Effect of root pruning and irrigation regimes on pear tree: growth, yield and yield components

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Abstract

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The effect of root pruning (RP) as compared with non-root pruning (NP) and the potential of supplemental irrigation in alleviating the negative effect of root pruning on fruit growth, yield and yield components were investigated in a pear orchard from 2010 to 2011. Results showed that the total shoot length and the number of shoots per tree decreased by 72% and 43%, respectively, in the RP compared to the NP trees; however lateral root growth was stimulated by the RP treatment in the upper soil layers (30–40 cm). Full irrigation and deficit irrigation treatments stabilized the return bloom and improved fruit yield and size compared with the non-irrigated treatment without stimulating vegetative growth. Conclusively, the results indicate that root pruning is an effective practice controlling excessive shoot growth, and supplemental irrigation can improve fruit yield and quality in the root pruned trees. Therefore, a combination of root pruning and irrigation could be a promising alternative to control tree size and secure a stable fruit yield in pear orchards.

Keywords: fruit yield; growth control; irrigation; return bloom; root growth

Growth control is one of the important elements in pear orchard management, as excessive vigour often causes a decrease in light penetration, reduction of fruit yield and quality, and an increase in pruning cost (Miller 1995). Thus, chemical growth retardants such as Cycocel (chlormequat chloride) were widely used for controlling canopy growth in pear orchards. However, due to increased environmental concerns, their use has been prohibited in Danish pear production since 2002. Therefore, in recent years great efforts have been made to develop sustainable alternatives to substitute the use of chemical growth regulators in the growth control of pear trees.

Root pruning was proven as one of such alternatives to control and regulate the vegetative growth of fruit trees (Geisler, Ferree 1984; Schupp, Ferree 1990). Poni et al. (1992) reported that root pruning was very effective in reducing shoot growth for potted grape, pear and apple trees. Ferree (1992) noted that root pruning reduced terminal shoot growth of apple trees by ca. 20%. Similarly, Khan

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et al. (1998) found that the height of apple trees was reduced by 12% in the second season and the shoot length, shoot number, and fruit diameter were all decreased as a consequence of root pruning. In pear trees, Asín et al. (2007) reported that root pruning significantly decreased shoot length by 25% compared with non-root-pruned control. The literature concerning the effect of root pruning on alternate bearing and flower induction is controversial. Some authors found root pruning reduced the occurrence of alternate bearing (Ferree 1992) and increased flowering spurs (Khan et al. 1998) in apple. Others found little or no impact on return bloom or alternate bearing (Schupp, Ferree 1987; McArtney, Belton 1992).

Despite the aforementioned advantages of root pruning in controlling canopy size, there are several obvious negative effects associated with this practice. Early studies show that root pruning could reduce the yields of fruit trees due to lowered leaf area index hence a reduced photo-assimilate supply (Ferree 1989; Khan et al. 1998). Besides, the capacity for water and nutrient uptake of fruit trees is often negatively affected under root pruning due to severe damage to the root system (Vercammen et al. 2005). Thus, the root-pruned trees are more likely to suffer from drought stress and nutrient deficiency, which may constrain fruit growth, fruit yield and quality, resulting in smaller fruit. Therefore, there is an urgent need to research on developing field strategies to mitigate those negative effects brought about by root pruning.

Among other possible management strategies, supplementary irrigation may counteract the negative effect of root pruning on fruit trees by supplying water directly to the curtailed root system to avoid water stress of the trees. The impact of no or deficit irrigation on fruit trees is similar to that of root pruning in that it restricts vegetative growth (Forshey, Elfving 1989; Ebel et al. 1995) and can reduce harvest fruit size in apple (Mpelasoka et al. 2001) and pear (Marsal et al. 2000). It is hypothesized that an improved tree water status of the root-pruned trees by supplementary irrigation management may be able to enhance fruit growth and yield without compromising the effect on vegetative growth. However, until now this possibility has not been investigated in pear orchards under Nordic climate where water deficits are unlikely to occur during most of the production seasons.

