
Spur Dynamics and Almond Productivity

Project No.: 07-HORT7-Lampinen

Project Leader: Bruce Lampinen
Dept. of Plant Sciences
University of California – Davis
One Shields Ave. Mail Stop #2
Davis, CA 95616
(530) 752-2588
bdlampinen@ucdavis.edu

Project Cooperators: Ted DeJong, University of California - Davis
Steve Weinbaum, University of California - Davis
Sam Metcalf, University of California - Davis
Claudia Negron, University of California - Davis
Mario Viveros, University of California Cooperative
Extension - Kern County
Joe McIlvaine, Paramount Farming Company
Nadav Ravid, Paramount Farming Company
Rob Baker, Paramount Farming Company

Interpretive Summary:

High nitrogen, high water (T1), high water, moderate nitrogen (T2), moderate water, high nitrogen (T3) and moderate water, moderate nitrogen (T4) treatments have been applied for seven years. In general, all three deficit treatments have tended to have negative impacts on canopy development and yields compared to the high water, high nitrogen control. However, in 2004 through 2006, when yields are adjusted for canopy light interception, yields for T2 and T3 were generally not significantly different than that for T1 (Table 3). In 2007, yield adjusted for canopy light interception were similar for T1 and T2, less for T3 and still less for T4 (Table 3). Seven year cumulative yields have ranked T1>T2>T3>T4 (Table 4). However, when yields are adjusted for similar levels of canopy light interception, treatments ranked T1=T2=T3 with T4 ranking significantly lower than all other treatments (Table 4). Deficit treatments have had less of an impact on yields for Monterey compared to Nonpareil and Wood Colony suggesting that Monterey may be less sensitive to canopy restriction resulting from deficit treatments.

Once the stress treatments were maintained within target values, all of the deficit treatments except T4 appear to generally be producing similar yields per unit light intercepted. This suggests that by planting the trees at a higher density and/or imposing treatments at a later stage of orchard development, it might be possible to produce equivalent or higher yields using a program of moderate nitrogen and or water applications as compared to a high nitrogen/high water regime.

When the seasonal average light interception is plotted against kernel yield, there appears to be an upper limit to production at any given level of light interception. A yield of about 2000 kernel pounds per acre is possible at 40% midday light interception and extrapolating out to 100% light interception, the upper limit to yields would be somewhere around 4200 to 4500 kernel pounds per acre for both Nonpareil and Monterey. Maximum yield for any variety from the regional almond variety trials have been about 4500 kernel pounds per acre.

Starting in the spring of 2008, all treatments are receiving the same levels of water and nitrogen. Results from 2008 and 2009 will show the impacts of the differential canopy development on productivity after all treatments have been returned to similar levels of irrigation and nitrogen.

Objectives:

In mature almond trees, yields reflect in large measure the number of fruit and fruit-bearing spurs. These spurs are perennial, i.e., persist for a number of years, but there are relatively few data concerning the renewal, regularity of fruitfulness and the reproductive longevity of almond spurs. How long almond spurs live, how regularly they fruit and how these parameters are influenced by orchard management practices have not been clearly addressed. We hypothesize that management variables such as nitrogen fertilization and irrigation rates, which are known to impact yield, influence the dynamics of spur renewal, fruitfulness. These variables may exert both direct and indirect effects. Thus, growth may be a direct effect of adequate nitrogen availability and tree water status. Shading of lower or interior branches, which reduces spur survival, may be an indirect result of excessive vegetative growth. This study will increase our understanding of spur turnover and yield dynamics in 'Nonpareil' almond and how internal (i.e., alternate bearing) and external (management) variables influence productivity.

The original objectives of this project were to a) quantify the dynamics of spur renewal, fruitfulness and spur longevity and b) determine how those dynamics are influenced by important orchard management variables; specifically, nitrogen and irrigation application rates and c) to assess the effects of the management variables on overall orchard development and productivity. The above objectives were completed in 2007 and in the spring of 2008, all treatments were converted to an optimal level of water and nitrogen to work at understanding how the different canopy structures that were developed with the variable water and nitrogen treatments effect productivity per unit light interception with the water and nitrogen variables removed.

Materials and Methods:

Plot establishment: A 146 acre orchard that was planted in 1996 was chosen for the study. Tree spacing was 24 feet between and 21 feet within rows. Variety composition was 50% Nonpareil with 25% Monterey and 25% Wood Colony as pollenizers. Spur tagging and water potential measurements were performed only on the Nonpareil trees, but irrigation and nitrogen treatments were applied throughout the orchard, and yield data were taken for all three cultivars.

The treatments imposed were as follows:

- 1.) High N application rate (>200 pounds N/ acre) and high irrigation [maintain midday stem water potentials in the range of -0.7 to -0.9 MPa (-7 to -9 bars)]
- 2.) Moderate N application rate (one-half normal rate when July leaf N concentration gets as low as 2.0%) and high irrigation.
- 3.) High N application rate and moderate irrigation rates [maintain midday stem water potentials of -1.2MPa (-12 bars)]
- 4.) Moderate N application rate and moderate irrigation rate

In the spring of 2008, all treatments were converted to one level of water and nitrogen. The plan is for the midday stem water potentials to be maintained in the -0.8 to -1.1 MPa (-8 to 11 bar) range and leaf nitrogen levels to maintained at or above mid-July leaf levels of 2.2%.

