Deficit Irrigation and Partial Rootzone Drying Compared in Figi Apples

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Abstract

Many agricultural/horticultural industries depend on a large and inexpensive supply of water for irrigation. However, increasing demands from cities, recreational users and environmental groups are competing for the same supply of water causing new approaches to irrigation management to be required to meet this challenge.

In this research, Figi apple trees were irrigated in three treatments: 1) a control where micro-sprinklers on both sides of a tree were operated to maintain soil moisture at field capacity, 2) deficit irrigation (DI) where both micro-sprinklers were operated at half the time as the control, and 3) Partial Rootzone Drying (PRD) where only one micro sprinkler alternately wetted half the rootzone with half the water as the control.

In 2001, the Figi apple trees received 22 inches of water in the control treatments and 12 inches of water in the DI and PRD treatments without any significant difference in yield or quality. In this deep silt loam soil, more than an additional inch of soil water was depleted from the DI treatments as compared to the PRD treatments.

Introduction

The success and survival of many agricultural/horticultural industries depends on the continued supply of large volumes of water for irrigation. However, good quality water is a scarce resource and competition between resource users will continue to increase. With increasing water demands from cities, recreational users and environmental groups, less of this finite resource will be available for agriculture/horticulture. Clearly, new approaches to irrigation management are required that will reduce both water consumption and the detrimental environmental effects of current practices. While irrigation strategies such as Regulated Deficit Irrigation (RDI) (Chalmers et al., 1981) can significantly reduce water use in crops such as peaches, pears and grapes, they have not been successful with apples due to a negative impact on fruit size and yield. In fact, many studies have shown that water deficits reduce final fruit size in apples, irrespective of timing (Ebel et al., 1993; 1995; Landsberg and Jones, 1981; Lötter et al., 1985; Mpelasoka et al., 2000). Partial Rootzone Drying (PRD) is a new deficit irrigation strategy that offers the potential to use deficit irrigation on crops where other deficit strategies such as RDI lead to negative outcomes.

Partial Rootzone Drying is a new deficit irrigation strategy that has been developed recently for grapevines (*Vitis vinifera* L.) in Australia (Dry et al., 1996; Dry and Loveys, 1998; Dry et al., 2000a; 2000b). With PRD, irrigation is withheld from a part of a plant's rootzone while the remaining part is kept well watered. Briefly, the proposed physiological mechanism of PRD is that roots in drying soil synthesize a hormonal signal (abscisic acid, ABA) which is transported to the shoots, indicating a developing soil-water deficit. In the leaves, ABA induces partial stomatal closure which increases water-use efficiency. However, as the remaining part of the rootzone is kept well watered, the effect on plant water potential is minimal. In order to maintain the ABA signal, irrigation is alternately applied to each side of the rootzone, allowing the wet side to dry while the dry side is rewetted. Such application of PRD to grapevines has resulted in water savings of up to 50% with significant reductions in vegetative vigor and improved fruit quality, but without loss of yield (Dry et al., 1996; Loveys et al., 1998).

In the last four years, trials were conducted with PRD on apples in the Marlborough region of New Zealand, and one preliminary trial in Washington State. In the New Zealand experiments with Royal Gala, Fuji and Braeburn apples, seasonal irrigation input was reduced by 30-50 % without loss in fruit size or yield (Caspari and Neal, unpublished). Similarly, PRD applied for the final seven weeks prior to harvest did not reduce fruit size and yield of 'Golden Delicious' apple growing near Prosser, WA while conserving 50 % of irrigation water over this same period (Caspari and Lang, 2000).

Many studies have compared one form or another of deficit irrigation to a well-watered control, but only few studies have included more than one type of deficit irrigation. During the 1999/2000 growing season, three different forms of deficit irrigation of Braeburn apples were compared to a well-watered control in the Marlborough region of New Zealand (Caspari and Neal, unpublished). All deficit treatments were irrigated at 50% of the control. Fruit size and yield was reduced by omitting every other irrigation and by applying 50% of the water to the entire planting area as compared to the control, but fruit size and yield were not affected by PRD. There was no significant treatment effect on soluble solids, firmness, color, starch pattern index, and the development of fruit disorders.

