Agronomía Colombiana
ISSN: 0120-9965
agrocolfabog@gmail.com
Universidad Nacional de Colombia
Colombia

Molina-Ochoa, María Jaqueline; Vélez-Sánchez, Javier E.; Rodríguez, Pedro
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Agronomía Colombiana, vol. 33, núm. 3, 2015, pp. 330-338
Universidad Nacional de Colombia
Bogotá, Colombia

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Effect of regulated deficit irrigation on tree growth of pear cv. Triunfo de Viena

Efecto del riego deficitario controlado en el crecimiento de la planta de pera cv. Triunfo de Viena

María Jaqueline Molina-Ochoa[1], Javier E. Vélez-Sánchez[1], and Pedro Rodríguez[2]

ABSTRACT

The deficit irrigation controlled (RDI) as reducing water in phases of the crops where it is less sensitive to water stress, three different drip irrigation treatments were applied in pear tree crop of Triunfo de Viena variety. Control, irrigated throughout the year at 100% of estimated crop evapotranspiration (ETc); 67%ETc and 55%ETc treatments were irrigated at 67 and 55% of the (ETc), respectively during the period of rapid fruit growth (from December 28, 2011 until February 29, 2012) and at 100% (ETc) during the rest of the season. Reference evapotranspiration (ETo) was determined by the Penman-Monteith, with hourly weather data collected in a nearby meteorological station. During the test total precipitation was 53.8 mm and the water application in the control treatments was 683.0 mm. The results indicate that none of the treatments differed significantly ($P \leq 0.05$) from control in terms of yield and quality, resulting in water savings of 33 to 45% in 67%ETc and 55%ETc respectively compared to the control. The vegetative growth of shoots had a behavior defined by a sigmoid curve fitted to a four parameter logistic equation, and it was significantly reduced in the 67%ETc and 55%ETc, respect to control, at the end of the restriction.

Key words: supplemental irrigation, pome fruits, vegetative growth, drip irrigation, soil water balance.

RESUMEN

El riego deficitario controlado (RDC) como la reducción de agua en fases de los cultivos en los que es menos sensible al estrés hídrico, se aplicó en tres tratamientos de riego por goteo en un cultivo de pera, variedad Triunfo de Viena. Control, regado durante todo el año al 100% de la evapotranspiración del cultivo - ETc, los tratamientos 67%ETc y 55%ETc fueron regados durante la etapa de crecimiento rápido del fruto (28 de diciembre 2011 hasta el 29 de febrero 2012) al 67 y 55% de la ETc, respectivamente, y el resto del año al 100% de la (ETc). La evapotranspiración potencial o de referencia (ETo) se determinó mediante la ecuación de Penman-Monteith, con datos climáticos que fueron recolectados cada hora mediante una estación meteorológica cercana a la parcela. Durante el ensayo la precipitación total fue 53,8 mm y la aplicación de agua en el tratamiento control 683,0 mm. Los resultados indicaron que ninguno de los tratamientos difirió significativamente ($P \leq 0{,}05$) del control en cuanto a producción y calidad, obteniéndose un ahorro de agua del 33 y 45%, respecto al control en los tratamientos 67%ETc y 55%ETc, respectivamente. El crecimiento vegetativo de los brotes tuvo un comportamiento definido por una curva sigmoide ajustada a una ecuación logística de cuatro parámetros, con diferencias significativas entre los tratamientos 67%ETc y 55%ETc, respecto al control, al final de la restricción.

Palabras clave: riego complementario, frutas de pepita, crecimiento vegetativo, riego por goteo, balance hídrico del suelo.

Introduction

Given the nutritional and medicinal properties of pear, planting and consumption has increased worldwide (Li *et al*., 2014). Climate change, rainfall, globalization of markets, and increasing costs of water and energy, require improvements in the development and utilization of water resources and irrigation equipment (Vélez *et al*., 2013).

Water consumption in agriculture represents about 87% of the total in the world and its demand is increasing (FAO, 2011). Since the 70`s the concept of regulated deficit irrigation controlled (RDI) defined as “reducing water input in those phases of the crops where it is less sensitive to water stress” was introduced (Chalmers *et al*., 1986). Several studies have been done since then using this RDI technique in pear tree crops (Marsal *et al*., 2002 and 2012; Wu *et al*.,

Received for publication: 24 June, 2015. Accepted for publication: 17 November, 2015.

Doi: 10.15446/agron.colomb.v33n3.50756

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2013; Naor *et al*., 2006) to achieve significant water savings without affecting yield and fruit quality and allowing some control of vegetative growth.

The Initiation, and differentiation of vegetative and reproductive structures, and cell elongation, once the cells were differentiated, are very sensitive to water stress, but they are not necessarily affected with the same intensity as other physiological processes (Barlow *et al*., 1980).

The vegetative development is very sensitive to water deficit, which normally reduces leaf surface area. This is a mechanism adopted by the plant to reduce water loss through transpiration (El-Sharkawy and Cock, 1987; Tudela and Primo-Millo, 1992). It is considered that the growth and crop productivity is proportional to the efficient use of water and a moderate water deficit in some cases may improve the quality of the product (Vélez *et al*., 2007a).