Irrigation and nitrogen

In mid-March 2001, the two moderate irrigation treatments (T3, T4) were outfitted with sprinkler heads that output at 80% of the amount of the control sprinkler heads. Midday water potential was monitored by two different methods over the season. For irrigation scheduling purposes, two trees in each treatment were monitored on an approximately weekly basis through the season. For these measurements, two shaded leaves per tree were wrapped in damp cheesecloth and immediately placed in a pressure chamber for measurement. In order to get a larger picture of orchard water potential variability and validate treatment effects on monitored trees, a single leaf was bagged on each monitored tree (12 trees per treatment for a total of 48 trees) and left to equilibrate for at least 15 minutes before placing in the pressure chamber for reading.

Nitrogen fertilizer was applied through the drip irrigation system. Application began in March and was continued throughout the season. Leaf samples were taken for nitrogen analysis in July from fully expanded outer canopy leaves on non-fruiting spurs. No nitrogen was applied to T2 or T4 in 2001. In 2002-2007 nitrogen was applied to T2 and T4 on every other nitrogen application for a total of 50% of the control level of nitrogen applied to T2 and 40% to T4. In 2003, leaf nitrogen samples were also taken approximately monthly on all 48 monitored tree (12 per treatment), in order to better assess seasonal patterns of leaf nitrogen to aid in interpreting the mid-July nitrogen readings..

In the spring of 2008, all treatments were converted to one level of water and nitrogen as described above.

Spur dynamics

The dynamics of shoot growth, spur renewal, fruitfulness, and spur mortality will be quantified using annual assessment of tagged spurs. A total of 2400 spurs were tagged with aluminum tags in late March and early April 2001. 12 spurs were selected on each of the north-east and north-west quadrants of the tree and 13 were selected on each of the south-east and south-west quadrants. The tags were placed on young spurs

spanning from the most shaded portion of the canopy (near the trunk) to the more exposed outer canopy positions at a height of about 8-10 feet.

In July 2001 the number of leaves per tagged spur were counted and leaf sizes were rated. In addition a similar spur from a nearby location (but not so near as to be a direct influence on the tagged spur) with a similar light exposure was sampled for leaf area and leaf specific weight analysis. Leaves were kept under refrigeration wrapped in moist cloth within a plastic bag until leaf areas were measured. Leaf area was assessed by taking a digital photograph of all of the leaves on each spur. Leaves were then dried at 70°C for approximately 48 hours and weighed. Sigmascan image analysis software was used to count the number of leaves and to calculate the leaf area for each spur from the digital photographs. Leaf area and leaf dry weights were used to calculate leaf specific area (leaf area per unit dry weight) which acts as an integrator of the total light exposure of the spur. A lower specific leaf area occurs where light conditions are better. Therefore, a lower specific leaf area in interior canopy positions would indicate better light penetration to those areas. In July 2002, the number of leaves per tagged spur were counted and leaf sizes rated. In addition, on one tree from each treatment, adjacent spurs were sampled for leaf area/dry weight analysis as described above. In July 2003, 2004, 2005 and 2006 the number of leaves per tagged spur were counted and leaf size was estimated. In addition, the length of the longest leaf on each spur was measured to allow comparisons to the calculated leaf area on spurs from eight trees that on which adjacent spurs were sampled (total of 400 spurs). In July 2004, adjacent spurs were sampled for leaf area/dry weight analysis from all 48 monitored trees. In July 2005, adjacent spurs were sampled from 2 trees per replications for a total of 8 trees. In July 2006 and 2007, adjacent spurs were sampled from all 48 monitored trees.

On August 3, 2003 one tree in T1 and one tree in T4 were outfitted with lightweight photodiodes to measure cumulative PAR interception. Photodiodes were taped on the midrib of one leaf on each of the 50 tagged spurs on the tree from T1 and T4. PAR incident on each photodiode was measured once every minute throughout the day. Then these minute by minute readings were used to calculate the daily cumulative photosynthesis on each spur.

Canopy light interception

In order to differentiate effects of overall canopy development from effects on spur quality, it is essential to have a measure of canopy light interception. Midday canopy light interception was measured twice during July and twice during August in 2001 using a Decagon Ceptometer (80 cm bar with light sensors mounted on it). In 2002, measurements were taken six times during the season starting in early April and ending in mid-July. In 2003-2007, midday canopy light interception was measured 5, 8, 5, 8 and 8 times during the season, respectively. Measurements were taken within 1 hour of the time the sun is directly overhead by making 100 measurements in a grid pattern covering the area between the Nonpareil and Monterey rows. A set of measurements was made near each tagged tree for a total of 48 measurements. Full sun measurements were taken periodically as a reference. In addition, midday measurements were taken directly beneath the canopy of each monitored tree in 2002-2007 on the same dates as midday canopy light measurements.

In December 2005 and 2007, both sides of all trees in the orchard were mechanically hedged. The hedger was set at a width of approximately 4 feet at the bottom and 5 feet at the top. In 2005, after hedging, prunings from the same area where midday light interception has been monitored were collected and weighed in the field.

Yield

Yield data were collected in two different ways in 2002-2007. First, the 48 individual trees (Nonpareil only), that were monitored for water potential over the season were harvested by hand raking and weighing. In addition yield data was collected for the overall plots by weighing the total nuts from each treatment in the Nonpareil, Monterey and Wood Colony varieties. In 2003, 2004, 2005, 2006 and 2007 the replications were kept separate for the overall plot data allowing statistical comparison of treatment impacts on yield for all varieties.

