

CARDIP 2006 report: Almond RDI and consumptive water use

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Abstract

This report covers the third year of a large scale RDI test designed to address the question of whether or not our proposed plant-based RDI regime is an effective method of reducing crop consumptive water use in almonds. A microsprinkler irrigated almond ranch of 320 acres (Magnum Ranch, Lassen Land Co.) was divided into 5 approximately equal blocks, and each block divided into unequal sized plots (1/3 West side and 2/3 East side of the block) in order to match the existing irrigation blocks. East and West plots were alternately assigned to control or RDI treatments. Control plots received normal grower practice (approximating full ETc), and RDI treatments were based on imposing a target level of stress, as measured by a midday stem water potential (SWP) of -14 to -18 bars during hull split. In 2006, separate irrigation control valves were installed so that irrigation to 3 rows in the center of each RDI plot could be adjusted remotely, allowing more precise application of water to these plots, on a block-by-block basis. SWP was measured approximately weekly (bi-weekly during hull split), and volumetric soil water content was measured with a calibrated neutron probe on for key dates: prior to irrigation in early spring (April 20), just prior to RDI (July 3), just prior to harvest (September 1), and at the end of the irrigation season (October 26), to estimate soil contribution to ETc. Entire rows in each plot were commercially harvested, gross harvest weight was determined with a weighing trailer in the field, and a 5 lb subsample was collected and used to convert harvest weight into yield of nutmeats. In the control, the overall seasonal pattern in applied water was parallel to the calculated CIMIS ETc, and when water use from soil reserves was included, by the end of the irrigation season the control treatment was identical to a full cover CIMIS ETc. By the end of the season, the RDI had a modest savings in applied water of about 4.7 inches, and, accounting for water used from soil storage, a savings in total water use of about 5.6 inches. Yield was slightly lower in the RDI treatment compare to the control, but not significantly. Our plant-based irrigation regime gave a seasonal pattern of irrigation coefficient (equivalent to an 'effective' crop coefficient) equivalent to a 35% reduction from the control, during the RDI period, with some indication that this reduction may depend on local soil conditions. As in previous years, the similarity in the SWP of both treatments following the resumption of normal irrigation in the RDI treatment, despite the continued occurrence of irrigation deficit in the RDI compared to the control treatment, suggested that tree water use was reduced during the imposition of RDI. These data indicate that RDI was associated with a reduction in tree consumptive use of about 5 inches seasonally. For all three years to date, yield, nut size and nut moisture were essentially unaffected by the RDI treatment.

Introduction

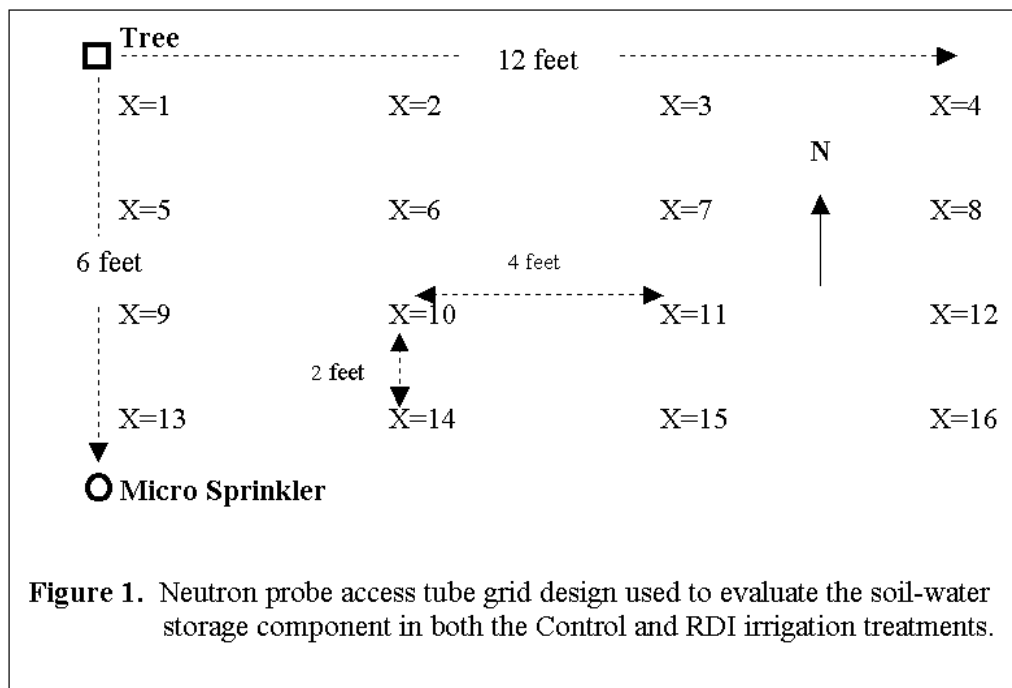
Currently, a number of irrigation scheduling methods are available to growers, and there is substantial variation in which methods are used, even for the same crop, irrigation system type and growing region. In California, the most widely recommended method is based on the calculation of crop water requirements (ETc), using weather information to calculate reference crop evapotranspiration (ET0) and a seasonally variable, crop specific coefficient (Kc). This approach however, is based on the assumption that the goal of irrigation is to maintain crops in a fully irrigated (i.e., non-limiting soil water) condition, and in a number of crops, particularly woody perennials, there is evidence that water deficits may improve crop quality, or reduce undesirable vegetative growth. One approach that seeks to strike an optimal horticultural balance between vegetative (shoot) and reproductive (fruit) growth is Regulated Deficit

