Dynamics of Fruit Growth in 'Conference' Pear as Affected by Root Pruning, Irrigation and Climatic Conditions

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Abstract

In 2002, daily fluctuations in trunk diameter and fruit diameter on 'Conference' pear trees were measured with linear voltage displacement transducers. On an average sunny day in July, trunk diameter started to decrease around 10 a.m. when air temperature increased. This continued until 8 p.m. when air temperature started to decline. Fruit diameter growth of 'Conference' ceased as soon as trunk diameter started to decrease and resumed immediately after trunk diameter started to increase. When fruit growth took place, the rate of diameter increase was fairly constant and was ~ 0.04 mm/h. Root pruning without irrigation significantly affected tree growth but not fruit growth. Fruit size increase was almost linear from early May up to harvest at the beginning of September and averaged 3.9 mm/week. Relationships between fruit growth, climatic condition, soil water availability and cultural practices are discussed.

INTRODUCTION

Root pruning has become common practice for controlling shoot growth in pear trees in the Netherlands since the ban on the use of the chemical growth retardant chlormequat (CCC, 2-chloroethyltrimethylammonium) in 2001. Although many fruit growers successfully apply this method of mechanical growth control, it is a risky method. Too strong pruning may result in reduced fruit size or decrease in fruit quality due to insufficient uptake capacity for water and nutrients by the remaining root system. As root-pruned trees are more likely to suffer from drought stress, the recommendation is to root prune only in orchards in which trees can be irrigated (Wertheim, 2004).

In order to optimize irrigation and growth control, more information is needed on the dynamics of fruit growth as related to water availability in the soil and the evaporation by the canopy of the tree. A technique to monitor the water demand of the tree would be helpful for establishing the relationships between water availability, water uptake and evaporation of trees before and after root pruning. Depending on the amount of water stress experienced by the tree, the grower might decide to carry out additional root pruning, supply water to the trees, or try to reduce the evaporation of the trees by sprinkling water on the leaves.

Trunk diameter fluctuations have been shown to be a good parameter for the water status of a tree. During daytime, the diameter of the trunk starts shrinking when the tree begins to transpire. Trunk diameter increases again as soon as the transpiration of the tree diminishes from the end of the day to the next morning. The degree of shrinkage of the trunk during daytime has been used in several species of fruit trees as a parameter to control irrigation (Huguet et al., 1992; Bonany et al., 2000).

This paper describes the first experiments on the use of linear voltage displacement transducers (LVDT's) for monitoring daily fluctuations and growth of trunks and fruits of pear trees in an orchard. In addition, effects of climatic and soil water conditions and root pruning on the dynamics of trunk and fruit growth are presented.

MATERIALS AND METHODS

Plant Material

In 2002, the experiments were performed on 'Conference' pear trees grafted on Quince MC and planted in 1997 in single rows at 3.50 x 1.00 m in the experimental orchard in Randwijk (51°North Latitude), The Netherlands. Trees were trained into a V-hedge with 4 main branches per tree starting from two-year old well-branched nursery trees. The trial of 2003 was carried out on trees planted in 1999 in Randwijk at 3.00 x 1.09 m. Two year-old 'Conference' trees on Quince MC with Doyenné du Comice as the interstem were trained as a V-hedge system consisting of 4 main branches per trunk. All trees were planted in fresh soil consisting of river clay with 30% silt.

Apparatus

Linear variable displacement transducers (LVDT's) for monitoring trunk and fruit diameter, watermarks for soil water tension, sensors for measuring temperature, relative humidity, global radiation, rain fall and wind speed, and Microisis data loggers were obtained from Sistemes Electronics Progres S.A. (www.progres-spain.com), Bellpuig (Lleida), Spain. A more detailed description of the material and its application is given by Bonany et al. (2000).

LVDT's were positioned on the trunk of trees at approx. 30 cm above the graft union using the specially designed sensor clamp made of temperature insensitive INVAR. The same clamps were also used to measure fruit diameter. In the latter case, fruit and sensor clamp were fixed to one the four bamboo canes supporting the fruit-bearing branches of the V-hedge. The tip of a measuring rod was attached to the trunk or fruit with a type of glue normally used for grafting.