Results and Discussion

Irrigation

In 2001, midday stem water potentials were considerably below the target values due to an intermittent problem with the water supply system to the orchard (Table 1). The impacts of the lower than target water potentials during the 2001 season most likely had impacts on treatment performance in 2002, and perhaps in 2003. Midday leaf water potentials in 2002 and 2003 were nearer to the target levels. In 2002, none of the treatments were significantly different from the control until mid June when T3 was significantly lower than the control (Fig. 1.). In July of 2002, both of the moderate water treatments were below the control values at the second sampling date (Fig. 1). In 2003, 2004, 2005, 2006 and 2007 the two moderate water treatments had significantly lower midday stem water potentials compared to T1 on most sampling dates (Fig. 1). Over the seven years of the study (2001 to 2007), seasonal average midday stem water potentials for T1, T2, T3 and T4 averaged -9.8, -9.9, -12.4 and -12.3 bars respectively (Table 1). These values were slightly lower than the targets of -0.7 to -0.9 MPa (-7 to -9 bars) for T1 and T2 and <-1.2MPa (-1.2bars) for T3 and T4. It is important to note that there was a 20% difference in water application that resulted in this approximately 0.14 to 0.16 MPa (1.4 to 1.6 bar) difference in seasonal average midday stem water potential.

Nitrogen

Leaf nitrogen analysis in July 2001 indicated the trees in T2 and T4 were right near the point where nitrogen applications should begin (Table 2). Therefore, in 2002, nitrogen was applied to T2 at a rate of 50% of that applied to T1 and T3 and at a rate of 40% for T4. In 2003, 248 lbs/acre were applied to T1 and T3 while 124 lbs/acre were applied to T2 and 99 lbs/acre to T4. In 2004, 284 lbs/acre were applied to T1 and T3 while 142 lbs/acre were applied to T2 and 114 lbs/acre to T4. In 2005, 262 lbs/acre were applied to T1 and T3 while 131 lbs/acre were applied to T2 and 105 lbs/acre to T4. Since 2002, leaf nitrogen levels have continued to gradually increase in both high nitrogen treatments while those in both moderate nitrogen treatments have remained relatively

stable (Table 2). By the July 2007 sampling date, leaf nitrogen levels were above significantly above 2.2% in all of the treatments except for the moderate water, moderate nitrogen treatment (T4; Table 2). The seven year average July leaf nitrogen levels for T1 to T4 were 2.45, 2.10, 2.20 and 1.95% respectively (Table 2).

Canopy light interception and tree size

Seasonal average midday canopy light interception was significantly higher in T1 compared to all other treatments every year until 2006 (Fig. 2a). Since hedging was initiated in the winter of 2005-6, seasonal average midday canopy light interception dropped in T1 but continued to gradually rise in the deficit treatments (Fig. 2a).

Midday canopy light interception varied across the orchard. By the summer of 2005 access through the T1 blocks was difficult due to limbs hanging in the drive path. In 2003 through 2007, some trees in the most densely shaded blocks died, most likely due to *Phytophthora*.

Canopy light interception below the tree canopy has been gradually decreasing in all three deficit treatments over the 6 years that it has been measured (Fig. 2b). This indicates that light is penetrating farther down into the canopy in these treatments and this will likely have implications for spur dynamics. Part of this effect is due to the spreading of the tree canopies which were tied with rope for the first 3 years of the study. However, the pattern has continued and the reason is unclear.

In December 2005 and 2007, all treatments were mechanically hedged on both sides of every row. The hedger was set to a width of approximately 4 feet at the bottom and 5 feet at the top of the canopy. In 2005, pruning weights were significantly greater for T1 compared to all three deficit treatments and the pruning weight was directly related to the previous seasons' midday canopy light interception (Fig. 3). Following hedging, seasonal average midday canopy light interception was similar in T1 and T2 but still significantly lower in T3 and T4 (data not shown).

Spur dynamics

Less than 20% of spurs tagged in 2001 flowered in all treatments and there were no significant treatment differences in the percentage of flowering spurs in 2002 (Table 6). In 2003, the percentage of flowering tagged spurs was even lower and T2 had significantly less flowering tagged spurs than T1 (Table 6). In 2004, T2 again had significantly more flowering spurs compared to T1 (Table 6). In 2005, T2 and T4 had significantly less flowering spurs compared to T1 (Table 6). In 2006, T1 and T2 had significantly less tagged spurs flowering compared to T3 and T4 but all treatments had a higher percentage of flowering spurs than they did in 2002 (Table 6).

In 2002, approximately 6-8% of the tagged spurs died in all of the treatments and there were no significant treatment differences (Table 7). In 2003, both of the moderate nitrogen treatments (T2 and T4) had significantly fewer tagged spurs that died compared to T1 (Table 7). In 2004, T2 had significantly less tagged spurs that died compared to T1. In 2005 and in 2006, both T3 and T4 had significantly fewer tagged

spurs that died compared to T1 (Table 7). These data suggest that improved canopy light penetration into the canopy may be allowing the spurs to live longer in the deficit treatments.