Irrigation (RDI, Chalmers et al, 1986) The management of RDI however, has most often been based on target levels of an irrigation deficit, based on full crop evapotranspiration (ET_c) as a reference. For instance, Teviotdale et al. (2001) reported that reduction to 50%ET_c during part of the hull splitting period of fruit development led to a lower incidence of hull rot disease in almonds. In some cases, plant-based measures have been used to manage RDI, for instance Prichard (1995) tested a post-harvest RDI strategy in almonds under full coverage irrigation, based on a single threshold value of predawn water potential (-1.2MPa), and found that almonds were very tolerant of postharvest water deprivation based on this approach. This contrasted with the recommendation of Goldhamer and Viveros (1999) that postharvest water deprivation was very detrimental to subsequent years yield in almond. Since it is expected that RDI will invariably result in the depletion of the soil water reservoir, it is possible that these differences in results, and in the relative success of RDI approaches under different soil conditions, may be related to differences in soils and rooting volumes, and in the necessarily site-specific ability of the rooted volume of soil to compensate for any particular level of irrigation deprivation. For this reason we have based RDI recommendations on the level of stress experienced by the plant, and have used midday stem water potential (SWP) as the measure of plant stress (McCutchan and Shackel, 1992). For prune trees, it has been reported that mild to moderate water stress may improve fruit quality without reducing dry fruit yield (Lampinen et al, 1995), and a regulated deficit irrigation (RDI) protocol, based on target levels of SWP, has been proposed to take advantage of the benefits of this level of stress (Lampinen et al, 2001).

A recently concluded four year study in almonds (Shackel et al, 2004) demonstrated that the same plant-based RDI regime could be applied across a wide variety of orchard soil and irrigation system types, with no negative effects of RDI on yield. In some cases there were horticulturally beneficial effects of RDI, such as improved hull splitting, nut harvestability, and reduced incidence of hull rot, but the overall savings in applied irrigation water were highly site and year specific, ranging from 0 to over 50% (Shackel et al., 2003). These water savings are promising, but in this study there was no data collected to estimate the contribution to ET_c from stored soil water, and hence we are not certain that large scale water savings can be achieved in almond using this method. This report covers the first year of a large scale RDI test designed to address the question of whether or not our proposed plant-based RDI regime is an effective method of reducing crop consumptive water use in almonds.

Materials and Methods

A microsprinkler irrigated almond ranch of 320 acres (Magnum Ranch, Lassen Land Co.) was divided into 5 approximately equal blocks in 2004, and each block divided into unequal sized plots (1/3 West side and 2/3 East side of the block) in order to match the existing irrigation blocks, as previously reported. Briefly, two NonPareil trees in the center row of each West block plot and two NonPareil trees in each of two rows in the East plots were designated as monitoring trees for the weekly measurement of midday stem water potential (SWP, McCutchan and Shackel, 1992, Fulton et al, 2001) Entire rows were commercially harvested, gross harvest weight was determined with a weighing trailer in the field, and a 5 lb subsample was collected and used to convert harvest weight into yield of nutmeats. Water meters measured the flow to a single lateral line which covered the central approximately 1/3 of each of monitored row in each block. Crop water demand was estimated using the ET₀ from a nearby CIMIS station (#64, Orland), together with the crop coefficients for a mature almonds (California Department of Water Resources, 1986), adjusted for the approximate full bloom date observed for this orchard in 2004 (March 5), 2005 (February 20) and 2006 (March 1). The orchard floor management was



intermediate between clean tilled and full cover, with a mowed herbaceous cover crop in winter and spring, drying to bare ground by about mid-summer. Hence, for comparative purposes, both full cover and clean tilled values of ET_c were calculated.

