Drying half of the root-zone from mid fruit growth to maturity in ‘Hass’ avocado (Persea americana Mill.) trees for one season reduced fruit production in two years

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1. Introduction

The efficiency of irrigation, defined as economic yield per unit water applied in irrigation, is an important production criterion in dry areas. Partial root-zone drying (PRD) involves withholding irrigation from half of the root system for periods of 2–4 weeks, before re-watering and alternating this treatment. PRD improves the efficiency of irrigation in perennial crops, such as grapevines, because it constrains vegetative growth without influencing yield (Loveys et al., 1997; Stoll et al., 2000). Its use in fruit crops, such as pear, has been investigated (Kang et al., 2002). PRD relies on the capacity of the root system to generate signals that influence leaf conductance and restrict vegetative growth. Such phenomena have been demonstrated in a number of plants using pot experiments involving split-root systems, e.g. apple (Gowing et al., 1990), passionfruit (Turner et al., 1996) and Ricinus sp. (Jokhan et al., 1996). In some species, such as Betula sp., split-root experiments do not support the hypothesis of a root-sourced signal (Fort et al., 1998) and this was recently demonstrated for avocado cv Hass (Neuhaus et al., 2007). The absence of signals indicates that PRD may not be an effective strategy for increasing the efficiency of irrigation in avocado.

In a pot experiment, Neuhaus et al. (2007) found that avocado plants exposed to partially dry root systems used a similar amount of water to well-watered controls because they absorbed more water from the well-watered side and maintained plant functions. Nonetheless, PRD may be useful in the field as other factors come into play, such as a restriction in the total amount of water supplied, the possibility of maintaining plant function if half the roots are well-watered and assessing yield and fruit quality.

Drying half the root system may improve the efficiency of irrigation since the reproductive structures (inflorescences) in avocado were better able to withstand drying soil than vegetative structures (Neuhaus et al., 2007). Before PRD can be used as a management technique in irrigation of avocado it is necessary to know the response of the trees to drying part of the root system. Of interest is the sequence in which different processes are affected as the soil dries and how the trees might adjust to a partially dry root...
system. To obtain this knowledge, we did not use PRD in the traditional sense, but an extended single cycle of drying half the root system applied during fruit growth to examine its effect on yield and fruit quality. In the Mediterranean environment of southwestern Australia the avocado flowers in spring (September-October) and the fruit matures in August/September, 10–11 months later. We evaluated selected plant physiological parameters, mineral nutrients fruit yield and the concentration of Ca in the fruit as this is correlated with fruit quality in avocado (Bower, 1985; Thorp et al., 1997; Hofman et al., 2002). The irrigation treatments were applied to mature, field-grown avocado trees irrigated with slightly saline bore water.

Our objective was to determine the effect of drying half of the root system on fruit yield and quality in mature avocado trees in the field.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted in a commercial orchard at Carabooda, Western Australia (31° S, 115° E), which has a Mediterranean climate with hot dry summers and cool wet winters. The 15-year-old cv ‘Hass’ avocado trees grew on a deep, siliceous, weakly podsolised sand of the Spearwood dune system (Salama et al., 2005). At this site, the upper 100 mm of soil was enriched with humus, the result of mulching over many years. All trees had been grafted onto Guatemalan seedling rootstocks and the tree were used for the analysis of minerals. Fresh and dry weights were recorded of all sampled tissues.

Leaves (n = 8 per tree) of the experimental trees were sampled in April 2000 and fruits (n = 4) were taken on 2 April 2000 in conjunction with the tissue water potential of the experimental trees. Leaf conductance was measured about every 2 weeks at midday on fully expanded leaves (n = 16, 4 leaves per WW- and DD-tree, 8 leaves per WW-tree) of non-fruiting branches at about 1.5–2.0 m height above ground using a combined infrared gas analysis system (CIRAS-1, Portable Photosynthesis System, Hitchin, UK). Diurnal readings were taken once on 2 April 2000 in conjunction with the tissue water potential of expanded leaves, a shoot and fruit. Measurements of conductance and water potential were alternated hourly from dawn to dusk. Tissue water potential was measured using a pressure chamber (Scholander et al., 1965). That day, photosynthetically active radiation varied from 50–100 μmol m⁻² s⁻¹ at 7 am and 5 pm to 1400–1550 μmol m⁻² s⁻¹ from 10 am to 2 pm. Air temperatures rose from 15 to 26°C during the first 3 h of measurements and remained at 25°C from 2 to 5 pm.