In Denmark, root pruning has become a common practice for controlling canopy size in pear orchards. Cv. Clara Frijs is the most important pear cultivar being widely planted in the country. The objectives of the present study were two-fold: (1) to examine the effectiveness of root pruning as compared with non-root pruning in growth control of pear trees; (2) to investigate the potential of supplementary irrigation on fruit yield and quality and vegetative growth in root pruned pear trees.

MATERIAL AND METHODS

The experiment was conducted over the growing seasons of 2010 and 2011, at the Department of Food Science, Aarhus University, Aarslev, Denmark (55°18'N, 10°27'E). The pear trees (cv. Clara Frijs grafted onto Quince Adams rootstock) were planted in March 1999 at a spacing of 3.5 m between rows and 1.5 m within rows in a north-south row orientation. One tree of cv. Conference pear was planted as pollinator between each plot. The pear trees were not root-pruned from 2005 to 2009. The soil was classified as sandy loam having soil water contents (% vol.) of 26.5% at field capacity and 7.5% at permanent wilting point, respectively, in the 1.0 m soil profile. The plant available water in the 1.0 m soil profile was 181.4 mm. The ground water table was below 5 m during the growing season. Nitrogen was applied at the rate of 50 kg/ha each year before the start of the treatment. The pear orchard was managed according to the local practices including pest management and weed control. Temperature and precipitation during the experimen-

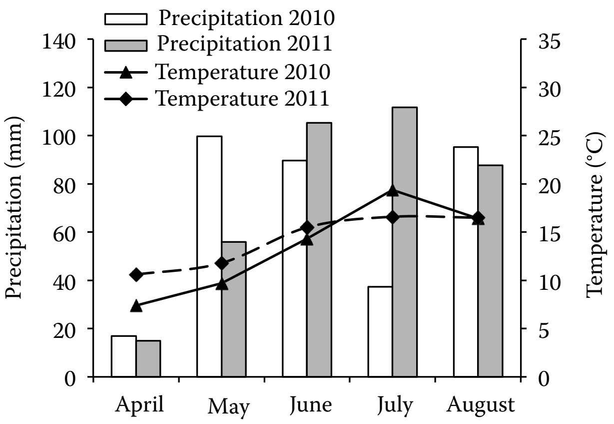

Fig. 1. The seasonal variation of precipitation and temperature during the experimental periods in 2010 and 2011 Recorded by the Danish Meteorological Institute within 1 km from the experimental pear orchard

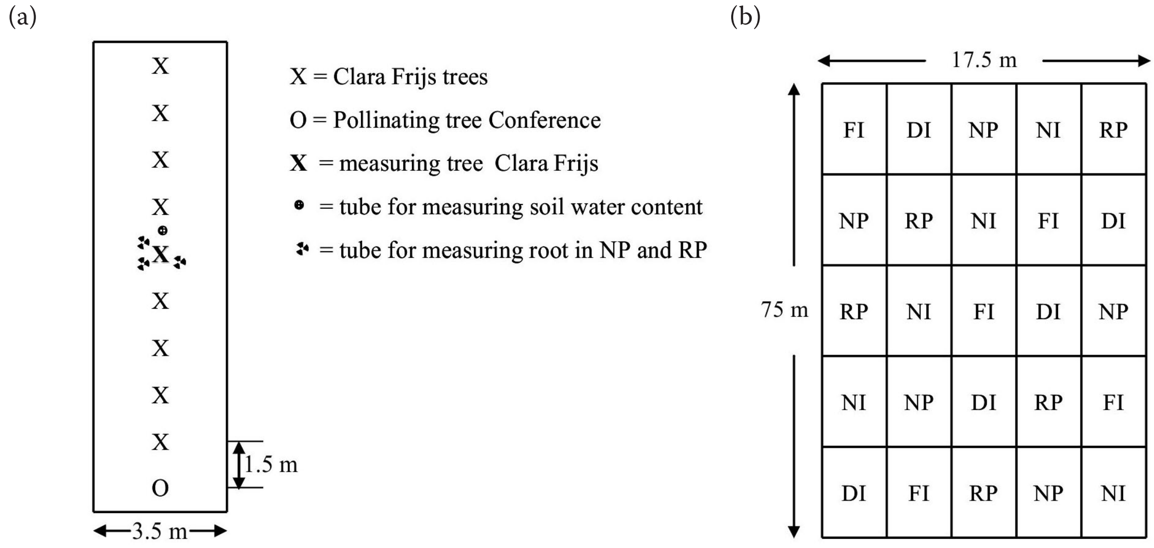

Fig. 2. Diagram showing the experimental plots for the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI), and non-irrigation (NI) treatments in the pear orchard: (a) layout of individual plot and (b) layout of field sites with plot locations