A grid of neutron probe access tubes constructed of Class 200 PVC pipe was installed adjacent to a single data tree in Block 4, Row 64 to represent the control irrigation plot and in Block 4, Row 32 to represent the RDI irrigation plot (Fig. 1). A total of 32 neutron probe access tubes were installed for soil water content monitoring.

The space around the data tree in each irrigation treatment was 12 feet in the tree row and 24 feet between tree rows. The grid of access tubes consisted of 16 neutron probe access tubes equally spaced in one quadrant with the dimensions of 6 feet by 12 feet. Access tube spacing was approximately 2 feet between tubes in the north-south direction and four feet in east-west direction.

The soils were stratified and had a significant gravel fraction and in some instances hardpan. In May, shallow water table was also evident. Attempts were made to install access tubes to a depth of 60 inches and to measure volumetric soil water content at 8, 18, 30, 42, and 54 inch depths to represent the middle point of each one-foot increment to a composite depth of 60 inches (five feet). However, the gravel, hardpan, and shallow water table restricted depth of installation for some access tubes. Measurements were taken to a depth of 42 inches in all access tubes. Volumetric soil water content was measured at 54 inches in 22 of the 32 access tubes, but since the purpose of the neutron data is to evaluate changes in soil water content over the season, average values for all tubes and depths will be reported.

The neutron probe was calibrated in April and September 2004 at this orchard site to acquire samples with a wide range in soil water content. Volumetric soil water content was measured gravimetrically by collecting 60 cm³ soil cores at 8, 18, 30, and 42 inch depths in the spring and fall of 2004 at three locations in the experiment. After collecting the volumetric soil samples

from each auger hole, a class 200 PVC access tube was installed into the hole and neutron probe measurements collected for the corresponding depths. Linear regression was performed to correlate the neutron probe count ratio to volumetric soil water content as determined by using gravimetric methods.

In the wetted zone of the instrumented and monitored tree in Block #4, watermark soil matric potential sensors were installed at depths of 3, 12, 19, 26, 33, 40 and 45 inches on June 18, 2004. These sensors were recorded every 30 minutes, and for each depth a daily average was calculated.

2006 Results

There were some rains after full bloom (March 1) in 2006, and hence, even though seasonal K_c 's and ET_o 's gave positive values for crop water demand, early season water balance estimates were negative, predicting an increase in soil water storage through about mid-April (Fig. 2). However, once irrigations began in late April, applied water in both treatments closely approximated 100% of the calculated ET_c (Fig. 2). Hull split and the RDI regime began around mid-July, and there was a clear separation in applied water between treatments from this time onward (Fig. 2).