Objective

Determine the impact of Partial Rootzone Drying on apple size, yield and quality, including the occurrence of sunburn, fruit cracking and post-harvest disorders as compared to Deficit Irrigation and a well-watered control group.

Method

At the beginning of the 2001 growing season, a block of 6 year old Figi apples containing 120 trees on a 9 foot by 16 foot spacing was converted from furrow to micro sprinkler irrigation at Washington State University's Irrigated Agricultural Research & Extension Center in Prosser, WA. The micro sprinklers were placed in the tree rows in the middle of the space between trees such that a micro sprinkler's wetting pattern only reached the trees on each side. This configuration isolated the irrigation to each side of a tree to allow for partial rootzone drying. Water supply pipe was installed to create three treatments, Control, Deficit Irrigation, and Partial Rootzone Drying, in a completely randomized block design of four replications (see Table 1).

The control plot was maintained at field capacity by applying 60 to 70% of the Public Agricultural Weather System (PAWS) estimated evapotranspiration rate. For the partial rootzone drying (PRD) blocks, one side of the sprinkler system (half of the tree's roots) was operated for the same length of time as the control. After 3 to 4 weeks, the sides were switched to irrigate the other half of the root system. In the deficit irrigation (DI), sprinklers on both sides of the tree were operated for half of the amount of time as the control, with a total quantity of about half of the total water applied to the whole root zone. Immediately following bloom, the moisture in all three plots was raised to field capacity. The plots were then irrigated as described above once a week until early October when all plots were returned to field capacity for winter dormancy. The total amount of water applied prior to refilling the rootzone was 22.1 inches in the control and 11.5 inches in both PRD and DI.

Soil water and apple size were monitored on a weekly basis throughout the 2001 growing season. Neutron Probe access tubes were located mid way between the micro sprinklers and the trees. One access tube was installed in each experimental unit with the exception of the PRD treatments in which case two access tubes were installed to measure soil water on each side of a tree's rootzone. The access tubes were inserted to a 3 to 4 foot depth depending on the soil depth encountered, and measurements were taken at a six-inch interval approximately 2 days after each weekly irrigation. The soil is classified as a very fine sandy loam to silt loam with a water holding capacity of nearly 2 inches per foot. Apple size was also measured on a weekly basis using a Cranston diameter gauge. The same ten fruit were measured in each experimental unit throughout the growing season.

Fruit was harvested from designated trees in each experimental unit on October 3, 2001. The fruit was sorted by size and each size group was counted and weighed. A sub sample of similar size fruit were evaluated for sunburn and then taken to the lab for further analyzed. Maturity indexes were measured at harvest and after 14 days of ripening in respiration chambers held at room temperature. Measurements of fruit firmness using the Fruit Texture Analyzer (Güss), soluble solid concentration (SSC) using a digital refractometer (Atago), starch index (0-6 scale for Fuji), density, titratable acidity, percentage of red color and internal ethylene using a gas chromatograph (Hewlett-Packard GC 5830 with a PLOT column). Ten fruit were used for each measurement. Six apples stored for 14 days in the respiration chambers had carbon dioxide (CO_2) and ethylene (C_2H_4) evolution recorded.

Results

Figure 1 shows the soil water trends for the three treatments; Control Irrigation (CI), Deficit Irrigation (DI), and Partial Rootzone Drying (PRD). It should be noted that the PRD soil-water content is an average of the wet and dry sides of the treatment. All treatments show a drop in soil water at the end of May because water deliveries were stopped during this time period to conserve reservoir water for use later in the growing season due to the drought conditions of 2001. Also, the drought caused water deliveries to be turned off earlier than normal at the end of the growing season and soil water profiles reveal a large increase in soil water to prepare for the dormant season. With the exception of these drought induced changes in soil water, the CI treatment was kept consistently at field capacity (3 in/ft) during the 2001 growing season. Both the DI and PRD treatments show a consistent decrease in soil-water content and significant use of water from the soil profile. However, DI soil water-content dropped at a faster rate than PRD. This could be the result of PRD creating a longer lasting ABA signal and thus reducing tree transpiration as discovered in earlier research, but it should be noted that PRD wets half of the surface area of the other treatments. PRD could be creating less soil surface evaporation and thus be increasing the application efficiency of this irrigation method.