Watermark sensors were positioned at 35 and 75 cm soil depth at approx. 30 cm from the trunk of the tree and the nearest drip point of the irrigation hose.

Temperature sensors were placed in a shaded position in the canopy and in the soil at the same position as the watermarks.

Humidity was measured at a height of 1.50 m within the canopy using a ventilated relative humidity sensor especially designed for environments with high humidity and great possibility of condensation in the sensor. Data were recorded using Microisis dataloggers (Progres-Spain).

In 2003, fruit diameter growth was measured on 25 marked fruits per tree using a digital calliper attached to a datalogger (Mitutoyo, The Netherlands; www.mitutoyo.nl)

Experimental Setup and Data Recording

1. Trial 2002. In 2002, the effects of root pruning on trunk and fruit diameter fluctuations of 'Conference' trees were compared to those of untreated trees and were related to climatic conditions and soil water tension. Each treatment consisted of three plots of 5 trees each. In each of the six experimental fields, one tree was selected for the measurements of trunk and fruit growth and soil water tensions at the two depths near the tree.

Recording of trunk and fruit growth dynamics, soil water tension and climatic conditions started in the first week of June 2002 and ended at harvest on 12 September. Data were recorded at an interval of 10 min and data collection from the dataloggers in the field was carried out every 3 to 4 days.

Root pruning was carried out on 26 June and 8 July 2002. The first time, the roots were pruned on one side using a 35 cm long, vertically-oriented knife that was pulled alongside the row at ca. 35 cm from the trunk. The second time, roots were pruned using a curved knife with a radius of approx. 30 cm. By using this type of knife at a distance of 30 cm from the trunk, almost half of the root system was pruned at a length of 30 cm from one side to below the trunk of the tree (50% root balling).

2. Trial 2003. In 2003, the following treatments were applied to 'Conference' trees: 1) no root pruning, optimal water; 2) no root pruning, no water; 3) 2-sided root pruning, optimal

water; 4) 2-sided root pruning, no water. Root pruning was carried out on 18 June 2003 on both sides of the tree using a 35 cm long vertical knife at a distance of approx. 30 cm from the trunk. Water was supplied to the optimal water treatment trees by drip irrigation when soil water tension increased above 40 kPa. From 24 May until 26 August, the total amount of water supplied to the tree corresponded to the equivalent of 370 mm of rain (37 liter water/ m² soil surface).

Recording of trunk and fruit growth dynamics, soil water tension and climatic conditions started on 30 May and ended at harvest on 9 September (fruits) or shortly after harvest. Climatic conditions, soil water tension, leaf temperature and trunk diameter were recorded once every 30 min. Fruit diameter was determined once a week.

Calculation of Vapour Pressure Deficit Between Leaves and Air

Vapour pressure deficit (VPD) between the leaves of the pear trees and the ambient air was calculated from the recorded air temperature and relative humidity of the air using the formula:

$$VPD = ((100-RH)/100) \times EXP(6.434 + ((17.27 \times T)/(237,2 + T)))/1000 \text{ kPa}$$

in which: RH = % relative humidity of the air, and T = temperature of the air in °C (Spomer & Tibbets, 1997).

Statistical Analysis

The data were statistically analyzed with the statistical software package Genstat (Hemel Hempstead, UK). In the case of significant differences ($P<0.05$), LSD values were calculated and used for comparing treatment means in pairs.

RESULTS AND DISCUSSION

Trial 2002

Trunk and fruit diameter of 'Conference' both showed distinct diurnal patterns. Fig. 1 presents an example of typical fluctuations in trunk and fruit diameter observed during several days in July 2002 as well as the fluctuations in vapour pressure deficit between leaves and air. As soon as it became light, VPD increased rapidly due to increasing air temperature and decreasing relative humidity (Fig. 2). Although transpiration of the tree was not determined, it can be assumed that transpiration of the trees increased with decreasing VPD. On an average sunny day in July, the diameter of the trunk began decreasing between 10:00 and 11:00 h and continued until about 22:00 h. The data suggest that above a certain vapour pressure deficit, the rate of transpiration exceeds the water uptake by the roots causing water to be drawn out of some cells of the trunk. Consequently, the trunk shrinks. As soon as the evaporative demand decreased at the end of day, the diameter of the trunk starts to increase.