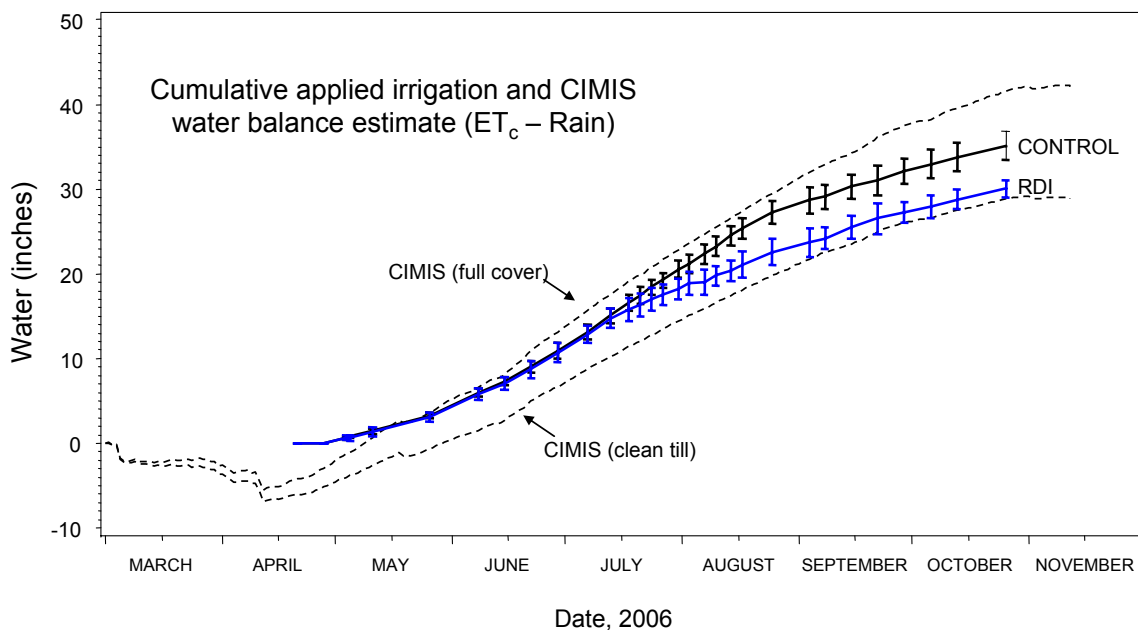


Figure 2. Cumulative water applied to the control and RDI treatments (solid lines), and cumulative estimated ($ET_c - \text{Rain}$) for 2006. Error bars are $\pm 2SE$.

Average neutron probe measurements of soil moisture showed that there was no difference between the treatments before RDI was imposed, and that during the RDI period, there was somewhat more water depleted in the RDI treatment compared to the control treatment (Fig. 3A). Following the RDI period, however, soil moisture levels recovered to the same value as that of the control (Fig. 3A). Based on the observed seasonal change in soil moisture (March 1 to October 26), a water balance estimate was made, and showed that a net reduction in consumptive water use of about 5.6 inches was associated with the imposition of RDI, which represented a savings of about 13% in applied water (Table 1).

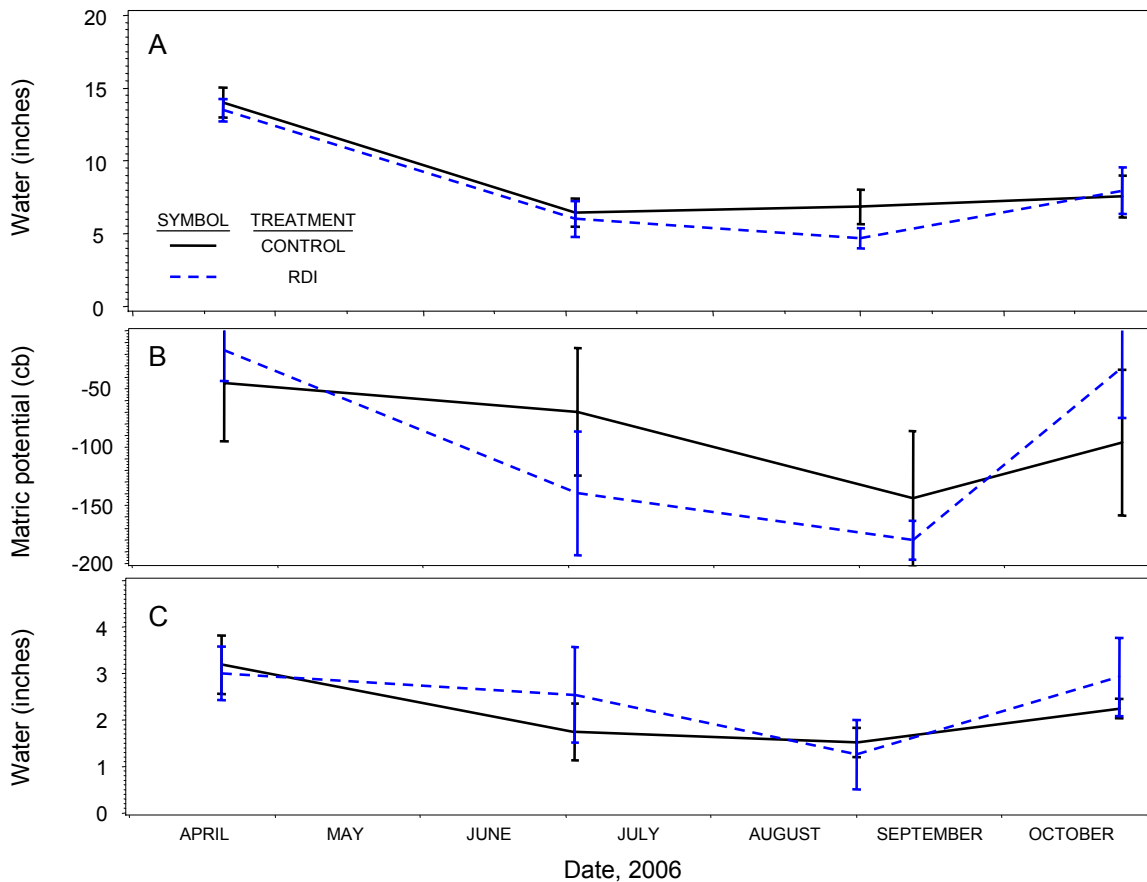


Figure 3. Seasonal pattern of entire quadrant volumetric soil moisture as determined by all depths and neutron probe sites (A), soil matric potential sensors at one neutron probe location (X = 13, fig. 1, B), and the soil moisture as determined in that location by the neutron probe (C). Error bars are $\pm 2SE$.