The indirect measurement of the water content of the plant has been performed by various techniques: using micro-variations of leaf thickness or of diameters of branches, stems and fruits (Kozlowski and Winguet, 1964; Kozlowski, 1967; Klepper *et al*., 1971; Huguet, 1985; Intrigliolo and Castel, 2006; Vélez *et al*., 2007b). During the day, when transpiration exceeds the capacity of roots for providing water to the plant, tissues dehydrated and the stem shrinks. Overnight, when transpiration ceases the diameter of the stem increases gradually until it reaches a maximum degree of hydration at dawn.

The most frequently parameters used as indicators of water stress on trees are: maximum daily trunk shrinkage (MDS), trunk growth rate (TGR) and, maximum diameter of the trunk (MDT) which is reached by the end of the night when hydration is maximum. Minimum trunk diameter is (MNDT) normally observed at sunset. MDS is equal to the difference between MDT and MNDT of the day (Garnier and Berger, 1986; Huguet *et al*., 1992; Cohen *et al*., 1997). The difference of MDT between one or more consecutive days is the TGR (Goldhamer *et al*., 1999; Goldhamer and Fereres 2001; Moriana and Fereres, 2002; Vélez *et al*., 2011).

The MDS can be used as a measure of the degree of dehydration of the plant, because it is closely related to water potential (So *et al*., 1979). Kozlowski (1967) was one of the first researchers to observe the shrinkage of the trunk diameter throughout the day; however Garnier and Berger (1986) were among the first ones who proposed automation of irrigation scheduling based on the data generated by trunk diameter variations. The trunk growth from medium to long term is reduced in proportion to the reduction of water supply (Hilgeman and Sharp, 1970). Reductions in stem growth by deficit irrigation have been reported in several fruit tree species (Conejero *et al*., 2007 in peach; Vélez *et al*., 2007a in Clementina de Nules; Intrigliolo and Castel, 2010 in plum). However, trunk growth is not always affected when the water deficit is low (Domingo *et al*., 1996).

A water deficit in adult pear trees during the stage of cell division, which corresponds to the period of vegetative growth, can restrict the growth of stems without affecting fruit size (Wu *et al*., 2013).

The aim of this study was to determine the effect of reducing the volume of water applied during the period of rapid fruit growth on yield and vegetative growth of shoots in a pear crop cv. Triunfo de Viena.

Materials and methods

The experiment was performed from December 2011 to February 2012 in an orchard planted with pear cv. Triunfo de Viena. The trees have been planted in 1998 at a spacing of 4 x 4 m in box and were drip irrigated by six emitters per tree, each giving 8.0 L h^{-1}. The orchard is located 5º02'53.65" N; 73º48'12.78 "W at the Sesquile city (Cundinamarca, Colombia), elevation 2,595 m a.s.l. and mean temperature of 14ºC.

The soil is of clay loam texture, with an effective depth of 1.0 m. Field capacity and wilting point are 26.9 and 15.3% by volume, respectively. The pH is 4.6. The soil is rich in available potassium (78.2 mg kg^{-1}), organic matter (5.06%) and phosphorus (23.9 mg kg^{-1}). The irrigation water used had an average electrical conductivity (at 20ºC) of 2 dS m^{-1} and a pH of 5.9.

Three different irrigation treatments were applied: control, drip irrigated throughout the year at 100% of estimated crop evapotranspiration (ETc) using an average Kc of 0.43 (Allen *et al*., 1998); treatments 67%ETc and 55%ETc that were irrigated during the period of rapid fruit growth (from December 28, 2011 to February 29, 2012) at 67% and 55% of the ETc, respectively and at 100% of ETc during the rest of the season, estimated values as a starting point to find a threshold. All treatments were irrigated at the same frequency which was two to three times a week. Effective rainfall during the period (53.8 mm) was considered and substracted from the irrigation estimates.

The statistical design was a randomized complete-block with four replicates per treatment. The experimental unit had four or five rows with three, four or five trees per row. In all cases perimeter trees were used as guard. Yield was determined as an average of all rows of the experimental units.

Water meters (Contagua, S.A., Model 13.115) were used to measure irrigation applied to each experimental unit. The water volume applied to each treatment was controlled by varying the run time, with a common frequency for all treatments of two to three days a week. Reference evapotranspiration (ETo) was determined by the Penman-Monteith (Allen *et al.*, 1998), with hourly weather data collected at an automated weather station located about 100 m away from the orchard.

The matric potential of soil water (Ψs) was measured with Watermark sensors (Watermark, Irrometer Company, Riverside, CA), which were installed at 30 cm deep and separated 25 cm from the irrigation line. Thirteen units were installed for each of the 67%ETc and 55%ETc treatments, and only 10 in the control.

Mid-day stem water potential (Ψstem) was measured since 16 December 2011 (34 days after full bloom (DAFB)) until 21 April 2012 (160 DAFB) with a Scholander pressure chamber mod. 600 (Soilmoisture Equip. Corp., Santa Barbara, CA), following procedures described by Scholander *et al.* (1965) and Turner (1981). The determinations of Ψstem were performed in three leaves per tree and two trees per treatment and were carried out (between 12:00 and 13:00 HR solar time, approximately, every 15 d) in mature leaves from the north quadrant close to the trunk, enclosed in plastic bags covered with silver foil at least 2 h prior to the measurements.