Leaf specific area is expressed as leaf area per unit dry weight and a higher number means that there is less energy invested in leaves in that area of the canopy, which generally means there are lower light conditions. Leaf specific area was generally similar across treatments for all canopy positions in 2001 (Fig. 4). In 2002, the patterns were considerably different with T3 and T4 all tending to have lower leaf specific areas throughout most canopy positions while T2 had similar values to the control. In 2003, leaf specific areas separated out among treatments much more clearly than in earlier years with the highest values in T1 followed by T2 with T3 and T4 being lowest and similar to each other (Fig. 4). High values are associated with less energy allocated to leaves in those locations suggesting light limitations were causing problems in the control treatment. By 2004 and 2005, treatments were all approaching the levels that T1 reached in 2003 and treatment differences largely disappeared (Fig. 4). In 2006, T1 had significantly higher leaf specific area than all the other treatments at all canopy positions except the outmost one (Fig. 4).

Bloom was advanced in T1 compared to all other treatments when measured on February 15, 2005 with bloom ratings of 94.2, 80.0, 68.3 and 55.0 percent of full bloom in T1, T2, T3 and T4 respectively. This delay in bloom could impact fruit set in some years when inclement weather is a factor. In 2006, bloom was measured on all three varieties on one date (data not shown). Bloom was again advanced in T1 compared to all other treatments and the pattern was similar in all three varieties (data not shown)..

Yield and Quality

Individual tree harvest 2002-2007

T1 has had significantly higher yields than any of the other treatments followed by T3, T2 and T4 respectively in all years except 2004 (Table 3). If the yield data are adjusted for the canopy light interception (Table 3), the T1 and T3 kernel yields were not significantly different in 2002 (Table 3). This suggests that if these treatments were imposed slightly later (perhaps one or two years), after the canopies had filled in more completely, the treatment differences between T1 and T3 may have been less. In 2004 and 2005, there were no significant differences between the control and deficit treatments for yield adjusted for canopy light interception (Table 3). In 2006, T1 yielded significantly less than T3 and T4 when yields were adjusted for canopy light interception. In 2007, yields were highest in T1 followed by T2, T3 and T4. Cumulative yields for T1, T2, T3 and T4 are 16,088, 12,888, 12,497 and 8812 pounds per acre respectively.

When canopy light interception versus yield is plotted by year, it is clear that within a given year, light canopy light interception is a good predictor of yield (Fig. 3). However, between years, it appears that a factor other than water or nitrogen is having a major impact on yields.

Because this sample is only for 48 trees out of a total of 148 acres, it may not be representative of the orchard as a whole (as indicated by the different estimated yields for the Nonpareil in Table 3 versus Table 4), but this is still a worthwhile data set since we have a detailed water potential history on these trees and this will allow further analysis in the future based on individual tree history rather than treatment averages.

In 2001 and 2002, there were no significant treatment effects on nut quality as measured by percentage doubles, twins, worm damage, gumming, shrivel, percentage sealed nuts, etc. (data not shown). In 2003, there were no significant treatment effects on quality parameters except that the two moderate water treatments (T3 and T4) had significantly less mold and kernel staining compared to T1 (data not shown). Individual kernel weight was significantly lower in T4 than in T1 in 2004 (data not shown). In addition there was significantly more kernel gumming in T1 than in T2 although both levels were very low (data not shown). In 2005 and 2006, individual kernel weight was significantly less in T3 and T4 compared to T1. T4 had significantly more kernel shrivel than T1 in 2005. Percent shell seal was significantly greater in T3 and T4 compared to T1 in 2005 as well. More stressed trees had a higher percentage of sealed shells (data not shown). In addition, trees with lower July leaf nitrogen levels also had a higher percentage of sealed shells (data not shown). These results have potential implications for food safety related issues.

Whole plot harvests 2001-2007

Yield data for the overall plots were collected as one composite sample for each treatment in 2001 and 2002. The entire crop for each treatment and variety was collected and weighed in the field, and then, followed through the hulling process to obtain a per acre kernel yield for each treatment and variety combination (Table 5). Because the samples for all replications were lumped together, it was not possible to statistically analyze the yield data. In 2001, the Nonpareil yield was similar for all treatments (Table 4). There was a trend towards lower yields in the moderate irrigation treatments in the Monterey and Wood Colony. In 2002 for Nonpareil and Monterey, T1 had the highest yield for the overall plot harvest followed by T3, T2 and T4 (Table 5). For Wood Colony, T1 had the highest yield followed by T3, T4 and T2. For the average for all three varieties, the ranking was T1, T3, T2, and T4. In 2003 and 2004, the yields for each replication were kept separate allowing statistical comparison of yields for all varieties. In 2003, Nonpareil yields for T1 were significantly higher compared to those for T2, T3 or T4 for the whole plot harvests (Table 5). In 2004, yields for T2 and T3 were not significantly different than those for T1 while those for T4 were significantly lower (Table 5). In 2005, yields all three deficit treatments were significantly lower than T1 for Nonpareil and Wood Colony but there were no significant treatment differences in Monterey (Table 4). In 2006, all three deficit treatments yielded significantly less than T1 in Nonpareil and Monterey while in Wood Colony only T3 and T4 had yields significantly less than T1 (Table 4). In 2007, Nonpareil and Wood Colony had significantly higher yields for T1 and T2 compared to T3 and T4 (Table 5).

