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Postharvest Performance of 'Pacific Rose™' Apple Grown Under Partial Rootzone Drying

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Abstract. **Quality and storability of 'Pacific Rose™' apple grown under partial rootzone drying (PRD) were studied over 2 years. The treatments were commercial irrigation (CI) and PRD, which were applied by watering one side of the tree row throughout the season (Expt. 1) or by alternating irrigation between two sides of the tree row when volumetric soil water content ranged between 0.18 and 0.22 $m^3 \cdot m^{-3}$ (Expt. 2). The PRD and CI fruit had similar quality attributes at harvest and after storage except that the former had lower weight loss during storage in Exp. 1 and a lower firmness after storage in Exp. 2. Compared with CI, PRD saved water by 0.15 mega liters per hectare in Exp. 1 and by 0.14 mega liters per hectare in Exp. 2. We recommend PRD for humid environments similar to ours.**

Water resources for irrigation are limited worldwide (Bouwer, 2003), and reduced irrigation strategies should be adopted especially for apple [*Malus ×sylvestris* (L.) Mill. var *domestica* (Borkh.) Mansf.], which has a large acreage and is often grown in water-limited areas. Partial rootzone drying (PRD) is a new reduced irrigation strategy where, at each irrigation time, part of the rootzone is watered with the other part left to dry to a predetermined level of soil water (Zegbe et al., 2006, 2007). Ideally, with PRD, water could be saved by 50% without negative impact on yield or product quality. PRD relies on using the plant's root-to-shoot chemical signaling mechanisms to restrict water use, and alternating between wet and dry sides maintains the supply of signaling molecules (and sustains the restriction of water use) from the root system along with the absorbed water from the soil (Dodd et al., 2006; Stoll et al., 2000). Thus far, research on PRD in apple has generally resulted in the saving of water with minor or no negative effect on yield and on fruit quality (Caspari et al., 2004a, 2004b; Einhorn and Caspari, 2004; Leib et al., 2006; Lombardini et al., 2004; van Hooijdonk et al., 2004; Zegbe et al., 2006, 2007). However, there is no information on the effects of PRD on long-term storage performance of apple fruit and on some fruit quality attributes such as fruit weight loss in storage and internal ethylene concentration (IEC) as an indicator of fruit maturity. The objective of this research was to test the hypothesis that PRD does not negatively affect fruit quality at harvest and after storage compared with commercial irrigation (CI) for 'Pacific Rose™' apple. Emphasis was placed on weight loss in storage because New Zealand apple is exported to distant markets and this quality parameter is important for the industry.

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Materials and Methods

Two experiments were conducted at the Fruit Crops Unit, Massey University, Palmerston North (lat. 40.2°S; long. 175.4°E), New Zealand, with 4-year-old 'Pacific Rose™' apple on 'M.9'/'MM.106', and were spaced at 4 × 3 m and trained to a central leader. The area has humid-temperate climate with an average annual rainfall of 960 mm. The soil is a Manawatu fine sandy loam. Trees received standard cultural practices for local commercial fruit production, including fertilization, pest, disease, and weed control. Trees were hand-thinned to 6 fruit per cm^2 of trunk cross-sectional area at 50 and 53 d after full bloom (DAFB), which occurred on 3 Oct. 2000 and on 23 Oct. 2001.

For Expt. 1 (growing season of 2000–01), 16 trees were divided into four blocks each having two plots of two experimental trees. Two guard trees at each end surrounded the plots. CI and PRD treatments were randomly allocated within each block. For PRD, irrigation was applied only to one side of the tree row, with the other side left unirrigated during the growing season. Expt. 2 (growing season of 2001–02) had the same design as Expt. 1 except that for the PRD treatment, water was applied to one side of the tree row with the other side allowed to dry to a volumetric soil water content (θ) between 0.18 and 0.22 $m^3 \cdot m^{-3}$ before being irrigated next to avoid permanent wilting point. For this soil, field capacity and permanent wilting point occurred at θ values of 0.35 and 0.17 $m^3 \cdot m^{-3}$, respectively. The θ was measured at a depth of 500 mm (where the apple root system is most prevalent) using time domain reflectometry as detailed in Zegbe et al. (2007). Soil in the PRD plots was covered with clear polyethylene 1 month before full bloom to keep the rain out.

Fruit quality was evaluated at harvest and after storage at 0 ± 1 °C for 12 weeks followed by storage at 20 ± 1 °C for 18 d in Expt. 1 and, respectively, for 10 weeks and 16 d in Expt. 2. From both experiments, four lots of fruit (24 fruit in each lot) were used for assessing quality at harvest and for each storage temperature. During storage at both temperatures, fruit were kept in commercial cardboard cartons.

Fruit IEC (as maturity index at harvest), background skin color, flesh firmness, and total soluble solids concentration were measured as described by Mpelasoka et al. (2000). Weight loss was evaluated by weighing the fruit individually at harvest and at 2-week and 2-day intervals during storage at 0 °C and 20 °C, respectively.