tal periods in 2010 and 2011 were recorded by the Danish Meteorological Institute (DMI) in Aarslev and are illustrated in Fig. 1. Full bloom of pear trees started on 17th May, 2010 and 28th April, 2011, respectively. The earlier full bloom in 2011 was probably due to the higher temperature (Fig. 1) at the beginning of the season in relation to 2010.

The experiment was a randomized block design consisting of five treatments (Fig. 2): (1) root pruning treatment (RP), where the trees were root-pruned and only received the rainfall; (2) non-root pruning treatment (NP), where the trees were not root-pruned and only received the rainfall. NP and RP treatments were used to compare the effect of root pruning. For the root-pruned trees three different irrigation strategies were included: (3) full irrigation (FI), where the root-zone of the trees were irrigated to field capacity (i.e. a volumetric soil water content of 26.5%), FI trees were irrigated once a week from 3rd July in 2010 and from 20th May in 2011; (4) deficit irrigation (DI), where the plots were irrigated to 70% of the plant available water (i.e., a volumetric soil water content of 20.8%), DI trees were irrigated weekly from 16th July in 2010 and from 1st June in 2011; (5) non-irrigation (NI), where the plots were refrained from irrigation and rainfall throughout the treatment period. FI, DI and NI treatments were used to compare the effect of irrigation on root pruned pear trees. For each tree, the irrigation area was 1.5 m × 0.8 m and the depth was 1.0 m. Immediately after root pruning the plots of the three irrigation treatments were covered with a white woven water-proof plastic to eliminate rainfall around the trunk area and approximately 1.2 m away from the root pruning cut. The covering was mounted on a wire along the rows of the trees at height of 60 cm and leaned to the middle between the rows so that all the rain water would be channelled to the centre of the alleyway.

Each treatment had five replicates (plots) and each plot consisted of nine trees demarcated by two pollinating trees. For each treatment, data were collected from one experimental tree within each plot and the sampling trees were selected based on the similar number of flower clusters (132–140 flower clusters/tree) and trunk diameter in April, 2010. Root pruning was done on 14th April, 2010 and 4th April, 2011, respectively, using a tractor mount-

Table 1. The irrigation amount (mm) on each irrigation date for full irrigation (FI) and deficit irrigation (DI) treatments

Treatment	Days after full bloom in 2010								Days after full bloom in 2011								
	47	54	60	67	73	81	88	103	48	55	62	69	75	82	90	97	105
FI	107	47	77	71	67	55	66	22	248	50	65	47	57	49	43	49	50
DI	0	0	33	22	57	30	38	23	62	11	14	7	11	6	6	12	11