Figure 2 shows the apple growth trends for the three treatments. Apple size is very similar early in the growing season for all the treatments. DI caused apple size to start decreasing around the end of July and the decreasing rate continued until the end of the growing season. PRD apple size also started to decrease at the beginning of September as compared with CI. The decrease in apple size for both the DI and PRD seemed to correspond to the time when soil water content dropped to around 2.1 in/ft (averaged for the entire rootzone) or around 50% depletion.

Table 2 shows that there was no statistical difference between treatments for any of the yield and quality parameters. It should be noted that these apples were harvested in a single picking about two weeks prior to their optimum maturity. The fact that no statistical difference was found seemed to contradict the growth response found in Figure 2 that seemed to indicate a noticeable difference in apple size. Figures 3 and 4 reveal some reasons for this discrepancy by showing the individual yield data in relationship to the crop load (number of apples per tree). The crop load varied from 50 to 350 apples per tree and this caused noticeable differences in fruit size and yield. Figure 3 shows decreasing average apple size with increasing crop load, and Figure 4 shows increasing yield per tree with increasing crop load until 300 fruit per tree were reached, then yield stayed the same as crop load increased to 350 apples per tree. A covariant analysis will reduce the variation caused by crop load and help identify treatment differences. In Figures 3 & 4, DI data points are lower in apple size and yield and may separate from the other treatments. Figures 3 & 4 also provide a possible reason for the apple size reductions observed in Figure 2. The DI treatments have greater crop load than both CI & PRD, and PRD has greater crop load than CI.

Conclusions

Figi apples grown in deep soils with high water-holding capacity were able to produce the same apple yield and quality when half the water was applied by either DI or PRD. However, soil-water monitoring revealed that more water was preserved in the soil profile under PRD than DI. In shallower and lower water-holding soils, the ability of PRD to conserve soil water may have a greater impact on fruit yield and quality. Also, crop load created a noticeable difference in yield and quality. Therefore, a covariant analysis would help identify treatment differences and greater care was taken in the 2002 growing season to created similar crop loads in each experimental unit. Also, the 2002 growing season may reveal a carryover effect in the deficit irrigation treatments.

Acknowledgements

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Table 1: Irrigation Amounts in 2001, Figi PRD Trial, Prosser, WA

PAWS ET Apples no cover crop	Control Treatments	Deficit Irrigation Treatments	Partial Rootzone Drying Treatments
29.8 inches	22.1 inches	11.5 inches	11.5 inches

Table 2: Apple Yield and Quality Statistics, Figi PRD Trial, Prosser, WA

Fruit Yield	Fruit Size	Soluble solids	Acids	Starch	Firmness	Sunburn Incidence	Sunburn Severity
CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns

CI - Control Irrigation
DI - Deficit Irrigtion
PRD - Partial Rootzone Drying

ns – no significant difference

Figure 1: Soil Moisture Trends for 2001 Figi PRD Trials, Prosser, WA

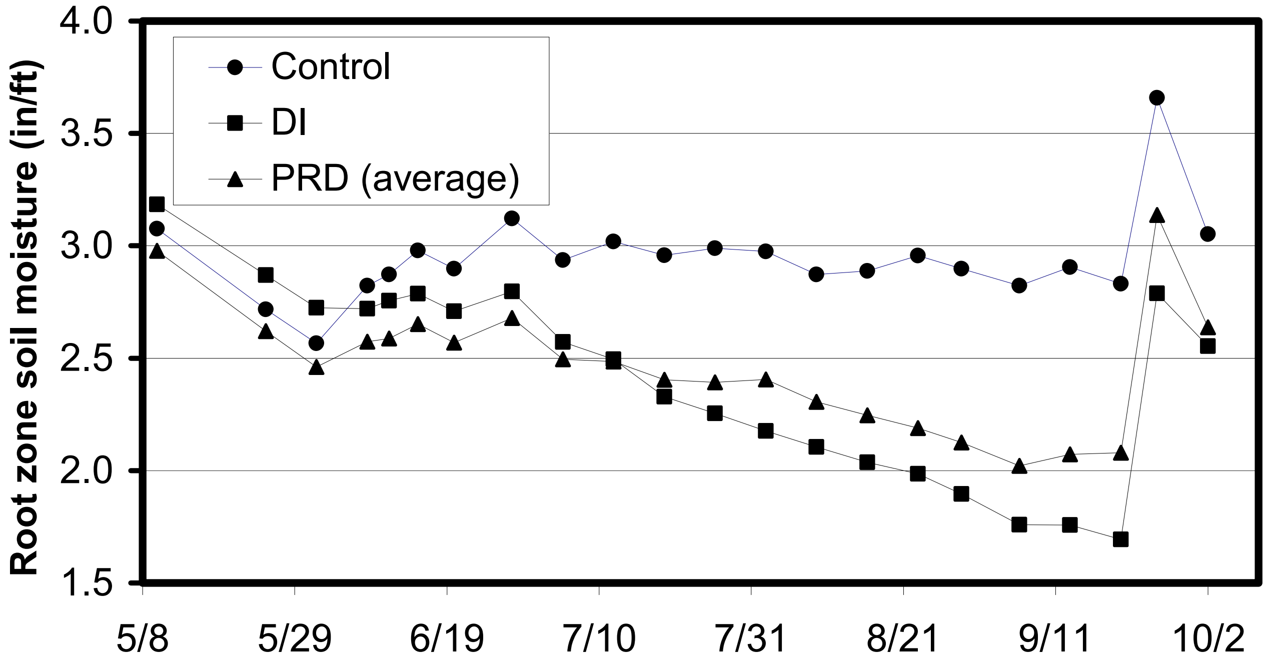