For vegetative growth of shoots, in 12 November 2011, 12 young shoots were selected for uniformity with an average length of 10 cm, in each experimental unit of each replicate for a total of 48 per treatment, and every 15 d their length and diameter of the base were measured, with a manual flexometer and caliper, respectively.

The behavior of a plant over time in a particular ecosystem is reflected by its growth curves. They constitute an essential tool for the rational implementation of agricultural work at the right time, and to ensure optimal response according to the crop demand (Casierra-Posada *et al.*, 2003). The phases of growth and development depend largely on the water status of the plant and environmental conditions such as: temperature, relative humidity and solar luminosity (Casierra-Posada, 2012). Plant growth is more commonly expressed by the absolute growth rate (AGR) and by the relative growth rate (RGR) (Hunt, 1990).

The absolute growth rate (AGR) indicates the size change per unit time, corresponding to the first derivative of growth with respect to time (Hunt, 2003) (Eq. 1).

$$AGR = \frac{\delta L}{\delta t} \tag{1}$$

where, dL/dt is the derivative of the dimension evaluated with respect to time, cm d^{-1}

The relative growth rate (RGR) indicates the variation of size per initial unit size, cm cm^{-1} d^{-1} (Hunt, 2003) (Eq. 2).

$$RCR = \left(\frac{1}{L}\right)\left(\frac{\delta L}{\delta t}\right) \tag{2}$$

where, L: is the dimension evaluated, cm.

The growth curves were adjusted to sigmoid equations of three or four parameters.

Trunk diameter variations (TDV) were measured from December 2011 in three selected trees per treatment (to wich are also measured the Ψstem). On each experimental tree, an Linear Variable Differential Transformer-LVDT sensor was fixed to the main trunk by a metal frame of Invar (a metal alloy with a minimal thermal expansion) located about 20 cm from the ground. Other details on sensors installation and calibration, and data recording were given in Vélez *et al.* (2007a). From TDV, we calculated the maximum daily trunk shrinkage (MDS) obtained as the difference between the maximum daily trunk diameter (MDT), reached early in the morning, and the minimum trunk diameter is (MNDT) normally observed at sunset. Trunk growth rate (TGR) is calculated as the difference between the MDT in two consecutive days (Intrigliolo and Castel, 2006).

At the end of the season April 2012, yield and yield components were determined by commercial harvest.

Statistical analysis was performed by analysis of variance (ANOVA) and multiple comparison test LSD. Using SPSS statistics 20.0 IBM program (IBM Corporation, 2011).

Results and discussion

Irrigation applied

During the experiment the estimated reference evapotranspiration (ETo), was 2.84 mm d^{-1} in January and 3.17 mm d^{-1} in February. The average Kc used was 0.43 considering type of crop (Allen *et al*., 1998), percentage of area measured and irrigation efficiency, and given that the effective precipitation was 53.8 mm, the resultant water application was 683, 460 and 377 L/tree, in the control, 67%ETc and 55%ETc, respectively. This represented water saving of 33 and 45% in 67%ETc and 55%Etc, respectively compared to the control during the period of the differential application of irrigation.

Growth of the shoots

The vegetative growth (length and basal diameter) was determined in the selected shoots. The maximum growth was obtained in the control, similar to what was found in cherry by (Podesta *et al*., 2010). The equation that best represents the growth pattern of shoots is a sigmoid of three parameters which had values of the coefficient of determination greater than 0.99 (Eq. 3).

$$y = \frac{\alpha}{1 + e^{-\left(\frac{x - x_0}{b}\right)}} \quad (3)$$

where, y, is the dimension of the shoots; a, the maximum dimension reached by the shoots; X, days after flowering; X_0, time when the absolute maximum growth rate is achieved and b, constant of proportionality. The values of the adjusted parameters and the coefficient of determination, R^2 are shown in Tab. 1.

When treatments started the shoots had already reached about 60% of its final length. In the period of restriction, growth per day decreased more in 67%ETc and 55%ETc treatments than in the control. However, differences were only significant between control and 67%ETc for days 111, 125, 139, 153 and 168 DAFB but not between 55%ETc and control and more surprisingly 67%ETc and 55%ETc also did not differ. According to the findings of Chalmers *et al.* (1986) in pear and of Wu *et al.* (2013) in 'Bretschneideri' pear, vegetative growth is affected by water deficit thereby reducing the final length of the shoots (Fig. 1).

The growth of the shoot basal diameter before and during the period of restriction was similar. Only after finishing

TABLE 1. Growth regression equations of shoot length and diameter for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia).

Treatment	Model length	Model diameter
Control	a = 89.216; b = 30.765; X_0 = 47.124; R^2 0.998	a =8.98; b =57.96; X_0 = -2.14; R^2 0.996
67%ETc	a = 69.178; b = 27.130; X_0 = 37.984; R^2 0.997	a =8.24; b =58.83; X_0 = -15.84; R^2 0.992
55%ETc	a = 79.262; b = 27.148; X_0 = 40.793; R^2 0.998	a =8.37; b =48.89; X_0 = -8.28; R^2 0.994

Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth. a, length (cm) and diameter (mm) dimensionless; X_0, days.