Shoot extension (n = 8, 2 shoots per WW- and DD-tree, 4 shoots per WD-tree) was monitored on labeled shoots from mid-February to mid-March 2000 using a digital caliper. One non-fruiting branch, 39–43 mm in diameter, was collected from all treatments (WD-tree was sampled on the dry and watered side) in May 2000 to examine the anatomy of xylem vessels. Hand cross-sections were taken, photographed and the outer secondary xylem vessels were examined using a light microscope with a fluorescent attachment (Axioplan Universal Microscope, Carl Zeiss Pty. Ltd., Oberkochen, Germany).

The effect of treatments on flowering in September 2000, 8 months after treatments began, was assessed visually. However, fruit number per tree and fruit fresh weights were recorded that month. Treatments were then stopped and water supply restored to all trees. Fruits per tree were counted during May 2001 and yields of these trees were obtained in September 2001 to assess the impact of the dry treatments in the following season.

2.2. Treatments

At Carabooda, fruit drop occurs in November, soon after fruit set, and again in January. Treatments began in early February 2000 when the number of fruit on the tree could reasonably be expected to grow through to maturity. They ended 8 months later in August 2000 when the number of fruit on the tree could reasonably be expected to grow through to maturity. They ended 8 months later in October. Each treatment ended 8 months later in October. Each treatment ended 8 months later in October.

2.2.1. Irrigation

Irrigation was applied following a replacement factor of 1.2 A canopy during the first 3 h of measurements and remained at 25°C from 2 to 5 pm. Shoot extension (n = 8, 2 shoots per WW- and DD-tree, 4 shoots per WD-tree) was monitored on labeled shoots from mid-February to mid-March 2000 using a digital caliper. One non-fruiting branch, 39–43 mm in diameter, was collected from all treatments (WD-tree was sampled on the dry and watered side) in May 2000 to examine the anatomy of xylem vessels. Hand cross-sections were taken, photographed and the outer secondary xylem vessels were examined using a light microscope with a fluorescent attachment (Axioplan Universal Microscope, Carl Zeiss Pty. Ltd., Oberkochen, Germany).

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2.2.2. Drying

Drying was achieved by shutting off sprinklers and by spreading a plastic sheet over the soil (WD) or were not irrigated (DD). Water deficit was achieved by

2.2.3. Fertilizer

Fertilizer was applied as liquid 20% nutrient solution (700 μmol N m⁻² s⁻¹) into the irrigation water. All trees received a single application of a liquid fertilizer containing 50% of its total nitrogen as urea (18 g N/tree) 4 months before treatments began and 1 month after treatments ceased. In February 2000, in addition to the irrigation water, all trees received 255 g N, 170 g K, 19 g Ca, 466 g S, 89 g Zn and 80 g Mn. The 8 months of treatment each well-watered (control) tree received as rain. The salinity of the bore water used for irrigation ranged from 0.94 to 1.09 dS/m and contained about 150 mg L⁻¹ Cl.

2.3. Soil and plant water status and fruit yield

Volumetric soil water content to 300 mm depth was measured each 2 weeks, from February to September, using Time Domain Reflectometry (TDR, Model Trase System 1, Irricrop Technologies Pty. Ltd., Narrabri, Australia). Measurements (n = 4) were taken under all experimental trees, on both sides of the root system of WW-, WD- and DD-trees. About 70% of the total root length of the trees was present in the top 300 mm of soil (Neuhaus, 2003).