Data from both experiments were analyzed by randomized complete block model using SAS (SAS Institute, Cary, NC). Categorical variables were transformed to stabilize the variance. Means are reported after back transforming. Treatment means were separated by the least significant difference (LSD) test at $P \leq 0.05$.

Results and Discussion

In Expt. 1, θ in the wet side of PRD and in CI was kept close to field capacity. However, θ in the drying side of PRD slowly decreased from 44 DAFB and tended to stabilize from 100 DAFB to the end of the growing season (Fig. 1A). The slow drying of the soil did not necessitate alternating irrigation on both sides of the root system in the PRD treatment. We do not discount the possibility of water movement from the wet side to the dry side of PRD plots. However, a stronger possibility is water uptake from the deeper soil profile and the occurrence of "hydraulic lift" as defined by Atwell et al. (1999), contributing to the stabilization of θ in the dry side of PRD trees.

In Expt. 2, θ for the PRD treatment changed according to the irrigation schedule (Fig. 1B). Significant differences of θ between CI treatments and the drying side of PRD were only detected on 155, 169, 175, and 196 DAFB. When PRD trees were irrigated on the drying side with half of the water given to CI trees, θ values did not reach those of CI. These values were 6% and 21% below field capacity after the two irrigation episodes in the season. More water should have been applied to the dry side to increase θ to field capacity. However, a decreased θ in this experiment was not reflected in the values of leaf water potential as discussed below.

The fruit quality attributes, listed in Table 1, were the same between CI and PRD, although the latter was irrigated at only 50% of the former. An exception was a lower firmness of PRD fruit after storage discussed below. Improvement of fruit quality in deficit irrigated fruit necessitates lowering of leaf xylem water potential (Ψ) to midday values between –1.5 and –2.5 MPa, as shown by Mills et al. (1996) and Mpelasoka et al. (2000, 2001). We assessed Ψ with a Scholander pressure chamber on 52, 87, 115, and 142 DAFB for Expt. 1, and on 146, 155, 176, and 184 DAFB for Expt. 2. For each of these days, Ψ was measured five times in regular intervals from dawn to dusk. In neither of the experiments was Ψ at noon lower than –1.5 MPa. Therefore, we cannot suggest a lower Ψ as an explanation for a lower firmness after storage for PRD fruit in Expt. 2 while the other quality parameters were the same between the two treatments (Table 1), including fruit size in terms of mean fruit weight. The mean fruit weight values (g ± SE) were 277.2 ± 4.7 and 277.4 ± 9.3 for CI and PRD, respectively. As fruit could be hydraulically isolated from the leaf (Davies et al., 2000), research on apple fruit water relations is needed to understand the impact of PRD on fruit quality as proposed by Davies et al. (2000) for tomato undergoing PRD.

Fruit IEC is a physiological indicator of fruit maturity (Graell et al., 1993; Mpelasoka et al., 2000). In Expt. 2, at harvest, the IEC tended to be higher in PRD fruit than in CI fruit. The mean values (LSD = 0.56 $\mu L \cdot L^{-1}$) were 0.63 and 0.83 for CI and PRD fruit, respectively. We measured the IEC only once at harvest in Exp. 2. However, in view of this finding and implications for fruit marketing, more research will be needed for securing a firm conclusion about possible differences for similar treatments in future experiments.

Reduced weight loss in storage is a positive quality attribute in fruit and this happened for the PRD fruit in Expt. 1 (Fig. 2). Fruit weight loss in storage is mainly from water loss (Maguire et al., 2001). This could have happened in Expt. 1 because of a lower skin permeance or a lesser incidence of microcracks in the skin of PRD fruit. The reduction of fruit weight loss in storage is an important attribute particularly for fruit destined for distant markets.

In summary, for 'Pacific Rose™' apple, we showed that PRD saved water by 50% but did not alter fruit quality adversely at harvest or after storage. Fruit weight loss in storage was significantly reduced when irrigation was applied to only one side of the tree row during the entire growing season. Weight loss

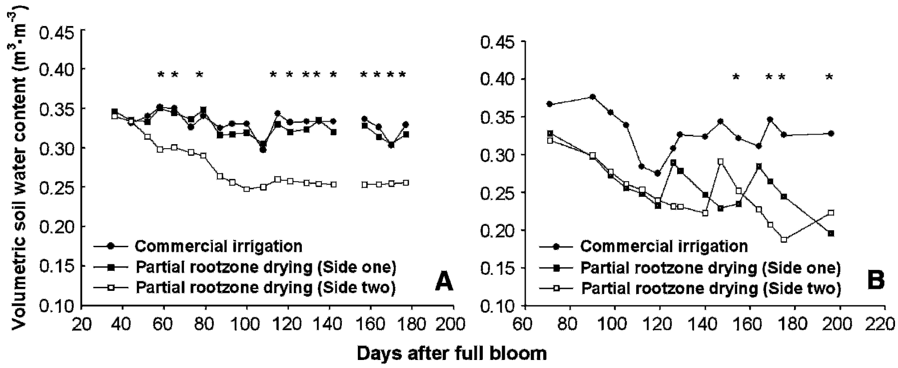

Fig. 1. Changes in volumetric soil water content (θ in the text) in commercially irrigated trees and both sides of PRD trees in Expt. 1 (**A**) and Expt. 2 (**B**). The asterisks indicate significant differences at the $P \leq 0.05$, LSD test.