Preliminary conclusions

In general, all three deficit treatments have tended to have negative impacts on canopy development and yields compared to the high water, high nitrogen control. In 2002 and 2003, the negative impacts on yield were not only limited to the smaller canopy because even when yields were adjusted for midday canopy light interception, the yields were still less in the all three deficit treatments (Table 3). However, in 2004 through 2006, when yields are adjusted for canopy light interception, yields for T2 and T3 were generally not significantly different than that for T1 (Table 3). In 2007, yield adjusted for canopy light interception were similar for T1 and T2, less for T3 and still less for T4 (Table 3). Seven year cumulative yields have ranked $T1 > T2 > T3 > T4$ (Table 4). However, when yields are adjusted for similar levels of canopy light interception, treatments ranked $T1 = T2 = T3$ with T4 ranking significantly lower than all other treatments (Table 4). Deficit treatments have had less of an impact on yields for Monterey compared to Nonpareil suggesting it may be less sensitive to canopy restriction resulting from deficit treatments.

When interpreting these results, it is important to keep in mind that in 2001 (the first year of the study), the moderate water treatments had average seasonal water potentials approximately 2 bars more negative than the target values. The high water treatments (T1 and T2) had water potentials as low as the targets for the moderate water treatments during the first year of the study. The fact that all of the treatments had a more negative average seasonal water potential during the first year of the most likely had an impact on the second year results. The effects of these factors can be seen in the decrease in yields in all three deficit treatments in 2002 compared to 2001 (Fig. 6). Although this problem was overcome in 2002, the leaf nitrogen levels were relatively low in all treatments in 2002. This most likely impacted 2003 yields. Differences in light interception among treatments and as well as alterations in spur characteristics started to appear in 2002 and continue to be pronounced in 2007. This suggests that treatments impacts on canopy light penetration will likely have larger impacts on spur longevity and quality in the following years.

Once the stress treatments were maintained within target values, all of the deficit treatments except T4 appear to be producing similar yields per unit light intercepted. This suggests that by planting the trees at a higher density and/or imposing treatments at a later stage of orchard development, it might be possible to produce equivalent or higher yields using a program of moderate nitrogen and or water applications as compared to a high nitrogen/high water regime. Results in 2008 and 2009 should show whether or not these trends will continue with similar water and nitrogen applied to all treatments.

When the seasonal average light interception is plotted against kernel yield (Fig. 5), there appears to be an upper limit to production at any given level of light interception. This limit seems to be similar for both Nonpareil and Monterey although Monterey has tended to stay closer to the line (Fig. 5). Based on Fig.5, a yield of about 2000 kernel pounds per acre is possible at 40% midday light interception and extrapolating out to 100% light interception, the upper limit to yields would be somewhere around 4200 kernel pounds per acre for both Nonpareil and Monterey. Maximum yield for any variety

from the regional almond variety trials have been about 4500 kernel pounds per acre which would agree with the data in Figure 5.

Although the differences among treatments in terms of trunk circumference, tree height and tree width appear to be relatively minor, visual appearances among the treatments continue to be very different. In addition, differences in canopy light interception, spur characteristics and yields continue. In 2004 through 2007 there were no significant negative impacts on Nonpareil yield per unit midday light interception for T2 or T3 compared to T1 suggesting as canopy size differences decrease over time, the deficit treatments may perform better relative to the control. The impact of the change to higher water and nitrogen levels in T2, T3 and T4 will be interesting.

Project duration

The proposed duration of the study is for two additional years to observe the impacts of the optimal level of water and nitrogen on the productivity and management difficulties for the different tree structures that were created by the variable water and nitrogen treatments in years one to seven.

Table 1. Average seasonal midday stem water potential by treatment for the 2001-2007 seasons. Measurements are for a total of 12 Nonpareil trees per treatment taken over the season.

Average midday stem water potential (bars)								
Treatment	2001	2002	2003	2004	2005	2006	2007	overall average
T1-high water, high N	-11.9a	-9.8ab	-9.0a	-8.4 a	-9.1 a	-10.9 a	-9.6 a	-9.8 a
T2-high water, mod. N	-11.6a	-9.7a	-8.8a	-9.2 a	-9.2 a	-11.0 a	-10.1 a	-9.9 a
T3-mod. water, high N	-13.8b	-11.4c	-12.4b	-11.3 b	-11.7 b	-13.6 b	-11.9 b	-12.4 b
T4-mod. water, mod. N	-13.0b	-11.0bc	-11.6b	-11.7 b	-11.8 b	-13.7 b	-12.0 b	-12.3 b

Table 2. July leaf nitrogen for 2001-2007 seasons. Approximately 50 leaves were sampled from non-bearing spurs about half way up the canopy on 12 trees (same trees monitored for water potential) per treatment.

Treatment	2001	2002	2003*	2004	2005	2006	2007	average
T1-high water, high N	2.20 a	2.02 a	2.39 a	2.48 a	2.55 a	2.59 a	2.75 a	2.45 a
T2-high water, mod. N	2.00 c	1.74 c	2.17 b	2.15 b	2.17 b	2.22 c	2.30 c	2.10 c
T3-mod. water, high N	2.11 b	1.91 b	2.19 b	2.23 b	2.25 b	2.38 b	2.50 b	2.20 b
T4-mod. Water, mod. N	1.96 c	1.67 c	2.00 c	1.96 c	1.99 c	2.03 d	2.06 d	1.95 d

* average of values from June 27th and August 9th sampling dates

Table 3. Average pounds of kernel yield per acre and kernel yield per acre of light intercepted for Nonpareil trees that were monitored for water potential over the season.