Table 1. Water balance estimate of consumptive water used in the 2006 season (March 1 to October 26) for control and RDI treatments.

Treatment	Seasonal applied water (inches)	Contribution from soil storage (inches)	Total water used (inches)	Percent of CIMIS ETc	
				Clean Cultivated	Full Cover Crop
Control	35.1	6.5	41.6	144%	100%
RDI	30.4	5.6	36.0	125%	87%

The overall seasonal pattern of soil moisture based on soil matric potential (Fig. 3B), and for the neutron access tube (Fig. 1, X = 13) located adjacent to the matric potential sensors (Fig. 3C) were similar to those of the treatment average (Fig. 3A), but with substantially increased variation, and, in some cases a reversal of the apparent treatment effects. However, in no case were there any significant differences between treatments based on these measures (Fig. 3B and C).

The irrigation management criteria for this study is midday stem water potential (SWP), and we were successful in achieving the -14 to -18 bar target during the RDI period (Fig. 4). The control (grower practice) irrigation treatment was also temporarily in this range in mid-June and around

harvest in early September, but otherwise this treatment exhibited SWP values close to the fully irrigated baseline for almonds, particularly during the hull split period (Fig. 4). Because irrigation was based on SWP, each block received somewhat different irrigation amounts, with the mean amount as shown in figure 1.

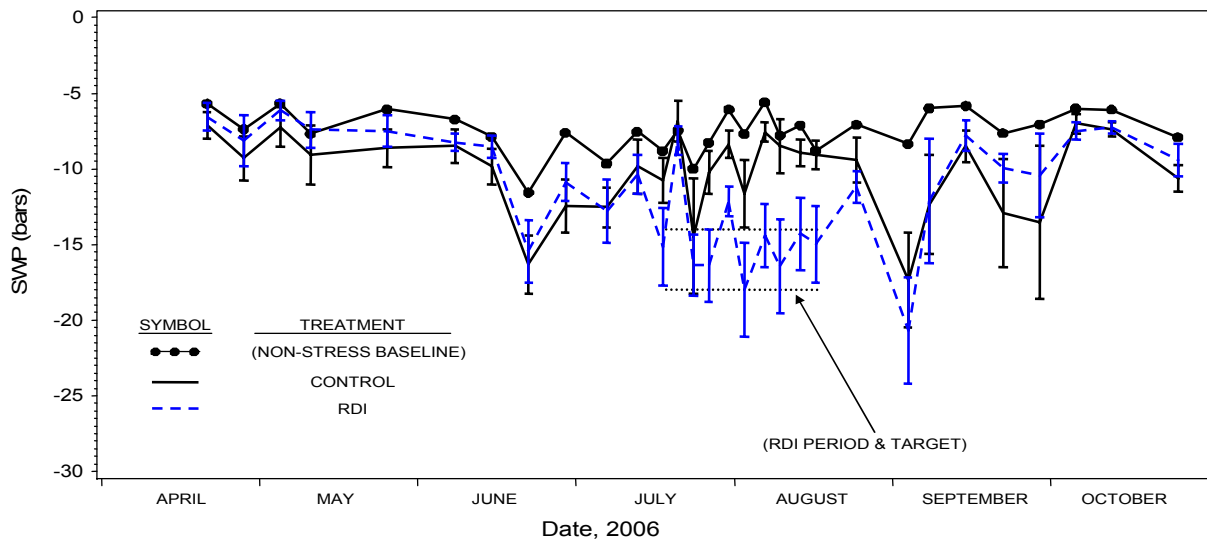


Figure 4. Seasonal pattern of stem water potential (SWP) in the two irrigation treatments, and the SWP expected for fully irrigated (non-stressed) almond trees. Error bars are $\pm 2SE$.