Fruit diameter also showed a diurnal pattern. When water loss by transpiration was low and no shrinkage of the trunk was observed, i.e. from the end of the day until the next morning, fruit diameter increased at an almost constant rate of 0.042 mm/h. However, as soon as global radiation increased, VPD increased. Naturally, leaf transpiration will rapidly increase as VPD decreases. The data clearly indicate that on bright sunny days in July, water uptake becomes limited before midday, causing the trunk diameter to shrink and the fruits to stop growing. Growth resumed at the end of the afternoon as soon as transpiration slowed down, as a result of a decrease in VPD. Fig. 3 illustrates the increase in fruit diameter of 'Conference' pears during the second week of July 2002. Pruning half the root system did not affect fruit growth. Fruit diameter increase, determined over a 9 day period in July, was approximately linear and amounted to 0.71 mm/day for both untreated and root-pruned trees. Apparently, the remaining root system was still able to take up sufficient water to sustain fruit growth at the same level as in untreated trees.

Trial 2003

In 2003, only trunk diameter was continuously monitored using LVDT sensors

while fruit diameter growth was measured once a week on 25 randomly chosen and marked fruits per treatment using digital calipers. Trunk diameter showed similar daily fluctuations as observed in 2002. As shown in Fig. 4, total diameter increase from the end of May until the beginning of September was approximately 5 mm for the irrigated trees and 3.2 mm for the non-irrigated trees. Root pruning carried out on 17 June immediately increased the extent of daily shrinkage of the trunk during the daytime. However, root pruning did not affect total trunk diameter increase in either irrigated or non-irrigated trees.

In 2003, the total increase in trunk diameter was only affected by irrigation. Without irrigation, the increase in trunk diameter was less compared to the increase observed in irrigated trees from about July onwards, as soil water availability became limiting during the exceptionally dry summer in 2003 (Fig. 4A).

Although fruit diameter increase is not constant during a 24-h period, overall growth, as determined by weekly measurements, was found to be quite linear from May to harvest (Fig. 5). On average, fruit diameter increased by 0.56 mm/day and only minor differences in the rate of fruit diameter increase were observed between the irrigation and root pruning treatments (Table 1). Total number of fruits, average fruit weight, and total yield also did not differ significantly among the four treatments. However, the average values clearly showed a tendency towards reduced yield and fruit numbers by root pruning and withholding irrigation.

Fruit firmness at harvest was similar for all treatments. Fruits from non-irrigated trees contained more sugars than irrigated trees and root pruning further increased the sugar content. Green background colour was highest for fruits of irrigated trees. Without irrigation, fruits were slightly less green and root pruning resulted in an even greater reduction in green background colour. As the fruits of all treatments were harvested on the same date, an enhanced maturation of the fruits, in combination with a lower fruit load in the non-irrigated and root-pruned trees, may at least partly explain the increase sugar levels and reduction in green background colour in these treatments.

As root pruning in 2003 was carried out as late as 17 June, at which time most of the shoot development had already taken place, no significant effects of irrigation or root pruning on the number of shoots and total shoot length per tree was observed. However, non-irrigated and root-pruned trees showed small but significant decreases in average shoot length as compared to the trees which were not root pruned.

In both 2002 and 2003, no clear relationships were detected between soil water tension at 35 or 75 cm soil depth and the growth of shoots and fruits of ‘Conference’. Especially in the dry and warm summer of 2003, the soil around the non-irrigated trees became very dry (water tension ≥120 kPa) without having noticeable effects on shoot growth and fruit development. Trunk diameter increase was only significantly less in non-irrigated trees, but did not respond to root pruning. This indicates that the remaining roots of the root-pruned trees can in some way compensate the loss of water uptake by the pruned part of root system. Such a compensation of water uptake has been observed in apple in response to partial root zone irrigation (Green and Clothier, 1998).