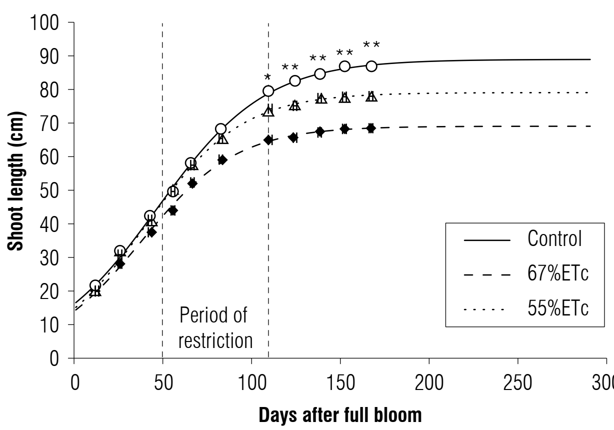

FIGURE 1. Growth curve of shoot length for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth. * and ** significant at $P \leq 0.05$ and $P \leq 0.01$, respectively with respect to control according to the LSD test.

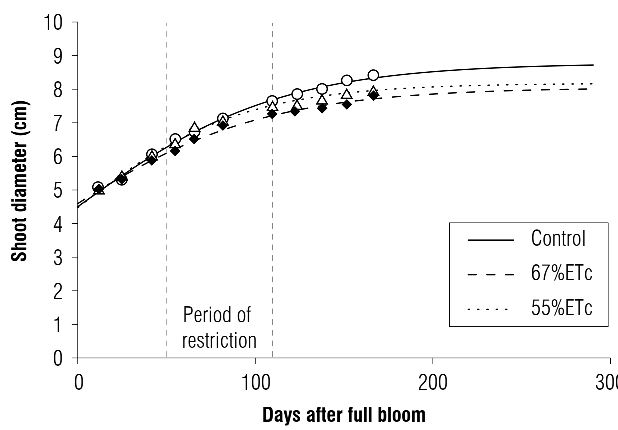

FIGURE 2. Growth curve of shoot basal diameter for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth.

this water restriction period a decrease in 67%ETc and 55%ETc was observed, finally reaching a smaller diameter than in the control treatment, with no significant differences (Fig. 2).

In deriving Eq. 3, the AGR of shoot length is obtained (Eq. 4).

$$\frac{\partial y}{\partial x} = \frac{\alpha^{*} e^{\frac{x-x_0}{b}}}{2b^{*}e^{\frac{x+x_0}{b}} + b^{*}e^{\frac{2x}{b}} + b^{*}e^{\frac{2x_0}{b}}} \tag{4}$$

The values of the parameters obtained from the regression for each treatment are shown in Tab. 2.

TABLE 2. Parameters of the absolute growth rate (AGR) model of shoot length for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia).

Treatment	Model
Control	X_0 = 47.124; a = 89.216; b = 30.765
67%ETc	X_0 = 37.984; a = 69.178; b = 27.13
55%ETc	X_0 = 40.793; a = 79.262; b = 27.148

Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth. *a*, length (cm) and diameter (mm) dimensionless; X_0, days.

The absolute minimal longitudinal shoot growth rate occurs in the 67%ETc treatment (0.64 cm d^{-1}), while in control and 55%ETc treatments it reached similar values (0.72 and 0.73 cm d^{-1} DAFB). The maximum AGR took place before starting the restriction period on 41, 38 and 47 DAFB for control, 67%ETc and 55%ETc, respectively, coinciding with the onset of rapid fruit growth (50 DAFB). After the restriction period 67%ETc and 55%ETc treatments had similar behavior, with lower values than the control (Fig. 3).

The AGR of the basal shoot diameter is calculated by derivation of Eq. 3 and 4. The value of the parameters obtained from regression for each treatment are indicated in Tab. 3.

TABLE 3. Parameters of the absolute growth rate model (AGR) of basal shoot diameter for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia).

Treatment	Model
Control	X_0 = -2.14; a = 8.98; b = 57.96
67%ETc	X_0 = -15.84; a = 8.24; b = 58.83
55%ETc	X_0 = -8.28; a = 8.37; b = 48.89

Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth. *a*, length (cm) and diameter (mm) dimensionless; X_0, days.

The highest growth rate of shoot diameter occurred in the 55%ETc treatment (DAFB 0.045 cm d^{-1}), while the control and 67%ETc treatments had similar values (0.039 and 0.036 cm d^{-1} DAFB). The maximum AGR occurred before starting the restriction period on days 1, 12 and 8 DAFB for control, 67%ETc and 55%ETc, respectively, before the onset of rapid fruit growth (50 DAFB). During and after the period of restriction the variation of shoot diameter on control and 67%ETc treatments was similar, while 55%ETc treatment had reduced values from mid restriction period onwards (Fig. 4).

The RGR of shoots was calculated with Eq. 2. The values of the parameters for shoot length and diameter models are shown in Tabs. 4 and 5. Figures 5 and 6 show the decreasing trend during the assessment period for both length and diameter, with no significant differences among treatments, $P \leq 0.05$.