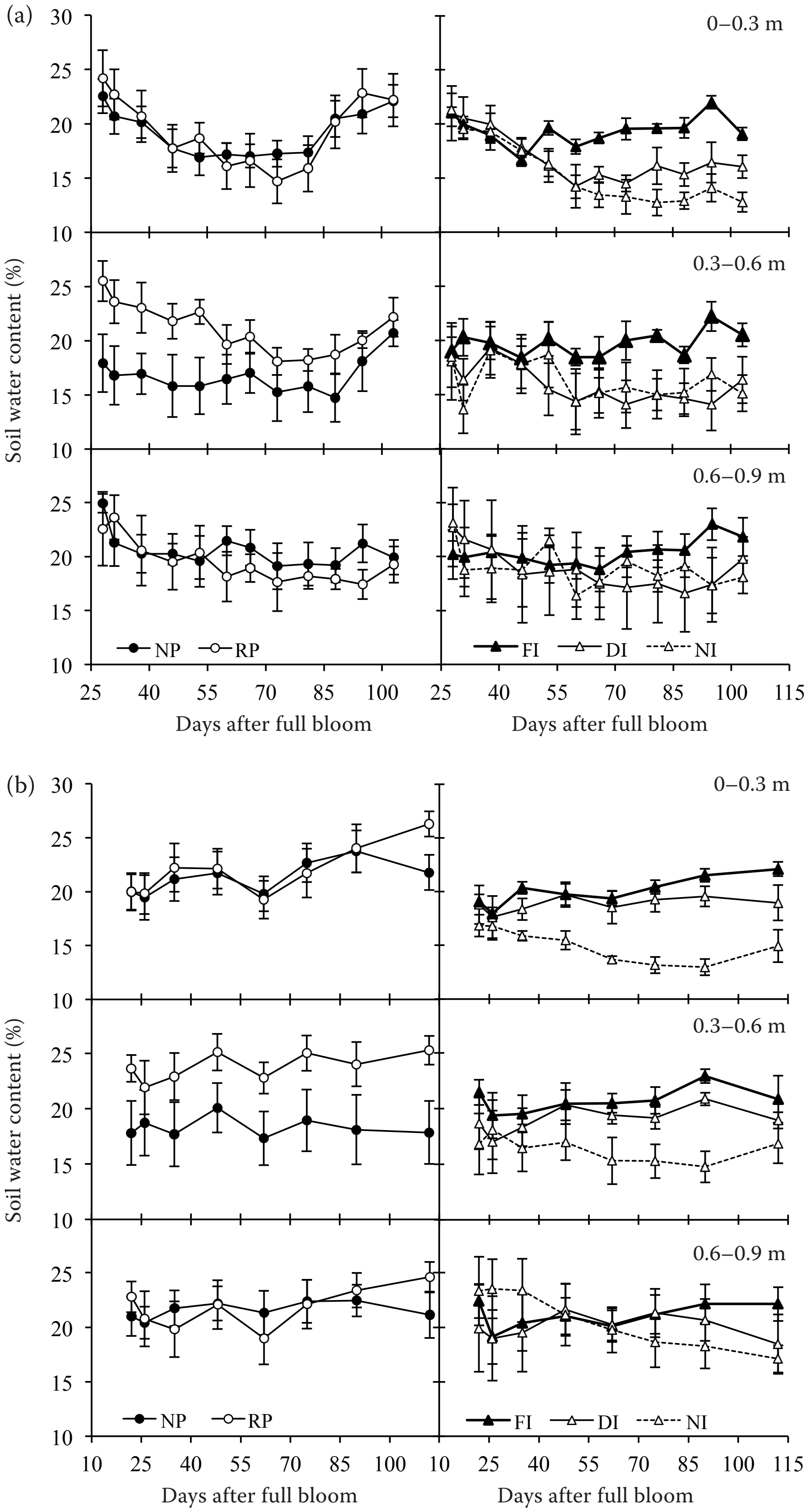

Fig. 3. Changes of soil water content in the 0–90 cm soil profile in the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI), and non-irrigation (NI) treatments during the experimental period of 2010 (a) and 2011 (b)

Values are means ± statistical error

ed root pruning knife that cuts to the depth of approximate 30 cm in distance of 40 cm from the truck on both sides of pear trees.

A drip irrigation system (Durable multi-season integral drip line; John Deere, Moline, USA) was used and the amount of irrigation water applied

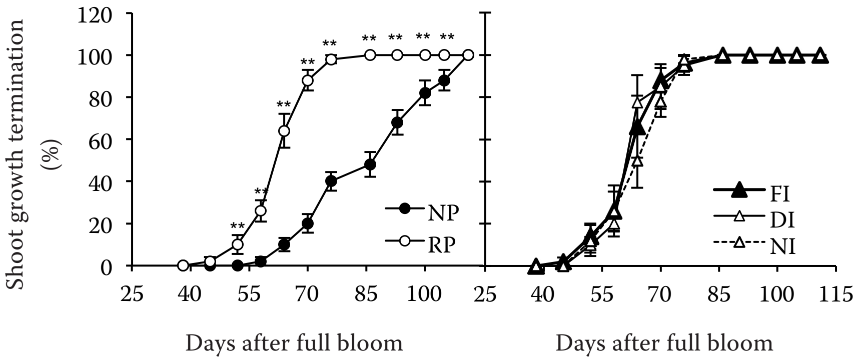

Fig. 4. Shoot growth termination in the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI) and non-irrigation (NI) treatments in 2010