CONCLUSIONS

Measurement of daily fluctuations in trunk diameter can be used to monitor the level of water stress experienced by a tree and the duration of fruit growth during a 24-h period. The maximum daily shrinkage increased immediately after part of the root systems was cut. Seasonal trunk growth responded to irrigation but not to root pruning. Root pruning did not affect fruit growth. Even when 50% of the root system was cut off and the upper 75 cm of the soil became very dry, the remaining root system of 4-year old trees could take up sufficient water to sustain fruit growth at an almost equal rate as in non root-pruned and well irrigated trees. More research is needed to determine whether a threshold level for maximum daily shrinkage exists at which fruit growth will be negatively affected. This could then be used as a trigger to regulate irrigation of ‘Conference’ trees.

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Tables

Table 1. Fruit growth and fruit quality parameters of 'Conference' pears as affected by root pruning and irrigation (Trial 2003).

Treatment[1]	Fruit diameter increase[2] (mm/day)	Yield/ tree (kg)	Number fruits/ tree	Fruit weight (g)	Fruit Firmness[3] (kg)	Sugar content (%Brix)	Background colour[4] (A-value)
-RP + W	0.57	10.1	44	234	6.7	12.9 a	-14.4 a
-RP - W	0.56	9.1	39	229	6.8	13.8 a	-13.1 b
+RP +W	0.55	8.6	38	237	6.5	14.1 ab	-12.7 bc
+RP - W	0.55	7.8	36	217	6.4	15.2 b	-11.8 c
F-test	ns	ns	ns	ns	ns	$p<0.05$	$p<0.01$
$LSD_{0.05}$	-	-	-	-	-	1.3	0.1

[1]RP = root pruning, W = water (irrigation);
[2]Determined by linear regression of weekly fruit diameter measurements from May until September as illustrated in Fig. 5.
[3]Determined on ground-colour side with a 7-mm diameter plunger.
[4]Measured with a Minolta colorimeter; more negative values = greener.

Table 2. Shoot and trunk growth parameters of Conference pears as affected by root pruning and irrigation (Trial 2003).

Treatment	Shoots/ tree >10 cm	Length/ shoot (cm)	Shoot length/ tree (m)	Trunk diameter Apr. 17 (mm)	Trunk diameter Dec. 17 (mm)	Total increase in trunk diameter (mm)
-RP +W	90	54.8 b	49.5	52.6	58.7	6.1 c
-RP - W	93	54.4 b	50.9	50.7	55.2	4.5 ab
+RP + W	97	51.8 ab	49.9	55.0	61.1	6.1 bc
+RP - W	99	46.8 a	46.5	53.1	56.9	3.7 a
F-test	ns	$p<0.05$	ns	ns	ns	$p<0.05$
$LSD_{0.05}$	-	5.1	-	-	-	1.6