Beside visual symptoms, plant water status was monitored using direct and indirect approaches. Leaf water content (n = 8, 2 leaves per WW- and DD-tree, 4 leaves per WD-tree) at midday of the youngest fully expanded leaf was taken as a volumetric measurement to directly indicate the leaf water status after 2 months of treatments. Leaf conductance was measured about every 2 weeks at midday on fully expanded leaves (n = 16, 4 leaves per WW- and DD-tree, 8 leaves per WD-tree) of non-fruiting branches at 1.5–2.0 m height above ground using a combined infrared gas analysis system (CIRAS-1, Portable Photosynthesis System, Hitchin, UK). Diurnal readings were taken once on 2 April 2000 in conjunction with the tissue water potential of expanded leaves, a shoot and fruit. Measurements of conductance and water potential were alternated hourly from dawn to dusk. Tissue water potential was measured using a pressure chamber (Scholander et al., 1965). That day, photosynthetically active radiation varied from 50–100 μmol m⁻² s⁻¹ at 7 am and 5 pm to 1400–1550 μmol m⁻² s⁻¹ from 10 am to 2 pm. Air temperatures rose from 15 to 26°C during the first 3 h of measurements and remained at 25°C from 2 to 5 pm.

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2.4. Analyses of Ca, Mg, K, Na and Cl concentrations in plant tissues

Leaves (n = 8 per tree) of the experimental trees were sampled in April 2000 and fruits (n = 4 per tree) were sampled in September 2000 for analyses of inorganic ions. All trees had a late summer flush and the second youngest fully expanded leaf from this flush was taken in April. This leaf would have been 8 weeks old. Growth of the late summer flush was suppressed on DD-trees and so fully expanded leaves were sampled from the previous flush which was a spring ‘flush’. These leaves were 5–7 months old and they showed some symptoms of chlorosis or necrosis. Fruit were at commercial maturity when harvested in September and were selected randomly. They were cut longitudinally and only mesocarp tissue was used for the analysis of minerals. Fresh and dry weights were recorded of all sampled tissues.
For leaf and fruit samples from the experimental trees, Cl was extracted from sub-samples of oven-dried and ground tissue that were boiled for 3 h in weak sulphuric acid at pH 3.5 (Chirchint and Turner, 1988). The extracts were then shaken for 2 days (Short and Colmer, 1999) before being analyzed using a Buchler-Cotlove Chloridometer (Buchler Instruments, Model 4-2000, New Jersey, USA). The Cl concentration was expressed in mmol L$^{-1}$, since Cl is soluble.

For the leaf and fruit samples of the experimental trees, Ca, Mg, Na and K were extracted from sub-samples of 0.8 g oven-dried ground tissue. A dry ashing technique was applied, as described by Brown et al. (1992), before samples were analyzed using Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP–OES). The instrument was checked using standard reference samples and blanks were included among the samples from the experiment. Na and K concentrations were calculated in the units of mmol L$^{-1}$ of ‘tissue water’ because they are soluble elements. The concentrations of Ca and Mg were expressed per unit of dry matter.

Orchard practice was to apply nutrient through the irrigation water and use leaf analysis as part of the strategy for nutrient management. We used the results of this sample to determine whether the trees used in the experiment had a similar nutrient status compared with the trees in the surrounding orchard. The leaf analysis sample of the orchard was taken in May 2000 using leaves of non-fruiting shoots of the late summer flush. The sample was analyzed by the Soil and Plant Analysis Service of CSBP Ltd., Bibra Lake, WA. These analyses were expressed as concentration of element per unit dry weight. Their molar concentrations in tissue water (see Tables 1 and 2) were calculated using the leaf water content of the well-watered (WW) trees in the experiment.

2.5. Statistical analysis

An ANOVA was used to analyze the data and the significance of differences between treatment means was evaluated using LSD at $P < 0.05$.

Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>WW</th>
<th>W side of WD</th>
<th>D side of WD</th>
<th>DD</th>
<th>$P &lt; 0.05$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (ml g$^{-1}$ d.wt)</td>
<td>1.57 (0.38)</td>
<td>1.77 (0.28)</td>
<td>1.64 (0.14)</td>
<td>1.41 (0.05)</td>
<td>ns</td>
</tr>
<tr>
<td>Na</td>
<td>1.3aA (0.2)</td>
<td>4.5b (1.3)</td>
<td>2.6b (0.4)</td>
<td>1.1a (0.2)</td>
<td>*</td>
</tr>
<tr>
<td>Excess Na</td>
<td>89</td>
<td>61</td>
<td>66</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>Orchard Na</td>
<td>3B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>110aA (23)</td>
<td>130a (23)</td>
<td>194ac (48)</td>
<td>265bc (31)</td>
<td>*</td>
</tr>
<tr>
<td>Orchard Cl</td>
<td>19B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>179aA (20)</td>
<td>105b (14)</td>
<td>68bd (11)</td>
<td>59c (7)</td>
<td>*</td>
</tr>
<tr>
<td>Adequate K</td>
<td>147–327</td>
<td>130–290</td>
<td>141–313</td>
<td>164–364</td>
<td></td>
</tr>
<tr>
<td>Orchard K</td>
<td>245B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>0.91a (0.1)</td>
<td>1.48 (0.2)</td>
<td>1.11 (0.1)</td>
<td>1.21 (0.18)</td>
<td>ns</td>
</tr>
<tr>
<td>Adequate Ca</td>
<td>1.0–3.0</td>
<td>1.0–3.0</td>
<td>1.0–3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>0.29aA (0.03)</td>
<td>0.45b (0.07)</td>
<td>0.26a (0.04)</td>
<td>0.26a (0.03)</td>
<td>*</td>
</tr>
<tr>
<td>Adequate Mg</td>
<td>0.25–0.80</td>
<td>0.25–0.80</td>
<td>0.25–0.80</td>
<td>0.25–0.80</td>
<td></td>
</tr>
<tr>
<td>Orchard Mg</td>
<td>0.49B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Leaves were sampled in April 2000. Leaves of the DD-trees were 5–7 months old and 8 weeks for the other treatment trees. Standard errors are in parentheses. The asterisk indicates significant differences between treatments at $P < 0.05$ and ns is not significant. Within rows, means followed by the same lower case letter are not significantly different. In italics are the excess concentrations for Na and Cl and the commercial range of K, Ca and Mg following Lahav and Whiley (2002). The ‘Orchard’ values are the concentrations in leaves sampled in May 2000 from the orchard surrounding the experiment. Within the WW column and within an element, values followed by the same upper case letters are not significantly different ($P = 0.05$).
trees suffered some defoliation and necrosis appeared on the leaf margins in winter. However, these trees showed enhanced flowering in spring (September/October 2000). The strong flowering response did not occur on WD- or WW-trees. Re-watering caused the DD-trees to retain the same number of fruits per tree in May 2001, 8 months after treatments had ceased, as did the WD- and WW-trees. However, at harvest in September 2001, DD- and WD-trees had again the lowest fruit number per tree, compared with the WW-trees, even though the DD- and WD-trees had been irrigated normally for 12 months.