Values are means ± statistical error; *;**significant differences between treatments at $P < 0.05$ and $P < 0.01$, respectively

was monitored using water meters. The space between emitters was 30 cm and average water discharge of emitter was 1.2 l/h. The volumetric soil water contents were measured with the Trime Time Domain Reflectometry system with T3 tube-access probe (IMKO Micromodultechnik GmbH, Ettlingen, Germany). The tubes were installed vertically within rows. The depth of the tubes was 1.0 m and soil water content readings were taken at every 10 cm of depth. The irrigation amount (mm) on each irrigation date for the FI and DI treatment was shown in Table 1.

The length of shoots and the max. diameter of fruit during the growing season were measured weekly on fifty randomly selected shoots and fifty fruit at different heights and exposures on the sampling trees in each treatment using a steel ruler and a digital calliper, respectively. The final shoot length was measured in the winter of 2010 and 2011. Return bloom was determined as the number of flower clusters per tree, and was evaluated in the sampling trees in April of 2011 and 2012. To observe root growth at different soil layers in the NP and RP treatments during the growth seasons in 2010 and 2011, three minirhizotrons glass tubes (70 mm in outer diameter and 1.5 m long) were installed on 25th May, 2010 in parallel to the row in a distance of approximately 50 cm from the trunk and with an angle of 30°. The root intensity was measured following the method described by Thorup-Kristensen (1998).

Harvests were commenced when fruit colour reached commercial specifications (i.e., on 31st August, 2010 and 18th August, 2011). The fruits were counted and weighed for each tree and the average fruit fresh weight was obtained. Fruit from each tree was graded using a commercial grader (Aweta Rollerstar, Nootdorp, the Netherlands). The output from the machine includes fruit weight and fruit diameter for individual fruit. The size distribution was determined based on fruit diameter categories of < 50 mm, 50–60 mm, 60–70 mm, and > 70 mm.

The means of measured parameters in the root-pruned irrigation treatments (DI, FI and NI) were compared by the analysis of variance (ANOVA) at $P < 0.05$ using SPSS 13.0 (SPSS, Chicago, USA). Independent t-test at $P < 0.05$ was performed to com-

Table 2. Total shoot length, number of shoots per tree and percentage of shoot length < 30 cm in the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI) and non-irrigation (NI) treatments in 2010 and 2011

Treatment	Total shoot length/tree (m)		Number of shoots/tree		Percentage of shoot length < 30 cm (%)	
	2010	2011	2010	2011	2010	2011
NP	74	58	130	124	18	33
RP	20	14	74	63	66	80
Significance	**	**	**	**	**	**
FI	24	19	91	87	71	80
DI	28	19	100	92	60	81
NI	26	20	90	90	57	80
Significance	ns	ns	ns	ns	ns	ns