When the water applied was expressed as a K_c value (i.e., equivalent to the 'effective' K_c used for the same amount of applied water), the RDI period was clearly seen as a period of low effective K_c (Fig. 5). The seasonal pattern in these effective K_c 's were relatively uniform across blocks in the control treatment (Fig. 6A), but showed that block 3 required relatively more irrigation during the RDI period than blocks 2, and 4-6 (Fig. 6B).

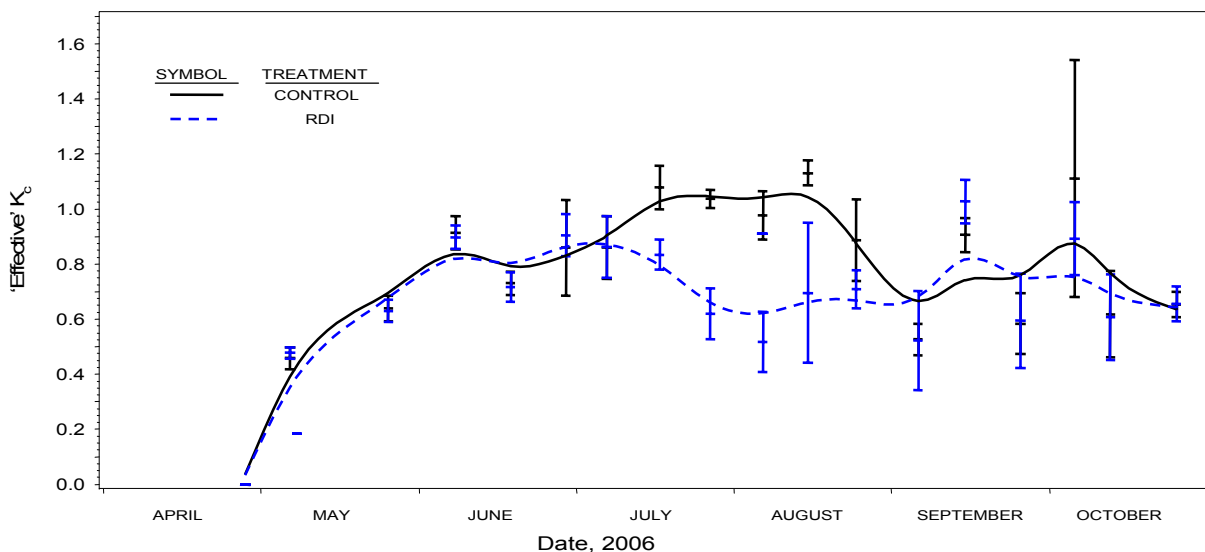


Figure 5. Seasonal pattern of the 'effective' K_c for the two irrigation treatments, as calculated by dividing the applied water by CIMIS ET_0 during each irrigation period. Error bars are $\pm 2SE$, and fitted lines are smoothed splines.