After 10 days of complete root-zone drying the stomata began to close. Leaf conductance at midday ($g_L$) fell by 50% compared with $g_L$ of irrigated trees (Fig. 3). During the summer and autumn months (10–50 days after treatments began), $g_L$ of DD-trees remained at 100–150 mmol m$^{-2}$ s$^{-1}$ at midday, whereas $g_L$ of watered trees fluctuated between 200 and 300 mmol m$^{-2}$ s$^{-1}$. Two months after treatments began, $g_L$ of DD-trees recovered to control levels (200 mmol m$^{-2}$ s$^{-1}$) although the top 300 mm of the soil profile remained dry. The WD treatment reduced $g_L$ on the unwatered side after 10 days of treatments. The $g_L$ on the unwatered side then recovered and followed the pattern of the watered side, and of fully watered trees. The $g_L$ of all trees varied diurnally. The $g_L$ of WW-trees was 25 mmol m$^{-2}$ s$^{-1}$ at 7 am and 5 pm on 2 April 2000, but increased to 200–250 mmol m$^{-2}$ s$^{-1}$ from 10 am until 2 pm. The $g_L$ of leaves of the WD-trees followed the same pattern as those of the WW-trees, but the maximum midday opening was less at 150–200 mmol m$^{-2}$ s$^{-1}$. The $g_L$ of the DD-trees behaved quite differently. The conductance gradually increased from 25 mmol m$^{-2}$ s$^{-1}$ at 7 am to 120 mmol m$^{-2}$ s$^{-1}$ at 2 pm and fell to 80 mmol m$^{-2}$ s$^{-1}$ at 5 pm.

At dawn on 2 April 2000, 2 months after treatments began, the water potential of the leaves, shoots and fruits was the same in all treatments ($-0.09 \pm 0.01$ MPa). Throughout the day there were no differences between treatments in their total water potential but the organs behaved differently. The water potential in all organs fell to $-0.88 \pm 0.01$ MPa by 1 pm. After this the leaves and shoots recovered and by 6 pm had risen to $-0.29 \pm 0.02$ MPa. Fruit, on the other hand remained drier and at 6 pm had a total water potential of $-0.65 \pm 0.03$ MPa.

Buds present when treatments began (1 February) commenced growth in the WW- and WD-trees in early March. After this they grew rapidly and increased from 10 to 65 mm in 15 days. The shoots of the W and D sides of the WD-trees followed the same pattern. However, complete soil drying almost stopped shoot growth during the first 2 months of treatment and these shoots were only 10 mm long while the shoots on the WD- and WW-trees had reached 65 mm in length. Shoots of the DD-trees contained tyloses in their vascular tissues, while those of the WW- and WD-trees did not.

Soil drying had no significant effect on leaf water content in April 2000 (Table 1) but the DD treatment reduced fruit water content by about 20% at maturity in September (Table 2). The concentrations of K, Ca and Mg in the leaves of the WW-trees were within the adequate range for avocado (Table 1) but the concentration of Cl was excessive, as it was in the orchard.

The WD treatment increased the concentration of Na in the leaf water by 2 to 4 times, compared with the control (WW) (Table 1). The values ranged from 1.3 to 4.5 mmol and were well below the concentration regarded as excessive. A feature of the concentrations of Cl in the leaf water of all treatments was that they all exceeded the range associated with excess Cl for avocado (Table 1). The WD treatment had no significant effect on the concentration of Cl in the leaf water but the DD treatment increased Cl by 2.5 times compared with the WW treatment (Table 1). However, the leaves of the DD-trees were much older than those of the WD-trees. Soil drying almost halved the concentration of K in the leaf water of the W side of the WD trees and more than halved it on the D side (Table 1). The concentration of K in the leaf water of the DD-trees was similar to that on the D side of the WD-trees. Soil drying had no effect on the concentration of Ca in the leaves. Soil drying affected the concentration of Mg in leaves (Table 1). The leaves on the W side of the WD-trees accumulated more Mg than the leaves of the control (WW) or the DD-trees. Soil drying increased the concentrations of Na and Cl in the water of the fruit mesocarp, but only in fruit from the D side of the WD-trees and the fruit from the DD-trees (Table 2). There was no effect of soil drying on the concentrations of K, Ca or Mg in the fruit mesocarp (Table 2).