Figure 2: Fruit Growth during 2001 Figi PRD Trial, Prosser WA

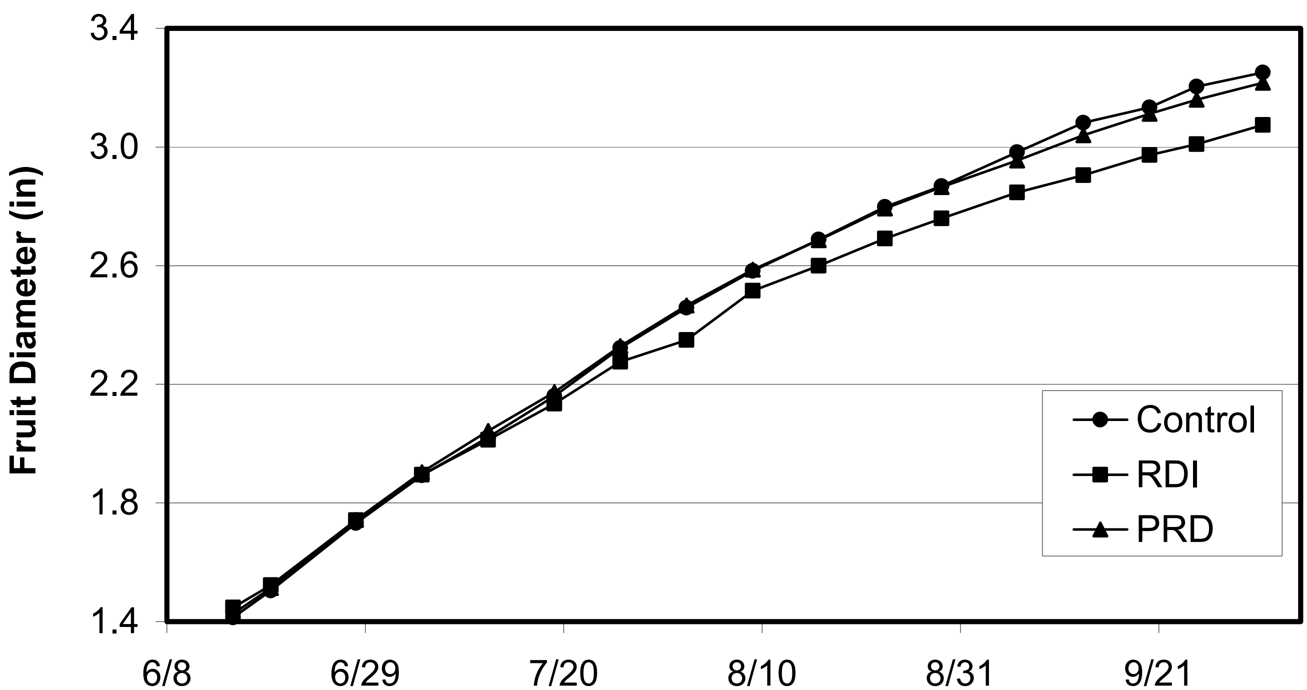

Figure 3: Apple Size at Harvest 2001
Figi PRD Trial, Prosser, WA

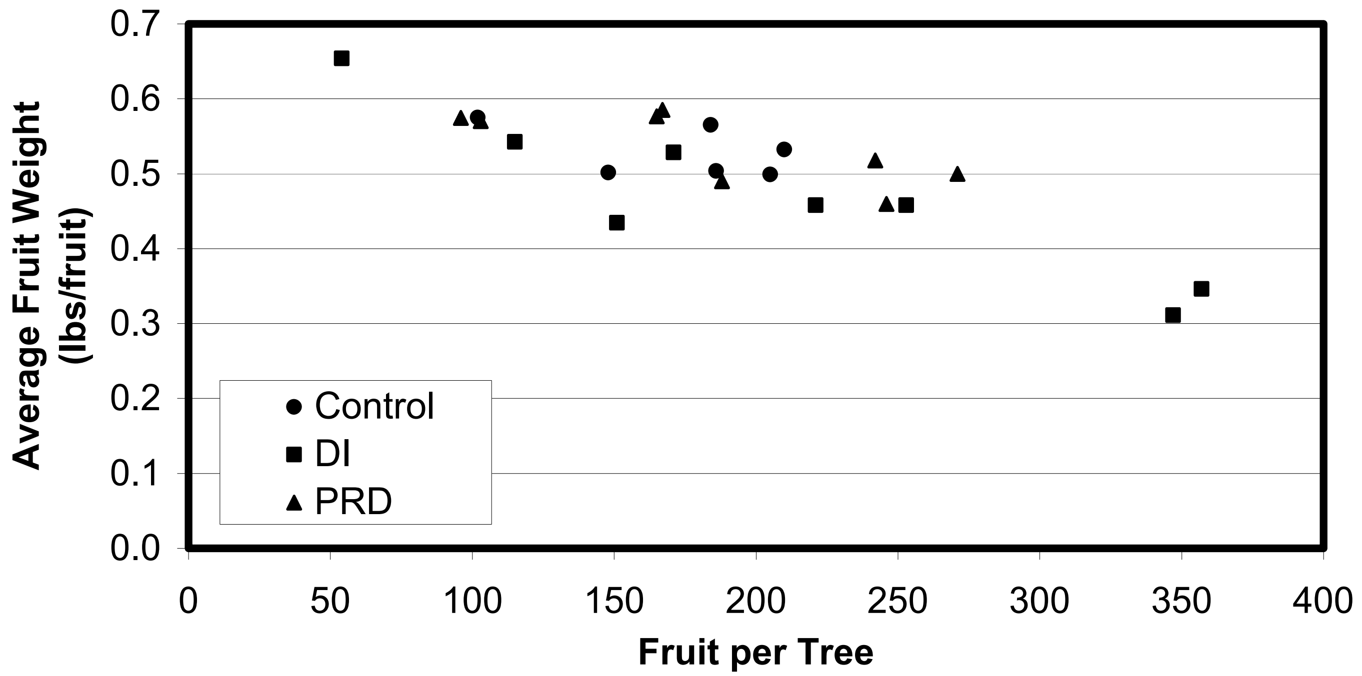

Figure 4: Apple Yield 2001
Figi PRD Trial, Prosser, WA