2002

Treatment Number	Treatment Description	Yield (lbs/acre)	Yield per acre light intercepted
1	+nitrogen, +water	2554 a	4652 a
2	-nitrogen, +water	1743 bc	3797 bc (82%)
3	+nitrogen, -water	1941 c	4103 ab (88%)
4	-nitrogen, -water	1266 c	3007 c (65%)

2003

Treatment Number	Treatment Description	Yield (lbs/acre)	Yield per acre light intercepted
1	+nitrogen, +water	4257 a	5704 a
2	-nitrogen, +water	3112 b	4481 b (79%)
3	+nitrogen, -water	3004 b	4416 b (77%)
4	-nitrogen, -water	2264 c	3418 c (60%)

2004

Treatment Number	Treatment Description	Yield (lbs/acre)	Yield per acre light intercepted
1	+nitrogen, +water	2932 a	4022 a
2	-nitrogen, +water	2746 a	4142 a (102%)
3	+nitrogen, -water	2251 b	3789 a (94%)
4	-nitrogen, -water	1984 b	3511 b (87%)

2005

Treatment Number	Treatment Description	Yield (lbs/acre)	Yield per acre light intercepted
1	+nitrogen, +water	2255 a	2826 a
2	-nitrogen, +water	1624 b	2219 b (78%)
3	+nitrogen, -water	1571 b	2454 a (87%)
4	-nitrogen, -water	1422 b	2312 a (82%)

2006

Treatment Number	Treatment Description	Yield (lbs/acre)	Yield per acre light intercepted
1	+nitrogen, +water	1586 b	2129 b
2	-nitrogen, +water	1465 b	2078 b (97%)
3	+nitrogen, -water	1976 a	3167 a (149%)
4	-nitrogen, -water	1676 a	2775 a (130%)

2007

Treatment Number	Treatment Description	Yield (lbs/acre)	Yield per acre light intercepted
1	+nitrogen, +water	2770 a	3594 a
2	-nitrogen, +water	2504 ab	3384 a (94%)
3	+nitrogen, -water	2198 b	3402 a (95%)
4	-nitrogen, -water	1754 c	2749 b (77%)

Table 4. Cumulative yield and cumulative yield adjusted to 100% light interception for 2001 to 2007 seasons.

Treatment	Cumulative yield (pounds/acre)	Percent of T1 yield	Cumulative yield adjusted to 100% light interception	Percent of adjusted T1
T1 (high N, high water)	16,088 a		22,717 a	
T2 (mod. N, high water)	12,888 b	80	20,119 a	89
T3 (high N, mod. water)	12,497 b	78	20,678 a	91
T4 (mod. N, mod. water)	8,612 c	54	15,023 b	66

Table 5. Average pounds of kernel yield per acre by year and variety. Weight is for the total plot. For 2001 data, see reports from earlier years.

2002

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Ave. of all varieties
1	+nitrogen, +water	1922	2656	2442	2340
2	-nitrogen, +water	1275	2164	1435	1626
3	+nitrogen, -water	1593	2284	1769	1882
4	-nitrogen, -water	1215	814	1567	1199

2003

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Ave. of all varieties
1	+nitrogen, +water	3004 a	2921 a	2908 a	2944 a
2	-nitrogen, +water	2030 b	2108 b	2034 bc	2057 bc
3	+nitrogen, -water	2352 b	2332 b	2192 b	2292 b
4	-nitrogen, -water	1901 b	2085 b	1570 c	1852 c

2004

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Ave. of all varieties
1	+nitrogen, +water	2838 a	3177 a	2399 a	2805 a
2	-nitrogen, +water	2752 a	2867 b	2510 a	2710 a
3	+nitrogen, -water	2307 b	2718 b	2124 b	2383 b
4	-nitrogen, -water	2209 b	2527 c	2209 b	2315 b

2005

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Ave. of all varieties
1	+nitrogen, +water	2227 a	1778 a	2085 a	2030 a
2	-nitrogen, +water	1493 b	2085 a	1447 b	1675 b
3	+nitrogen, -water	1758 b	1856 a	1460 b	1691 b
4	-nitrogen, -water	1536 b	2020 a	1027 c	1417 b

2006

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Ave. of all varieties
1	+nitrogen, +water	3241 a	2593 a	2739 a	2858 a
2	-nitrogen, +water	2697 b	2253 b	2518 a	2489 b
3	+nitrogen, -water	2739 b	2147 bc	2234 b	2374 b
4	-nitrogen, -water	2330 c	1942 c	2170 b	2147 c

2007

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Ave. of all varieties
1	+nitrogen, +water	2680 a	2291 a	2749 a	2574 a
2	-nitrogen, +water	2405 ab	2221 a	2524 ab	2383 ab
3	+nitrogen, -water	2045 b	2277 a	2147 bc	2157 bc
4	-nitrogen, -water	2084 b	1941 a	2010 c	2011 c

Table 6. Average percentage of total tagged spurs that flowered by treatment and year.

Treatment	Treatment Description	2002	2003	2004	2005	2006
1	+N, +H ₂ O	18.2 a	16.1 a	17.2 b	28.0 a	25.2 c
2	Mod. N, + H ₂ O	18.4 a	10.7 b	22.4 a	17.9 c	26.2 c
3	+N, mod. H ₂ O	17.2 a	16.5 a	18.7 b	27.3 a	36.4 b
4	Mod. N, mod. H ₂ O	15.6 a	13.4 ab	19.2 ab	22.4 b	32.2 a

Table 7. Average percentage of total tagged spurs that died by treatment and year.