4. Discussion

Drying half the root system of mature avocado trees, after their normal fruit drop, reduced their yield further, compared with well-watered trees. The number of fruit on the WD trees was reduced proportionately more than the reduced amount of irrigation applied so that irrigation efficiency was reduced. In the season following treatment, the WD- and DD-trees were well watered but yielded much less than the WW-trees and so the irrigation efficiency of these trees was reduced by the treatments applied in
the previous season. The treatments caused the soil under the trees to dry out from mid-February until September. Despite 7 months of dry soil, the effect of the treatments on leaf water status, as reflected in stomatal conductance, lasted less than 2 months. The top 300 mm of soil in this orchard contained about 70% of the avocado roots (Neuhaus, 2003). The trees in the DD treatment obtained water presumably from deeper in the soil and possibly by extending roots laterally beyond the protective plastic cover. This is consistent with a flush of root growth that would normally be expected in avocado trees in this environment at this time of year (Whiley, 2002). The new root growth was sufficient for the trees to access water and replenish the water status of the leaves, in addition to the effect of reduced evaporative demand. The WD treatment did not affect leaf conductance to a large degree on either side of the trees and so the reduced amount of water supplied to these trees maintained leaf function, but did not prevent fruit abscission.

The reduction in yield in the WD- and DD-trees was mainly the result of fruit abscission (Fig. 2) caused by drying the root system either partially or completely. These treatments indicate that leaves attract water and retain their function compared with fruit. This is supported by the water potentials of the leaves, shoots and fruit in April, 2 months after the treatments began. In the middle of the day the total water potential of the leaves, shoots and fruit was the same across treatments and so each organ within each treatment had the same capacity to attract water from the stems. However, at the end of the day the water potential of the fruit had not risen, as it had in the leaves. This was the case in the WW-trees with roots in moist soil as well as when the roots were extensively exposed to dry soil in the WD- and DD-trees. Thus it was not the extent of the dryness of the root system that maintained low water potentials in the fruit, compared with the leaves. It is more likely that the low water potentials in the fruit at the end of the day reflect osmotic solutes, such as sugars, that are used for fruit growth because the water potential is restored by the next morning. A reduction in carbon supply is believed to contribute to fruit drop in avocado (Schaffer and Whiley, 2002), and while this may be true for the DD-trees where leaf conductance was reduced, our results show that other factors are important since the WD-trees had functioning leaves but lost as many fruit as the DD-trees. Thus, in avocado, soil water deficit applied to half of the root system did not close the stomata, but contributed significantly to fruit abscission (Fig. 2).

In this experiment, where commercial practices were used, nutrients were applied in the irrigation water and so some of the effects caused by the differential supply of water could be attributed to a differential supply of nutrients. Leaf analysis indicated that K supply was the most affected since it was reduced in the WD- and DD-trees. The data for the DD-trees are not strictly comparable since older spring flush leaves made up the sample for this treatment. However, there is a clear indication that drying half of the root system reduced K concentrations in the fully expanded leaves of the late summer flush (Table 1). Despite the effect of drying on the K concentration in the leaves of the trees sampled 2 months after treatments began, there was no effect of treatment on the K concentration in the fruit at commercial harvest. Nonetheless, K supply could still be involved since the reduced K uptake in February and March, when fruit were growing rapidly (Whiley et al., 1995; Neuhaus, 2003) could limit the capacity for fruit growth, resulting in abscission, then the limited amount of K within the trees could be allocated to remaining fruit. However, this mechanism is unlikely to explain the impact of the WD and DD treatments in the following season, since K supply to the trees was restored when they were returned to the standard orchard practice in September 2000. Since the irrigation water supply available to this orchard was slightly saline, the results need to be interpreted with this in mind.

Chloride concentrations in the leaves of the control and treated trees, 2 months after treatments began, and in the leaves of the orchard trees 1 month later, were above those concentrations considered excessive (Table 1) (Reuter and Robinson, 1986; Lahav and Whiley, 2002). This applied to all treatments and one explanation for the impact of the treatments in 2000 on the crop in the following year might be the increased accumulation of Cl caused by the treatments. Our data were too variable to determine whether this was the case. While there was a tendency for Cl concentrations in the leaves to increase as more of the root system was exposed to drying (Table 1), the differences between the WW- and WD-trees were not significant and the sample for the DD-trees contained leaves that were much older than those in the samples from the WW- and WD-trees. Chloride concentration, per unit dry matter, increases in avocado leaves as they age (Lahav et al., 1990).