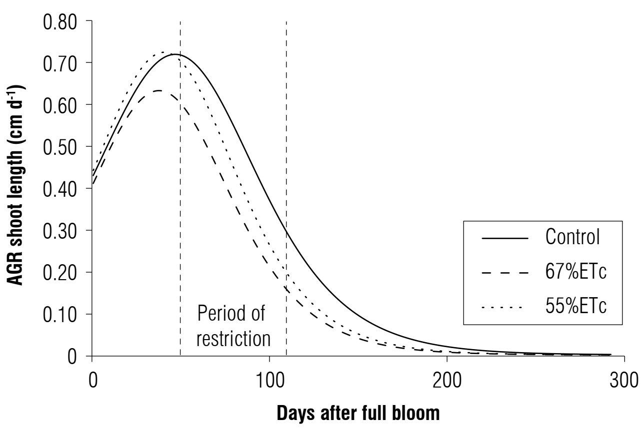

FIGURE 3. Behavior of absolute growth rate (AGR) of shoot length for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth.

FIGURE 4. Behavior of absolute growth rate (AGR) of shoot diameter for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth.

TABLE 4. Values of the parameters of the relative growth rate models (RGR) of shoot length for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia).

Treatment	Model
Control	X_0 =47.124; a = 89.216; b = 30.765
67%ETc	X_0 = 37.984; a = 69.178; b = 27.13
55%ETc	X_0 = 40.793; a = 79.262; b = 27.148

Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth. *a*, length (cm) and diameter (mm) dimensionless; X_0, days.

TABLE 5. Values of the parameters of the relative growth rate models (RGR) of shoot diameter for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia).

Treatment	Model
Control	X_0 =-2.14; a = 8.98; b = 57.96
67%ETc	X_0 = -15.84; a = 8.24; b = 58.83
55%ETc	X_0 = -8.28; a = 8.37; b = 48.89

Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth. *a*, length (cm) and diameter (mm) dimensionless; X_0, days.

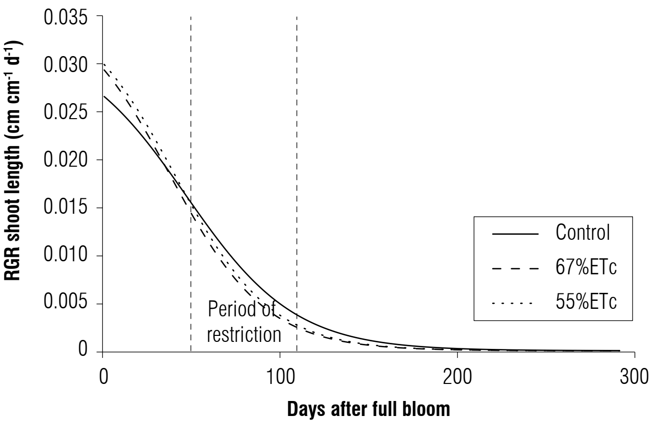

FIGURE 5. Relative growth rate (RGR) of shoot length for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth.

Variation of the trunk diameter

Once the restriction finished on 110 DAF, the daily variation of the trunk diameter, clearly shows vegetative growth, which is directly related to the water status of the plant.

The maximum trunk diameter in the control treatment was greater than in 67%ETc and 55%ETc treatments, and the maximum daily trunk shrinkage (MDS) was significant difference ($P \leq 0.05$) between the control and 55%ETc treatments at 116 DAFB, coinciding with the less negative soil (Ψs) and plant (Ψstem) water potential. This pattern is similar to that found by several authors in other fruit tree species (Huguet *et al.*, 1992; Goldhamer *et al.*, 1999; Moriana and Fereres, 2002; Intrigliolo and Castel, 2006; Vélez *et al.*, 2007a).

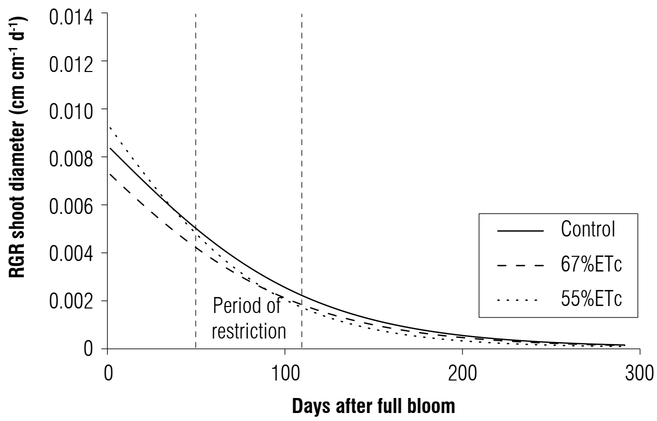

FIGURE 6. Relative growth rate (RGR) of shoot diameter for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth.

