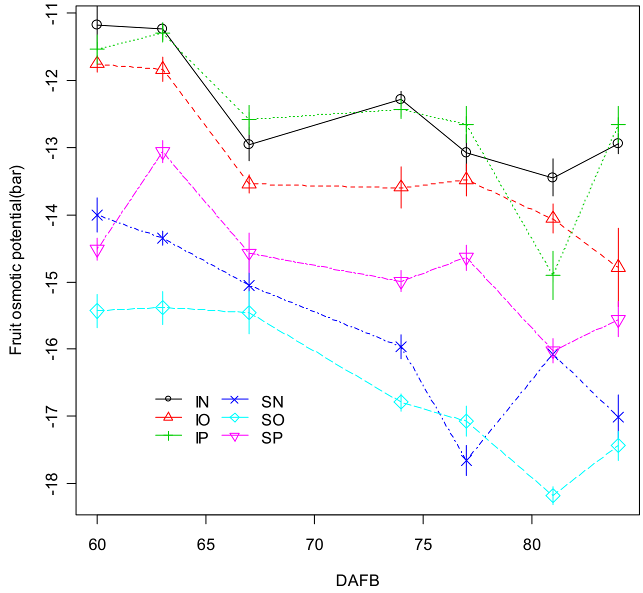

Fig. 8 Evolution of fruit osmotic potential during phase III of fruit growth. Values are means (± S.D.) of measurements from 7 fruits for each treatment (n = 7).

Fruit surface conductance varied during fruit growth (**Fig. 9**). The pattern of variation differed according to date and treatment. Water stress and fruit bagging affected fruit conductance (more extremely for the P^+ plastic). At the early stage of fruit development (60 to 75 DAFB), a clear decrease of fruit conductance for all treatments was observed (from 1100 to 650, from 960 to 600, from 600 to 550, from 750 to 490, from 1000 to 550, from 650 to 450 cm h^{-1} for IP^+, IO, IN, SO, SP^+ and SN, respectively). At the later stages of fruit development, mean fruit conductance decreased weakly for the majority of treatments, and increased lightly for IP^+. The bagging effect on the fruit surface conductance was most significant ($P < 0.01$) at harvest (450, 515, 550, 520, 650 and 780 cm h^{-1} for SN, SO, SP^+, IN, IO and IP^+, respectively).

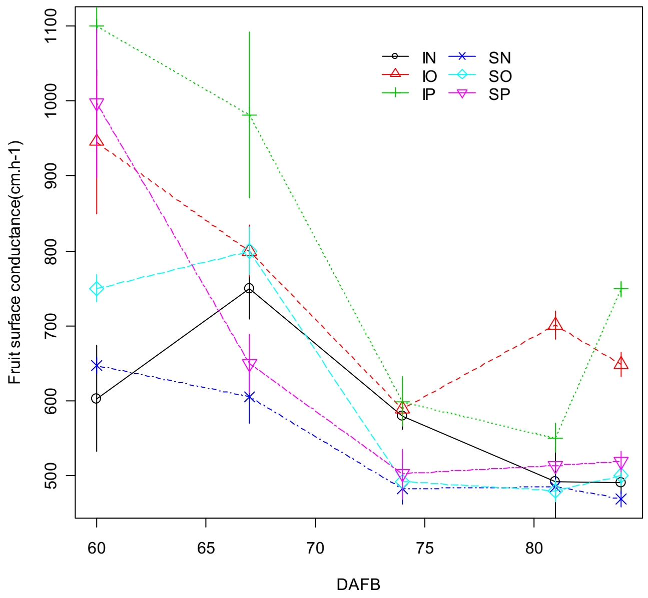

Fig. 9 Evolution of fruit surface conductance during phase III of fruit growth. Values are means (± S.D.) of measurements from 6 fruits for each treatment (n = 6).

Supposing that water transfer resistance is identical for the peduncle of irrigated and stressed fruits, the xylem flow (Equation 3) decreased by 35.7% with water deficit at harvest.

DISCUSSION

In this study, the significant effect of water deficit appears directly throughout the variations of water potential and stem diameter of tree. Moreover, during the III phase of fruit growth, diameter, fresh mass, dry mass and the soluble solids content of fruit were affected by water deficit. Such an effect was previously observed on peach (Chalmers *et al.* 1985; Natalie *et al.* 1985; Wu *et al.* 2007). These results suggest that the water deficit limits the water entry, as well as the assimilate accumulation, in the fruits by limiting the photosynthesis of the branches and leaves and by accelerating leaf senescence that disturb the primary source of assimilates (Berman and Dejong 1996; Plaut *et al.* 2004; Agüero *et al.* 2011). The reduction in the fresh mass with water deficit may be explained by a slowing in xylem flow due to a decrease in the number and area of conducting vessels (Ho *et al.* 1987; Dichio *et al.* 2003; Araki *et al.* 2004; Windt *et al.* 2006). In addition, the fruit surface conductance is reduced by the formation of continuous and much thicker cuticles than in the case of irrigated fruits (Carlos *et al.* 1994; Knoche *et al.* 2001; Liu *et al.* 2009; Gibert *et al.* 2010) and the water loss by transpiration is decreased. The fruit surface conductance measured on peach cv. 'Alexandra' varies between 650 and 420 cm h^{-1} (for the uncovered irrigated treatment) and between 735 and 200 cm h^{-1} (for the uncovered stressed treatment). These values are comparable with those obtained on same variety by Gibert *et al.* (2005) and higher than those obtained by Lescourret *et al.* (2001) (170-585 cm h^{-1}). The conductance has a tendency to decrease with time (**Fig. 9**). Although the decrease of the conductance according to the fruit development was already observed by Smith *et al.* (1995) on kiwi, Major *et al.* (2011) on pumpkin and by Jones and Higgs (1982) on apple, Lescourret *et al.* (2001) revealed an increase in the conductance according to the fresh mass on several varieties of peach including "Alexandra". Similarly, the water deficit increases the soluble solids content which is produced by a weaker dilution of sugar, due to the reduction of the water entering into the stressed fruit. These results agree with those from other experiments which show significant differences concerning the fruit soluble solids content during water stress (Bryla *et al.* 2005; Muratore *et al.* 2005).

Bagging the fruits adds an additional effect to the fruit water status by affecting its water potential and its conductance. The water flow into the fruit bagged with osmolux is equal to that of control fruit with no bagging, but its transpiration (Equation 2) is higher (140%), since the conductance of the fruit surrounded by the osmolux is higher than that of the control. Such an effect explains the reduction observed in the diameter, the fresh mass and the dry mass of the fruits bagged with the osmolux whatever the irrigation treatment. The significant effect of the plastic on the fruit conductance could be explained by the significant increase in the humidity around the fruit, which induces a reduction in the fruit transpiration (Li *et al.* 2001; Crisosto 2006; Cantin *et al.* 2008).

In conclusion, water stress and the modification of fruit microclimate by surrounding it with plastics more or less permeable to water affect its growth and its quality. The effect of the water stress on fruit growth and quality was more important than that of the plastic cover. Further studies are necessary to determine the economic viability of this practice.

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