Figures

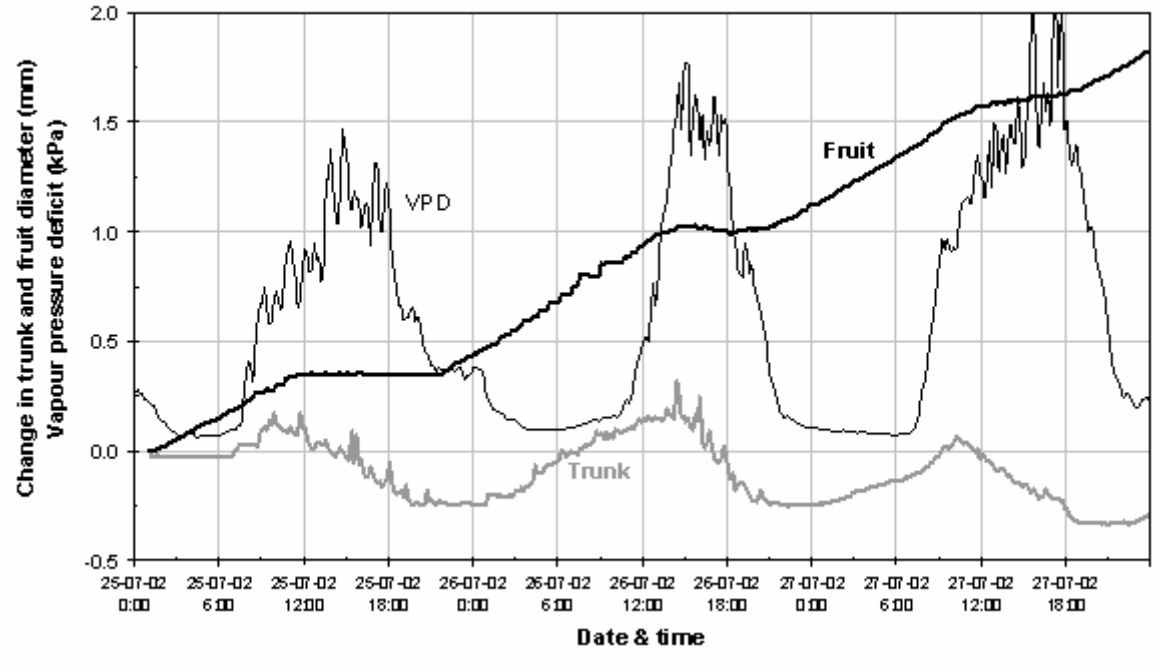

Fig. 1. Daily fluctuations in trunk and fruit diameter of 'Conference' and vapour pressure deficit (VPD) from 25 to 27 July 2002.

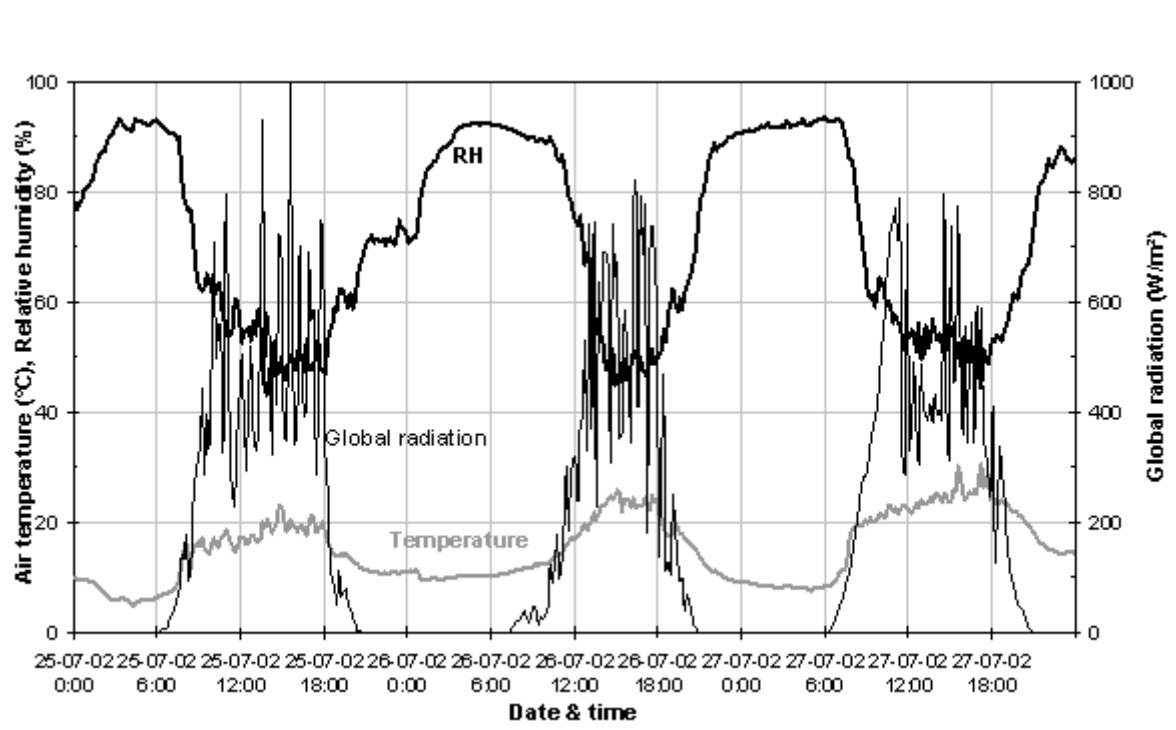

Fig. 2. Daily fluctuations in global radiation, air temperature and relative humidity in pear orchard in Randwijk from 25 to 27 July 2002.