**significant differences between treatments at $P < 0.01$; ns – no significance

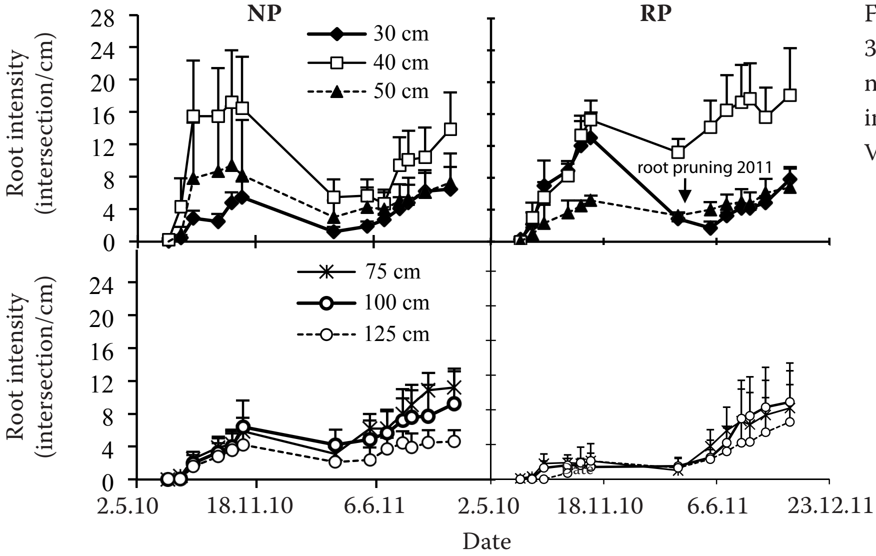

Fig. 5. Root intensity at the depth of 30, 40, 50, 75, 100, and 125 cm in the non-root pruning (NP) and root pruning (RP) treatment in 2010 and 2011 Values are means + statistical error

pare the measured parameters between the RP and NP treatment.

RESULTS AND DISCUSSION

For each treatment, the soil water contents showed similar pattern of development among the years (Fig. 3). RP and NP treatments had similar soil water contents at 0–0.3 m and 0.6–0.9 m soil layers, whereas at 0.3–0.6 m soil layer the soil water contents were significantly higher in the RP than those of the NP treatment. In 3–10 year old apple trees most of the fine roots (< 0.2 mm) are found in the upper 30 cm soil layer within a radius of ca. 1 m from the trunk (Gong et al. 2006; Sokalska et al. 2009). But depending on soil type, irrigation practice, rootstock and other factors a substantial amount of fine roots may also be found in lower soil layers (Sokalska et al. 2009). In the present study, by root pruning a large part of the fine roots of the pear trees in the upper 0–0.3 m soil layer was removed thereby reducing the water uptake and this may have increased the downward movement of water in the RP treatment resulting in the observed increased soil water content in the 0.3 to 0.6 m soil profile compared with the NP treatment. After the initiation to the FI and DI treatments, soil water content was the highest for the FI treatment at 0–0.3 and 0.3–0.6 m soil layers, intermediate for DI, and the lowest for NI treatment. In these irrigation treatments, soil evaporation was reduced due to the rain out shelter and when irrigation was supplied a downward movement of water was found

Table 3. Return bloom of pear trees in the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI) and non-irrigation (NI) treatments

Treatment	Bloom 2010	Return bloom		Significance	
		2011	2012	2011–2010	2012–2011
NP	140	58	120	**	**
RP	138	208	93	**	**
Significance	ns	**	ns		
FI	134	170	132	ns	ns
DI	138	200	131	ns	ns
NI	132	212	81	ns	*
Significance	ns	ns	ns		

*, **significant differences between treatments at $P < 0.05$, $P < 0.01$; ns – no significance, respectively

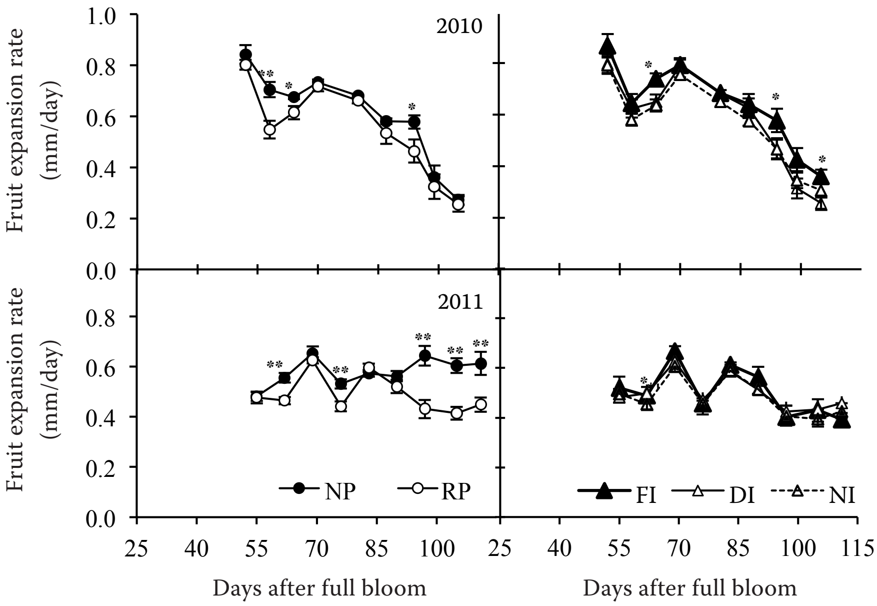

Fig. 6. Fruit expansion rate of pear trees in the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI) and non-irrigation (NI) treatments in 2010 and 2011