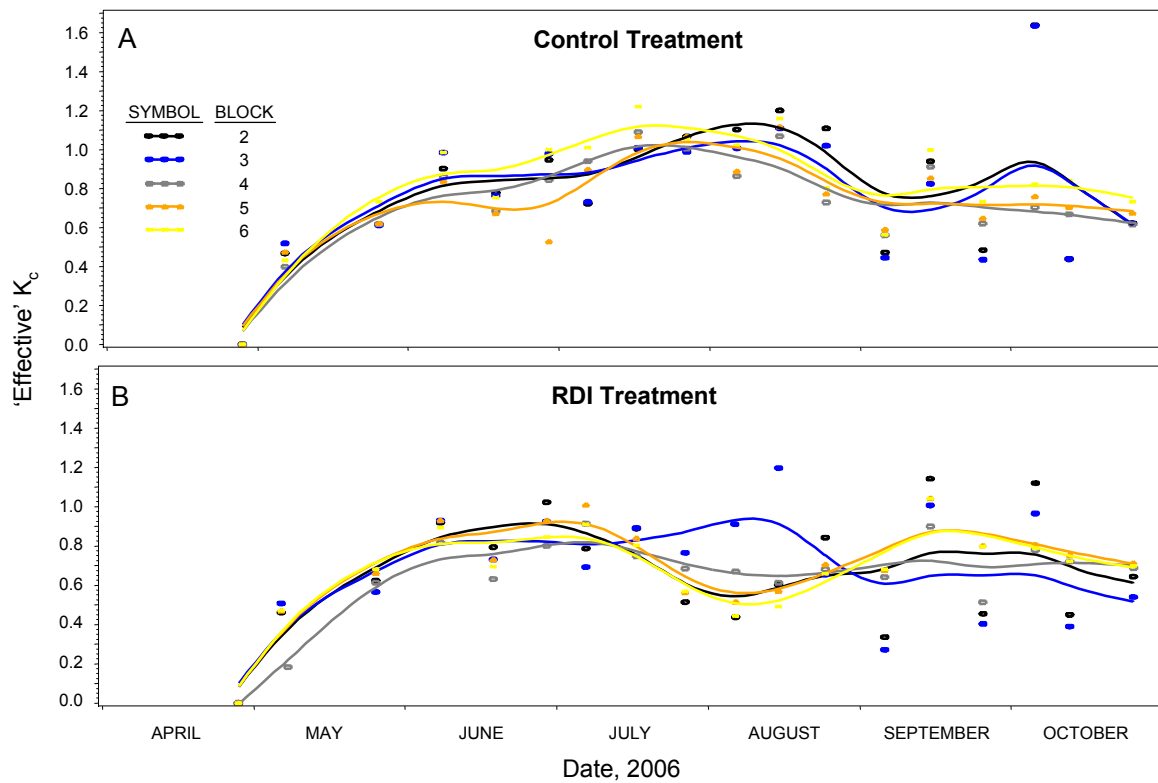


Figure 6. Seasonal pattern of the 'effective' K_c for the two irrigation treatments (as in Fig. 5), for each individual block in the control (A) and RDI (B) treatments. Each point is based on the cumulative irrigation and E_{Tc} over 10-day periods, and the fitted lines are smoothed splines

Yield and other aspects of nut quality were not influenced by the RDI treatment (Tables 2 and 3).

Table 2. Yield, applied WUE and harvested nut characteristics (± 1 SD) for control and RDI treatments in 2006, and the probability (p) values from a two-way ANOVA for the main effects of block and treatment.

Treatment	Yield (pounds nutmeats per acre)	Applied WUE ⁻¹ (gallons irrigation per pound nutmeats)	Nut size (gram per kernel)	Nut moisture (%)
Control	2,200 \pm 560	450 \pm 100	1.10 \pm 0.05	4.65 \pm 1.2
RDI	1,880 \pm 620	490 \pm 200	1.07 \pm 0.05	4.50 \pm 1.1
p-value Block	0.15 NS	0.42 NS	0.99 NS	0.14 NS
p-value Treatment	0.27 NS	0.68 NS	0.57 NS	0.78 NS

Table 3. Nut and kernal quality parameters (± 1 SD) for the 2006 harvest. Treatment p-values from a 2-way ANOVA (block, treatment) are also shown, as in table 4.

Treatment	Percent sealed sutures	Percent physical defect	Percent insect damage
Control	64 \pm 10	4.5 \pm 1.0	0.3 \pm 0.4
RDI	51 \pm 23	6.1 \pm 1.1	0.5 \pm 0.6
p-value Block	0.34 NS	0.70 NS	0.72 NS
p-value treatment	0.24 NS	0.10 NS	0.48 NS

Summary of experimental results to date

A statistical analysis of the yield, applied WUE and nut size and moisture content over the 3 years of the study indicated that both year and block were significant factors, but that irrigation treatments were not (Table 4). Almond orchards can exhibit alternate bearing, and there is some indication of alternation in the annual yields of this orchard (Fig. 7). In addition, there may be some evidence of progressively detrimental effects of the RDI on yields from these data, because the difference between the treatments is largest in the most recent year (Fig. 7). However, determining such longer term effects will require additional years of study.

Table 4. Yield, applied WUE and harvested nut characteristics for control and RDI treatments from 2004 - 2006, and the probability (p) values from a three-way ANOVA for the main effects of year, block and treatment.

Treatment	Yield (pounds nutmeats per acre)	Applied WUE ⁻¹ (gallons irrigation per pound nutmeats)	Nut size (gram per kernel)	Nut moisture (%)
Control	2,025	537	1.22	3.0
RDI	1,922	522	1.19	3.0
p-value Year	0.07 NS	0.006**	0.003**	<0.001***
p-value Block	0.04*	0.02*	0.14 NS	0.13 NS
p-value Treatment	0.38 NS	0.59 NS	0.20 NS	0.94 NS