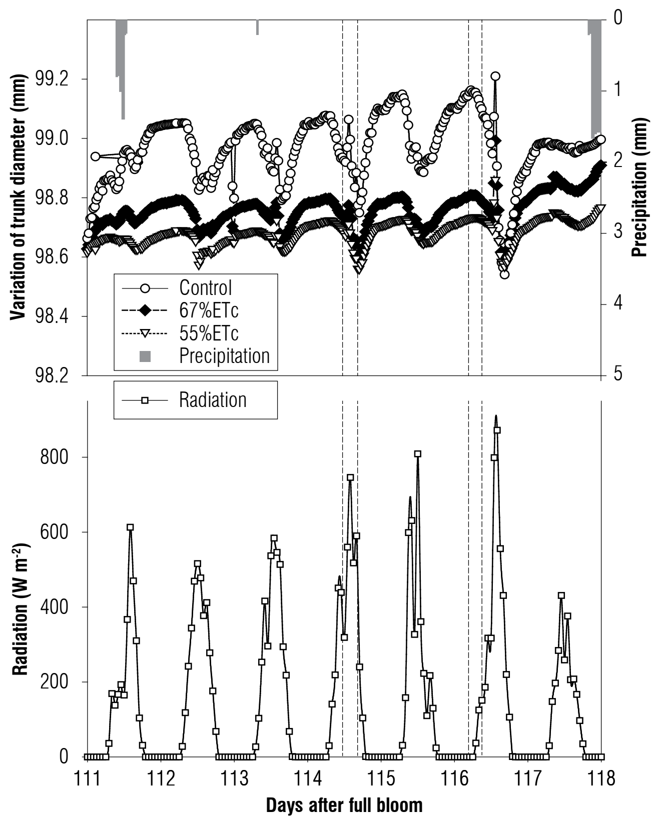

FIGURE 7. Evolution of trunk diameter for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). A, precipitation; B, solar radiation. Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth.

The evolution of the trunk diameter is very sensitive to the evaporative demand, and to the use of the tree's water reserves. The response of the trunk diameter of pear 'Triumph Vienna' to water loss is rapid, in the control treatment the shrinking phase beginning with a delay of about 2 h respect to the solar radiation, while in the deficit treatment 67%ETc, the shrinkage was even faster. Figure 7 shows the daily variations of the trunk diameter during a typical period of about a week. At noon, when the higher evaporative demand occurs, the smallest value of trunk diameter is reached and at midnight, the highest for all treatments is observed. A similar behavior was observed by Hilgeman (1963) in Valencia orange and by Ginestar and Castel (1996) and Vélez *et al.* (2007a) in clementine Nules.

Water relations

The vegetative shoot growth fluctuated according to the water volume application to each of the treatments.

The Ψs of control treatment was maintained during the period of restriction between -20 and -60 kPa, higher than 67%ETc and 55%ETc; being more negative in the higher restriction treatment and differences among treatments disappearing after periods of rain (Fig. 8).

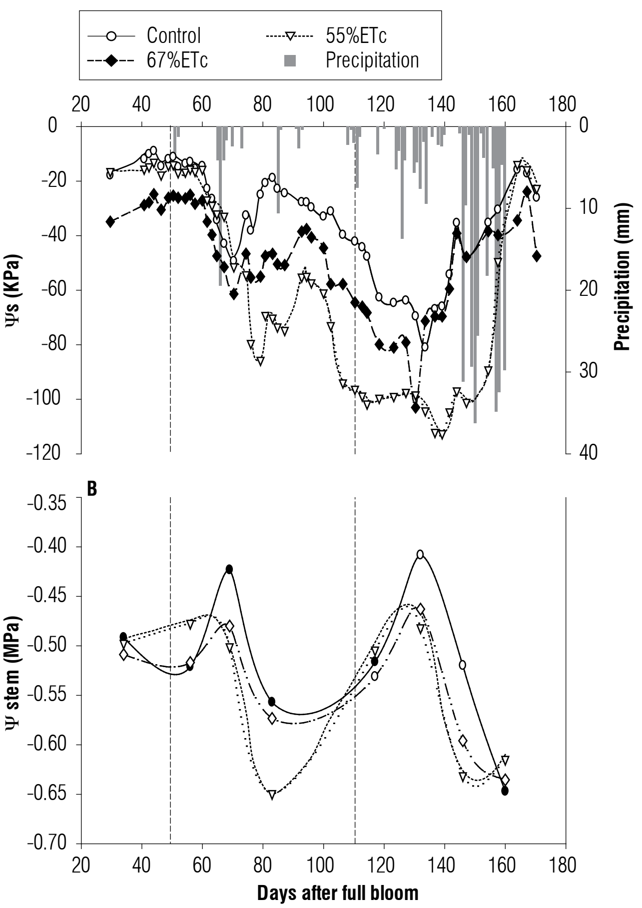

FIGURE 8. Water relations for pear 'Triunfo de Viena' crop with regulated deficit irrigation (Bogota Plateau, Colombia). A, soil water potential (Ψs); B, stem water potential (Ψstem, averages of three leaves per tree and three trees per treatment). Control, irrigation with 100% ETc; 67%ETc, irrigation with 67% ETc during the period of rapid fruit growth; 55%ETc, irrigation with 55% ETc during the period of rapid fruit growth.

With the imposition of the water restrictions the Ψstem, as expected, tended to decrease (Fig. 8). The 55%ETc treatment, which was the less irrigated, had lower values than the control and 67%ETc treatments, although the differences were not significant, $P \leq 0.05$). The minimum Ψstem value observed, -0.65 MPa, occurred after 33 d of starting the water restriction (83 DAFB) and was indicative of only mild plant water stress.

Yield and quality

Yield and fruit quality data are described in detail elsewhere (Molina *et al.*, 2015). Here it should be remarked that there were no significant differences ($P \leq 0.05$) in the yield and quality parameters, possibly due to the fact that the level of water stress originated by the deficit treatments was only mild. Thus, control treatment had a yield equal to treatment 55%ETc and only 4.4% higher than 67%ETc.