Values are means ± statistical error; *;**significant differences between treatments at $P < 0.05$ and $P < 0.01$, respectively

in the FI treatments in both years and the DI treatment in 2011.

Root pruning significantly inhibits the shoot growth of pear trees. It was found that the shoot growth terminated two weeks earlier in the RP than in the NP treatment (Fig. 4). Consequently, the total shoot length and the number of shoots per tree decreased by more than 72% and 43%, respectively, in the RP than in the NP treatment for 2010 and 2011 (Table 2), which was in good agreement with earlier findings (Schupp, Ferree 1990; Khan et al. 1998; Vercammen et al. 2005; Asín et al. 2007). Even though root pruning had stimulated the root growth in certain soil layers, e.g., 30–40 cm (Fig. 5), which however seemingly not corresponded to an increased soil water extraction from that layer (Fig. 3). The higher soil water content in the 30 to 60 cm soil layer (particularly in 2011) indicated that root pruning caused partial loss of the root had reduced water uptake, and is likely to have had similar effects on nutrient uptake. In addition, root pruning re-established the equilibrium between root and shoot growth, involving the mobilisation of stored carbohydrates to provide energy for new root growth (McArtney, Belton 1992). In the early growth stage, the greater part of carbohydrate reserves in roots are utilized during metabolism associated with new root growth and activity, resulting in declined available carbohydrates (McArtney, Belton 1992). Therefore, the

Table 4. Average fruit weight, number of pears per tree, diameter and marketable yield (diameter > 50 mm) of pears in the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI) and non-irrigation (NI) treatments in 2010 and 2011

Treatment	Average fruit weight (g)		Number of pears/tree		Diameter (mm)		Marketable yield (kg/tree)	
	2010	2011	2010	2011	2010	2011	2010	2011
NP	109.8	118.7	181	82	58.5	60.0	19.4	9.3
RP	99.7	89.9	138	186	56.5	54.3	12.9	14.2
Significance	*	**	*	**	*	**	**	**
FI	105.9	93.7	152	204	57.5	55.1	15.4	17.0
DI	103.1	91.2	142	216	57.0	54.7	13.9	16.9
NI	95.5	86.8	149	192	55.5	53.8	13.0	13.5
Significance	**	ns	ns	ns	**	ns	*	*

*, **significant differences between treatments at $P < 0.05$, $P < 0.01$; ns – no significance, respectively

Table 5. Fruit number distribution (%) of different size categories at harvest in the non-root pruning (NP), root pruning (RP), full irrigation (FI), deficit irrigation (DI) and non-irrigation (NI) treatments in 2010 and 2011

Treatment	< 50 mm		50–60 mm		60–70 mm		> 70 mm	
	2010	2011	2010	2011	2010	2011	2010	2011
NP	4.1	6.2	58.1	42.7	36.5	45.7	1.3	5.5
RP	8.7	21.4	68.8	64.4	22.1	13.3	0.4	0.9
Significance	*	**	ns	**	*	**	ns	**
FI	6.8	17.4	62.7	64.5	29.6	17.6	0.8	0.6
DI	7.2	19.5	67.7	63.7	24.8	15.9	0.4	0.9
NI	11.8	25.9	72.1	60.9	15.8	12.6	0.3	0.6
Significance	*	ns	ns	ns	*	ns	ns	ns

*, ** indicate significant differences between treatments at $P < 0.05$, $P < 0.01$; ns – no significance

shoot growth was inhibited following root pruning. No significant differences in shoot growth termination, total shoot length, number of shoots per tree and the percentage of shoots shorter than 30 cm were found among the FI, DI and NI treatments (Table 2), implying that the depression of shoot growth following root pruning might have not been due to water stress, other factors such as reduced carbohydrates availability or lowered nutrient uptake maybe involved. Consistent with this, Asín et al. (2007) found that with 50% reduction of irrigation water in the period from April to May, shoot length and the number of shoots per pear tree were not affected.