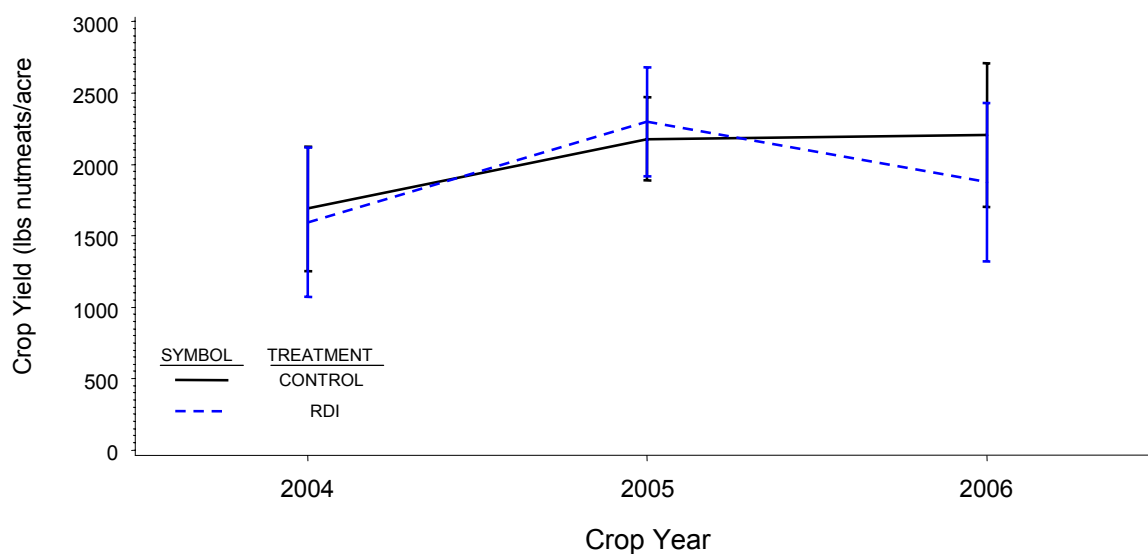


Figure 7. Annual pattern of nut yield for the experiment to date. Error bars are $\pm 2SE$.

Discussion

The orchard chosen for this study is on a relatively shallow soil, with highly variable physical properties, and as such, represents a significant challenge to irrigation management in general, particularly the imposition of RDI. In 2005 and 2006 the orchard experienced a substantial problem with *Alternaria* leaf spot disease, and this also added to the challenge. After three years of study however, it is encouraging to note that there was a small but consistent savings in both irrigation water applied and calculated consumptive water use (Fig. 2, Table 1), with no reduction in yield or quality (Tables 2, 3, and 4). The trend for a greater reduction in this, the third year of the study in the RDI treatment (Fig. 7), must be confirmed with additional years of data.

Compared to results in other almond orchards (Shackel et al., 2004) the levels of stress that occurred in the RDI treatment of this study (Fig. 4) were not substantial. The recommended "target" levels of SWP during the hull split period are -14 to -18 bars (Shackel et al., 2004), and for most of the hull split period in this study (mid-July to mid-August) the SWP of the RDI treatment trees were in this range and the control trees substantially above it (Fig. 4). As was reported in 2005, the RDI plots were reduced in size this year and an automated irrigation control system installed, which allowed us for the first time to control irrigation on a block-by-block basis, without exposing the grower to undue risk. On average, the 'effective' K_c used for the RDI treatment was 0.65 during the RDI period, compared to a value of 1.05 for the control treatment (Fig. 5). However, it is interesting to note that for different blocks, the 'effective' K_c to achieve the same target level of stress ranged from 0.5 to 0.9 (Fig. 6B). If this is confirmed with further study, it will indicate that an RDI strategy based solely on a reduced K_c may not achieve reproducible results in terms of plant water status.

Previous results have indicated that, presumably because of the shallow soil conditions at this site, the contribution of stored soil water from rainfall and irrigation was modest in these plots (13-14% in 2005), and this was also the case in 2006 (about 15% in both control and RDI treatments, based on the values in Table 1). As in 2005, over the entire season the RDI treatment used somewhat less of the stored soil moisture than the control treatment, and hence, combined with less applied water (Table 1), this resulted in an **overall savings of about 13% of consumptive water use (in 2005 this was 15%)**. It is particularly interesting that the soil in the RDI plot was significantly drier than the soil in the control plot at harvest, but the same by the end of the season (Fig. 3). Since irrigation was essentially resumed at control levels after the RDI period (Figs. 2 and 5), this is strong evidence that trees under RDI had a significantly reduced consumptive water use, at least at this time, compared to the trees of the control treatment. Thus far there have been no statistically significant negative effects on nut yield or quality in the RDI treatment, but almond yields may be influenced by carryover effects which can take many years to express, and so these results are encouraging, but must be treated as cautiously optimistic at this point.

Acknowledgements

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