Conclusions

Deficit irrigation applied during the period of rapid fruit growth in this experiment produced a reduction of vegetative growth of trees. However, yield and fruit quality were not significantly affected.

The vegetative growth was adjusted to a logistic model in all treatments, allowing to observe the coincidence of completion of the rapid growth of the shoots with the onset of rapid fruit growth.

The LVDT measurements allowed clear differentiation of tree growth among treatments, which was proportional to the amount of water applied to each treatment. Therefore, these instruments show promise for scheduling irrigation based on plant water status estimated in real time and continuously.

Acknowledgements

This research was supported by funds from Hermes, project 20719 and Acqua Irrigation Ltda. Thanks also to Dr. Juan Ramón Castel for his help.

Literature cited

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration, guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56. FAO, Roma.

Barlow, E.W.R., R.E. Munns, and C.J. Brady. 1980. Drought responses of apical meristems. pp. 191-205. In: Turner, N.C. and P.J. Kramer (eds.). Adaptation of plants to water and hight temperature stress. Wiley, New York, NY.

Casierra-Posada, F. 2012. Manzano y peral (*Malus domestica* Borkh. y *Pyrus communis* L.). pp. 657-681. In: Fischer, G. (ed.). Manual para el cultivo de frutales en el trópico. Produmedios, Bogota.

Casierra-Posada, F., D.I. Hernández, P. Lüdders, and G. Ebert. 2003. Crecimiento de frutos y ramas de manzano 'Anna' (*Malus domestica* Borkh.) cultivado en los altiplanos colombianos. Agron. Colomb. 21, 69-73.

Chalmers, D.J., G. Burge, P.H. Jerie, and P.D. Mitchell. 1986. The mechanism of regulation of 'Barlett' pear fruit and vegetative growth by irrigation withholding and regulated deficit irrigation. J. Amer. Soc. Hort. Sci. 111, 904-907.

Cohen, M., T. Ameglío, P. Cruisiat, P. Archer, C. Valancogne, and S. Dayau. 1997. Yield and physiological responses of walnut trees in semiarid conditions: application to irrigation scheduling. Acta Hort. 449, 273-280. Doi: 10.17660/ActaHortic.1997.449.39

Conejero, W., J.J. Alarcón, Y. García-Orellana, E. Nicolás, and A. Torrecillas. 2007. Evaluation of sap flow and trunk diameter sensors used for irrigation scheduling in early maturing peach trees. Tree Physiol. 27, 1753-1759. Doi: 10.1093/treephys/27.12.1753

Domingo, R., M. Ruiz-Sánchez, M. Sánchez-Blanco, and A. Torrecillas. 1996. Water relations, growth and yield of Fino lemon trees under regulated deficit irrigation. Irrig. Sci. 16, 115-123. Doi: 10.1007/BF02215619

El-Sharkawy, M.A. and J.H. Cock. 1987. Response of cassava to water stress. Plant and Soil 100, 345-360. Doi: 10.1007/BF02370950

FAO. 2011. The state of food insecurity in the world. Rome.

Garnier, E. and A. Berger. 1986. Effect of water stress on stem diameter changes of peach trees growing in the field. J. Appl. Ecol. 23, 193-209. Doi: 10.2307/2403091

Ginestar, C. and J.R. Castel. 1996. Us of stem dendrometers as indicators of water stress in drip-irrigated citrus trees. Acta Hort. 421, 209-219.

Goldhamer, D.A. and E. Fereres. 2001. Irrigation scheduling protocols using continuously recorded trunk diameter measurements. Irrig. Sci. 20, 15-125. Doi: 10.1007/s002710000034

Goldhamer, D.A., E. Fereres, M. Mata, J. Girona, and M. Cohen. 1999. Sensitivity of continuos and discrete plant and soil water status monitoring in peach trees subjected to deficit irrigation. J. Amer. Soc. Hort. Sci. 124, 437-444.

Hilgeman, R.H. 1963. Trunk growth of the 'Valencia' orange in relation to soil moisture and climate. Proc. Amer. Soc. Hort. Sci. 82, 193-198.

Hilgeman, R.H. and F.O. Sharp. 1970. Response of 'Valencia' orange trees to four soil water schedules during 20 years. J. Amer. Soc. Hort. Sci. 95, 739-745.

Huguet, J.G. 1985. Appréciation del´ état hydrique d´ une plante á partir des variations micrométriques de la dimension des fruits ou des tiges au cours de la journée. Agronomie 5, 733-741. Doi: 10.1051/agro:19850809

Huguet, J.G., S.H. Li, J. Lorendeau, and G. Pelloux. 1992. Specific micromorphometric reactions of fruit trees to water stress and irrigation scheduling automation. J. Hort. Sci. 67, 631-640.

Hunt, R. 1990. Basic growth analysis. Plant growth analysis for beginners. Unwin Hyman, Boston. Doi: 10.1007/978-94-010-9117-6

Hunt, R. 2003. Growth analysis, individual plants. pp. 579-588. In: Encyclopaeida of plant sciences. Academis press, London. Doi: 10.1016/B0-12-227050-9/00028-4

IBM Corporation. 2011. IBM SPSS statistics for windows. Version 20.0. Armonk, NY.