Treatment	Treatment Description	2002	2003	2004	2005	2006	Total
1	+N,+H ₂ O	6.0 a	13.5 a	10.3 a	29.7 a	26.0 a	85.5
2	Mod. N,+H ₂ O	7.3 a	5.5 c	4.5 b	29.2 a	23.2 ab	69.7
3	+N, mod. H ₂ O	6.3 a	10.7 ab	8.7 a	23.2 b	20.5 b	69.4
4	Mod. N, mod. H ₂ O	8.3 a	7.8 bc	7.3 a	21.3 b	14.8 c	59.5

Fig. 1. Midday leaf water potential by treatment over the 2002-2007 seasons.

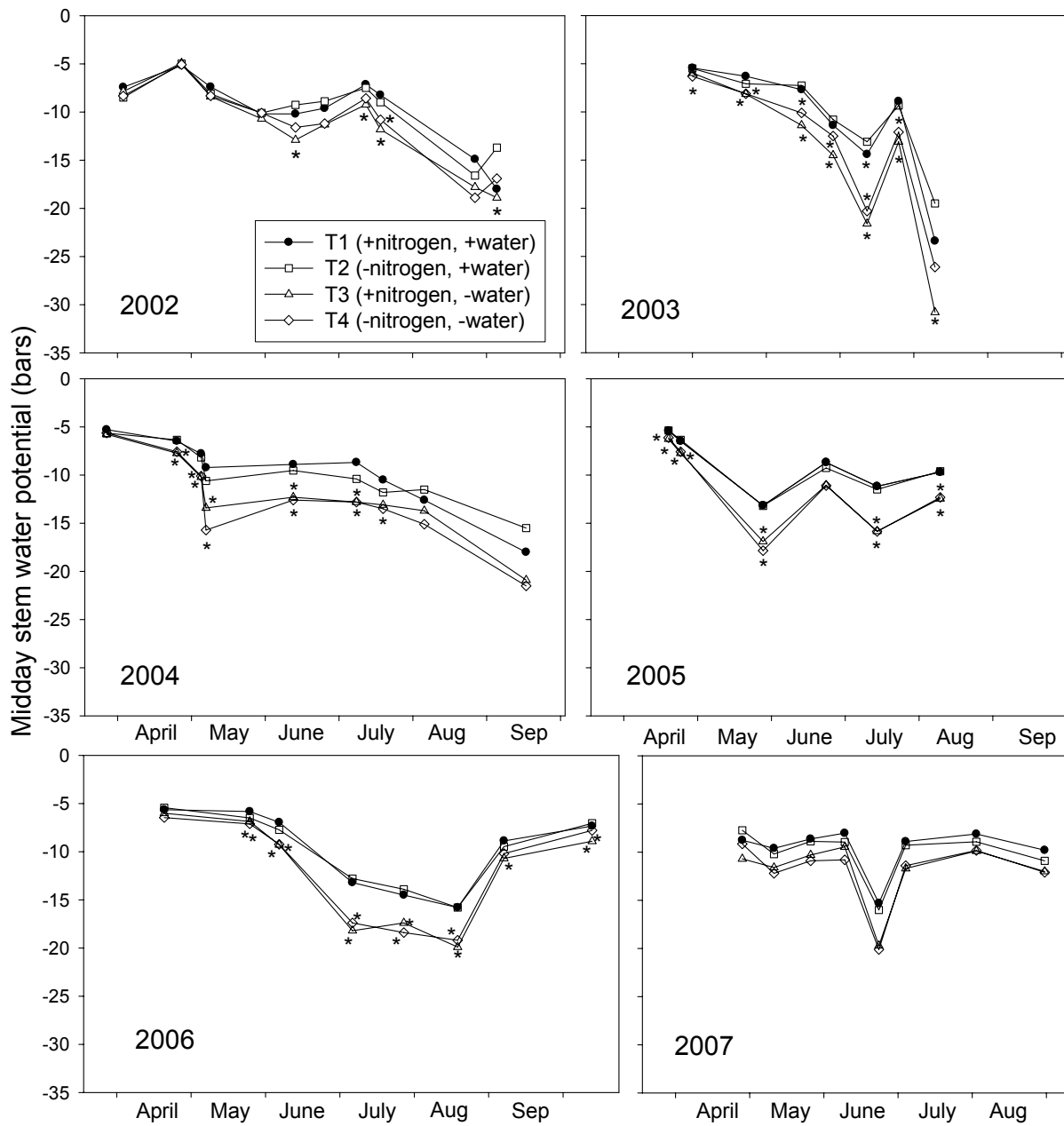


Fig. 2. Seasonal average canopy light interception a) measured between the Nonpareil and Monterey rows for the 2001-2006 (100 measurements in a grid pattern) and b) under individual Nonpareil trees by taking 30 readings distributed evenly under canopy shaded area. Error bars indicate plus or minus one standard error.