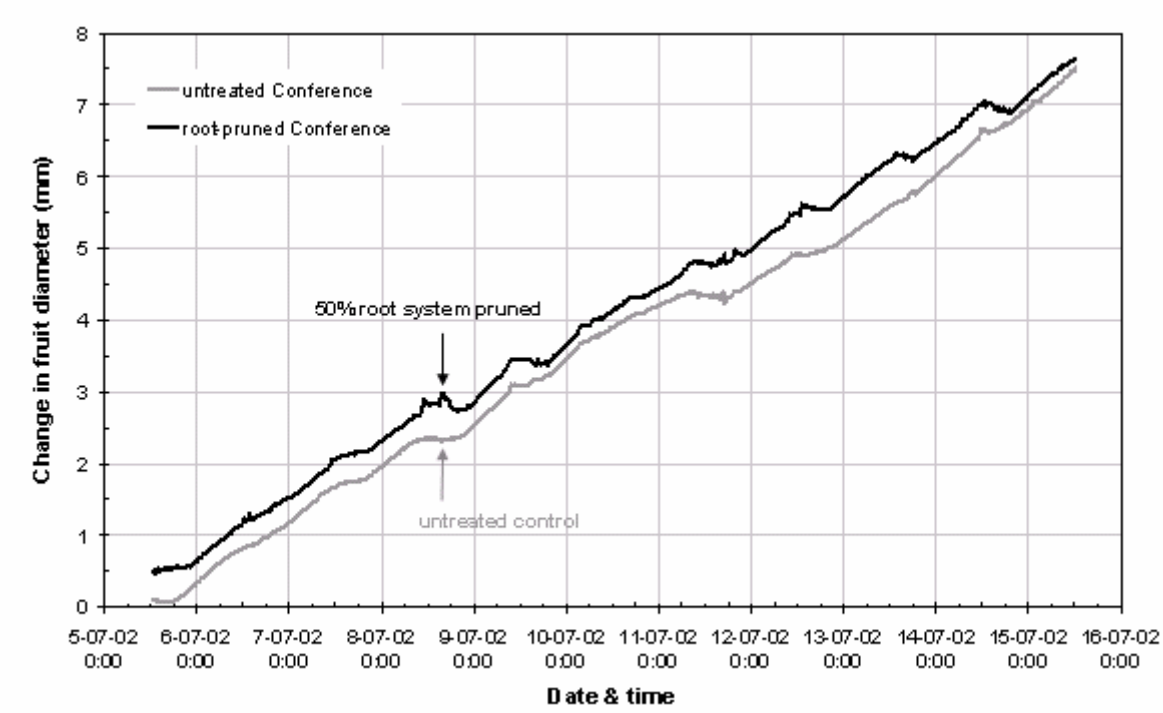

Fig. 3. Fruit diameter increase of 'Conference' pears in untreated and root-pruned trees in Randwijk from 6 to 15 July 2002.