Intrigliolo, D.S. and J.R. Castel. 2006. Performance of various water stress indicators for prediction of fruit size response to deficit irrigation in plum. Agri. Water Manage. 83, 173-180. Doi: 10.1016/j.agwat.2005.12.005

Intrigliolo, D.S. and J.R. Castel. 2010. Response of plum trees to deficit irrigation under two crop levels: tree growth, yield and fruit quality. Irrig. Sci. 28, 525-534. Doi: 10.1007/s00271-010-0212-x

Klepper, B., D.V. Browning, and H.M. Taylor. 1971. Stem diameter in relation to plant water status. Plant Physiol. 48, 683-685. Doi: 10.1104/pp.48.6.683

Kozlowski, T.T. 1967. Diurnal variations in stem diameter of small trees. Bot. Gaz. 123, 60-68. Doi: 10.1086/336380

Kozlowski, T.T. and C.H. Winguet. 1964. Diurnal and seasonal variation in radio of tree stems. Ecology 45, 149-155. Doi: 10.2307/1937115

Li, X., T. Wang, B. Zhou, W. Gao, J. Cao, and L. Huang. 2014. Chemical composition and antioxidant and anti-inflammatory potential of peels and flesh from 10 different pear varieties (*Pyrus* spp.). Food Chem. 152, 531-538. Doi: 10.1016/j.foodchem.2013.12.010

Marsal, J., M. Mata, A. Arbone´s, J. Rufat, and J. Girona. 2002. Regulated deficit irrigation and rectification of irrigation scheduling in young pear trees: an evaluation based on vegetative and productive response. Eur. J. Agron. 17, 111-122. Doi: 10.1016/S1161-0301(02)00002-3

Marsal, J., G. López, M. Mata, and J. Girona. 2012. Postharvest deficit irrigation in 'Conference' pear: effects on subsequent yield and fruit quality. Agri. Water Manage. 103, 1-7. Doi: 10.1016/S1161-0301(02)00002-3

Molina, J., J. Vélez, and A. Galindo. 2015. Resultados preliminares del efecto del riego deficitario durante el periodo de crecimiento rápido del fruto (pero, cv. Triunfo de Viena) en la producción y calidad del fruto. Rev. Colomb. Cienc. Hortíc. 9, 38-45. Doi: 10.17584/rcch.2015v9i1.3744

Moriana, A. and E. Fereres. 2002. Plant indicators for scheduling irrigation of young olive trees. Irrig. Sci. 21, 83-90. Doi: 10.1007/s00271-001-0053-8

Naor, A., R. Stern, M.A. Flaishman, Y. Gal, and M. Peres. 2006. Effects of postharvest water stress on autumnal bloom and subsequent-season productivity in mid-season 'Spadona' pear. J. Hortic. Sci. Biotech. 81, 365-370.

Podesta, L., E. Sánchez, R. Vallone, and J.A. Morabito. 2010. Efecto del riego deficitario controlado sobre el crecimiento vegetativo en plantaciones jóvenes de cerezo (*Prunus avium* L.). Rev. Fca. UN. Cuyo. 42, 73-91.

Scholander, P.F., H.T. Hammel, E.D. Bradstreet, and E.A. Hemmingsen. 1965. Sap presure in vascular plants. Science 184, 339-346. Doi: 10.1126/science.148.3668.339

So, H.B., D.C. Reicosky, and H.M. Taylor. 1979. Utility of stem diameter changes as predictors of plant canopy water potential. Agron. J. 71, 707-713. Doi: 10.2134/agronj1979.00021962007100050004x

Tudela, D. and E. Primo-Millo. 1992. 1-Aminocyclopropane-1-carboxylic acid transported from roots to shoots promotes leaf abscission in Cleopatra mandarin (*Citrus reshni* Hort. ex Tan.) seedlings rehydrated after water stress. Plant Physiol. 100, 131-137. Doi: 10.1104/pp.100.1.131

Turner, N.C. 1981. Techniques and experimental approaches for the measurement of plant water status. Plant and Soil 58, 339-336. Doi: 10.1007/BF02180062

Vélez, J., D.S. Intrigliolo, and J.R. Castel. 2007a. Scheduling deficit irrigation of citrus trees with maximum daily trunk shrinkage. Agri. Water Manage. 90, 197-20. Doi: 10.1016/j.agwat.2007.03.007

Vélez, J., D.S. Intrigliolo, and J.R. Castel. 2007b. Programación del riego deficitario en Clementina de Nules, mediante Dendrómetros. Int. Mag. Citrus 38, 313-317.

Vélez, J., D.S. Intrigliolo, and J.R. Castel. 2011. Programación de riego en base a sensores de medida del estado hídrico del suelo y de la planta. Rev. Cient. U.D.C.A. 14, 197-20.

Vélez, J., H. Camacho, and J. Álvarez. 2013. Evaluación de goteros utilizados en micro irrigación en Colombia. Rev. Colomb. Cienc. Hortic. 7, 186-200. Doi: 10.17584/rcch.2013v7i2.2234

Wu, Y., Z. Zhao, W. Wang, Y. Ma, and X. Huang. 2013. Yield and growth of mature pear trees under water deficit during slow fruit growth stages in sparse planting orchard. Sci Hort. 164, 189-195. Doi: 10.1016/j.scienta.2013.09.025