The extended nature of the soil water deficit (7 months) may have killed roots beneath the trees in the WD and DD treatments and this may have contributed to the impact of the treatments on the crop in the following season. There are two factors of importance here. One is whether there was a significant amount of root death under the DD-trees and the D side of the WD-trees and the other is whether this had any effect, given the capacity of the DD-trees to adjust within 2 months of the treatments being applied (Fig. 3). Neuhaus (2003) investigated the root systems of several trees in this orchard during 1998 and 1999. Irrigation had been withheld from one tree for 6 months from late spring until late autumn. At the end of the period of root-zone drying there was no effect on the root length density down to 1.3 m soil depth. The proportion of root tips that were either white or brown was similar to trees that had been irrigated throughout the season. However, the extended root-zone drying significantly reduced the length of roots adjacent to the soil surface from 2.1 ± 1.5 m m⁻² to 0.8 ± 0.4 m m⁻². If there had been extensive root death beneath the WD- and DD-trees, then we would expect this to reduce the capacity of the trees to retain their fruit during the normal periods of fruit drop in spring and summer, in this environment. This did not occur (Fig. 2) as the WW-, WD- and DD-trees had a similar number of fruit in May 2001, well after the summer fruit drop. We conclude that the treatments did not significantly damage the root system in terms of its capacity to supply water to the tree canopy. However, immediate and long term changes in the root system were instigated by the WD and DD treatments that prevented the trees from retaining all the fruit present at the end of the period of summer fruit drop.

Shoots of the DD-trees contained tyloses in the vascular tissue that can significantly reduce axial hydraulic conductivity (Neuhaus et al., 2007). This may have contributed to loss of fruit in the second season but it does not explain the loss in the WD-trees where no tyloses could be detected in this field experiment or in the pot experiment conducted by Neuhaus et al. (2007).

We assessed fruit quality indirectly by assuming that the Ca concentration in the fruit mesocarp was correlated with fruit quality. Hofman et al. (2002) established correlations between the Ca concentration in the fruit mesocarp and days to eating ripe, mesocarp discoloration and the severity of anthracnose (Colletotrichum gloeosporioides). Since the drying treatments did not significantly affect Ca concentration in the fruit (Table 2) we conclude that drying part of the root system reduced yield but was unlikely to have affected fruit quality. Hofman et al. (2002) attributed the associations between Ca concentration and fruit quality to variations in the rootstocks (seedling Guatemalan, unknown origin) of the trees or the root stock-scion interaction. Willingham et al. (2001) found that rootstocks of known origin influenced anthracnose development in the fruit of Hass trees, but there was no significant effect on the concentration of Ca in the fruit flesh. So, it is possible in our
experiment that the association between Ca concentration in the fruit and fruit quality established by Hofman et al. (2002) may not apply. This needs further investigation.

The knowledge gained from this study increases the options for irrigation management of avocado trees where water supply is limiting. Under reduced supply, water may be withheld either from part of an orchard (a combination of DD and WW treatments) or may be withheld from part of the root system in each tree in the orchard (WD treatment). Withholding water from the whole root system will reduce yield and tree growth and this effect is likely to carry over to the second season (longer term effects were not assessed). Withholding water from part of the root system will also reduce yield, and for (at least) two years, but the growth and functioning of the vegetative component of the trees is maintained. Whether partial root-zone drying (PRD), in the traditional sense, where the drying would be shorter term and switched from one side to another, would be effective in avocado needs to be evaluated. Our data suggest PRD would not reduce vegetative growth and may cause some fruit to drop.

We conclude that extended drying of half of the root-zone in one season reduced irrigation efficiency by promoting the abscission of developing fruit to the same extent as occurred when the whole root-zone was exposed to extended drying. The abscission of fruit was promoted by exposure of the roots to dry soil and was not necessarily related to the water status of the fruit or canopy. Drying half of the root system does not appear to affect fruit quality.

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References