The number of flower clusters per tree, is an important predictor of fruit number and yield at harvest. At the onset of the experiment trees carried a uniform number of flower clusters that were sufficient for a full and uniform crop to develop. After onset of the treatments, the root-pruned trees had remarkably higher return bloom than that in the NP treatment in 2011 (Table 3), indicating that there was a significant positive effect of root pruning on return bloom. Similar positive results of root pruning were reported by McArteney and Belton (1992) and Asín et al. (2007). The changes of hormonal concentrations such as cytokinines in the xylem during root regeneration after pruning may be involved in the increased return bloom for the RP treatment (Webster et al. 2003). Nonetheless, both NP and RP treatments showed significant alternation of return bloom between years, and the trees of the NP treatment exhibited a large flowering fluctuation compared to the RP treatment. In the current study, we found that FI and DI treatments had higher return bloom as compared with the NI treatment, though not always statistically significant (Table 3), indicating that irrigation can stabilize flower bud formation at a level sufficient for a high regular crop load of the root-pruned pear trees.

It has long been recognized that root pruning reduces fruit size (Schupp, Ferree 1987; Ferree 1989; Mika, Krzewinska 1995; Khan et al. 1998). In accordance with this, here we observed that fruit expansion rates were lower and fruit size was smaller in the RP trees during the two experimental years (Fig. 6, Table 4). The mechanisms behind this may be dual. Khan et al. (1998) proposed that the decrease in fruit size as a consequence of root pruning may partly be due to the reduced availability of photo-assimilates because of the reduction in size and number of leaves during fruit growth. Hsiao and Xu (2000) stated that fruit cell expansion relies on water availability and on solute uptake and is facilitated by turgor pressure, which is generated by differences in osmotic potential. Therefore restrictions in water and solute uptake have a potential to alter cell expansion and ultimately fruit size. In the present experiment we saw an increase in fruit size in response to irrigation supporting the latter argument. The NP treatment had higher crop load in 2010 compared with the RP trees, and this resulted in a 25% larger marketable yield (Table 4) with a better size distribution (Table 5). However, in 2011 the number of fruit was 56% higher in the RP than in the NP treatment, but despite a much reduced average fruit size, and a large increase in number of small fruit (Table 5) the marketable yield increased significantly (Table 4) in the RP treatment. The three irrigation treatments resulted in similar fruit expansion rates in both years during most of the experimental period, only at a few occasions the FI trees have significantly higher fruit expansion rate than the DI and NI trees. While it was notable that, for all treatments, the pattern of fruit expansion growth differed between the two years, being that the fruit grew much faster in 2010 than in 2011 from 55 to 75 days after full bloom, whereas at later stage (e.g., from 80 days after full bloom), the reverse was the case (Fig. 6). The greater fruit expansion rate at earlier fruit development stage in 2010 might have been due to the fact that the temperature was higher during the period compared to that in 2011 (Fig. 1). There was no difference in fruit set between the FI, DI and NI treatments, but average fruit size and fruit size distribution were reduced in the NI treatment. Marketable yield obtained for the harvest was significantly better in the FI than in the NI treatment with the DI showing intermediate results (Table 4). Therefore, supplementary irrigation (FI and DI) increased fruit size, improved fruit size distribution and thereby marketable yield compared with the NI treatment.

CONCLUSIONS

The results of this study indicate that root pruning is an effective practice for controlling the shoot growth and improving the return bloom of pear trees in two experiment years; however, it also results in smaller fruit. Irrigation of the root-pruned trees can stabilize the return bloom and improve fruit yield and quality without stimulating additional shoot growth. Therefore, a combination of root pruning and irrigation could be a promising alternative to control the tree size, and to mitigate the negative effect of root pruning on fruit yield and quality in pear orchards.

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