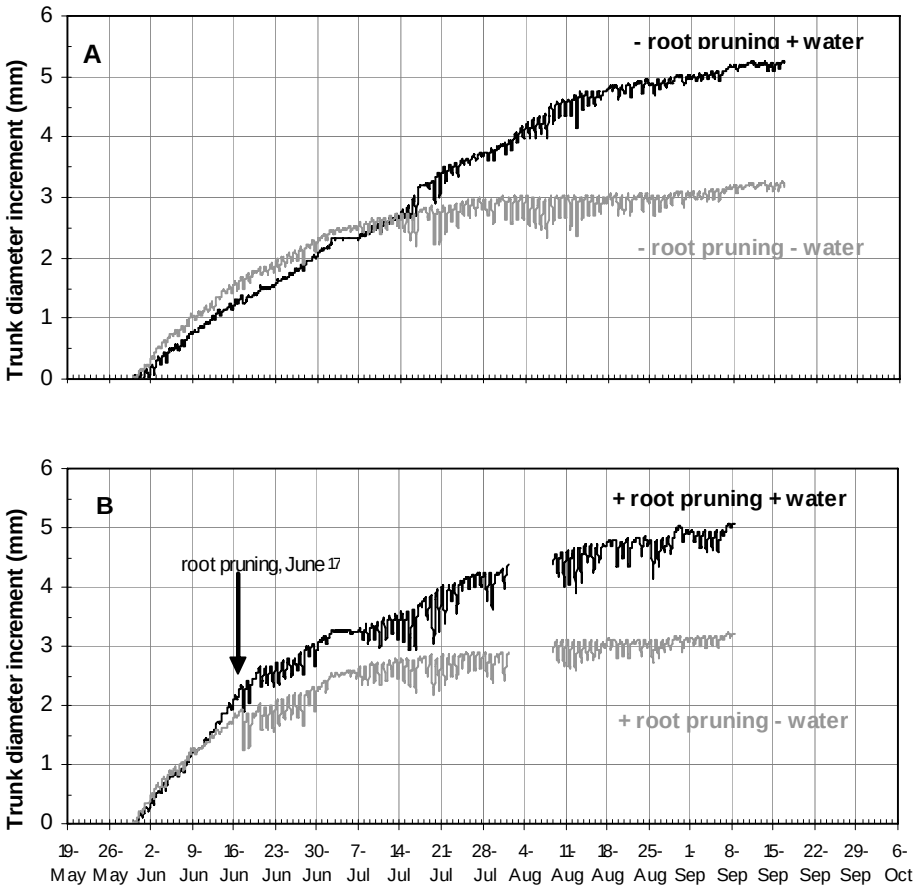

Fig. 4. Trunk diameter increase of 'Conference' trees in 2003 as affected by irrigation and root pruning (A = control ; B = root-pruned trees).

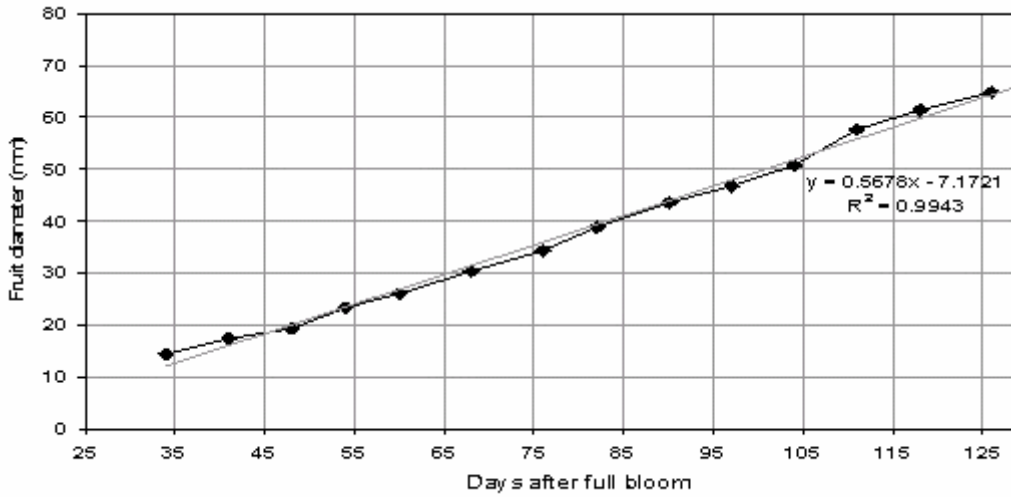

Fig. 5. Fruit diameter increase in 'Conference' between 15 May and 15 August 2003. The data represent the average diameter of 25 fruits.