Table 1. Influence of CI and PRD on some quality attributes of 'Pacific Rose™' apple at harvest and after storage for 12 weeks and 18 d (Exp. 1) and 10 weeks and 16 d (Exp. 2).

	Irrigation treatments					
			After storage			
	At harvest		0 ± 1 °C		20 ± 1 °C	
Quality attribute	CI	PRD	CI	PRD	CI	PRD
Experiment 1						
Total soluble solids concentration (%)	13.0a[z]	12.0a	14.0a	14.0a	15.0a	14.5a
Flesh firmness (N)	83.0a	84.0a	81.0a	80.0a	80.0a	80.0a
Experiment 2						
Flesh firmness (N)	85.0a	84.0a	84.0a	86.0a	85.2a	73.6b
Total soluble solids concentration (%)	13.4a	12.9a	14.4a	14.5a	14.7a	15.2a
Fruit skin color (HA°)[y]	31.6a	29.5a	29.4a	29.6a	—	—
	35.0a	34.7a	—	—	34.4a	32.4a

[z]For the harvest and each of the storage periods, means within rows followed by the same letter are not significantly different at $P \leq 0.05$, LSD test.

[y]Three different lots (one for each condition) of fruit were used to asses changes in fruit quality at harvest and at two storage temperatures. Hue angle was measured at the start and at the end of each storage temperature.

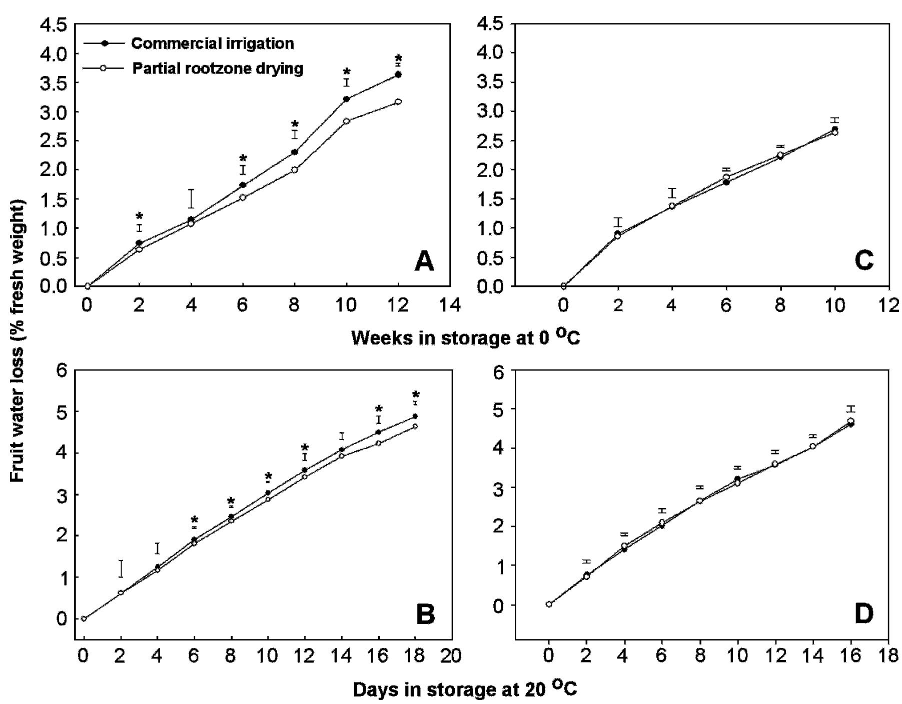

Fig. 2. Cumulative fruit weight loss as percentage of original weight during storage for 'Pacific Rose™' apple under PRD and CI for Expt. 1 (**A** and **B**) and Expt. 2 (**C** and **D**). Vertical bars represent LSD values and the asterisks indicate significant differences at $P \leq 0.05$, both for each sampling date.

of PRD fruit and CI fruit was the same when PRD irrigation was alternated between two sides of the tree row. Application of PRD saved water by 0.15 mega liters per hectare in Expt. 1 and by 0.14 in Expt. 2. Further research is warranted to see whether the effect of PRD on fruit quality in a dry climate and fruit weight loss during storage yield the same results as in these experiments that were carried out in a humid environment.

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