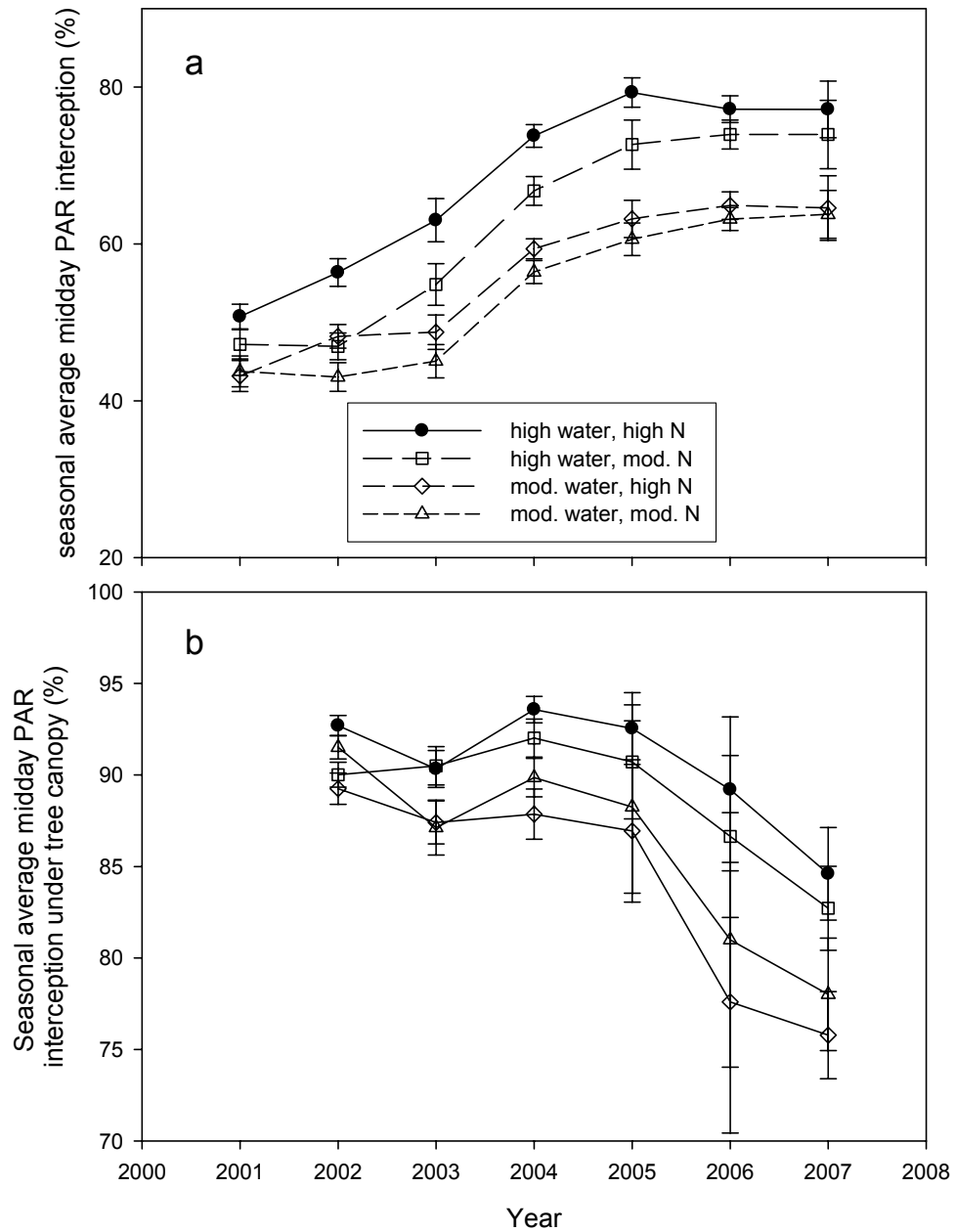


Fig. 3. Annual treatment average midday canopy light interception versus yield by treatment for 2002 to 2007 seasons. Within a given year, treatments one to four are always from left to right.

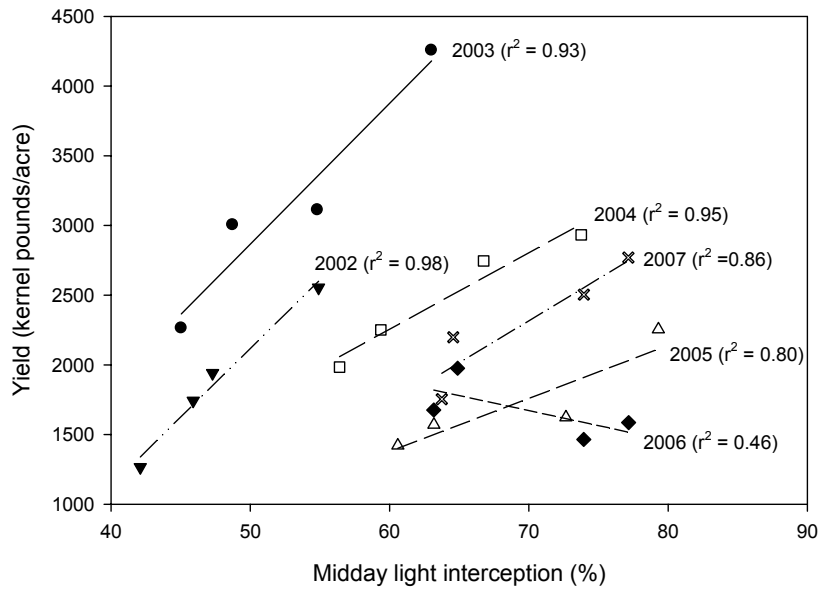


Fig. 4. Leaf specific area for spurs adjacent to tagged spurs from one tree from each treatment. Position #1 is in the innermost position, low in the canopy near the trunk, while position 13 is in the outer exposed canopy at approximately 8-10 foot height. Tables to right give average seasonal midday stem water potential and leaf nitrogen for the individual trees for which data are presented in the adjacent graph.

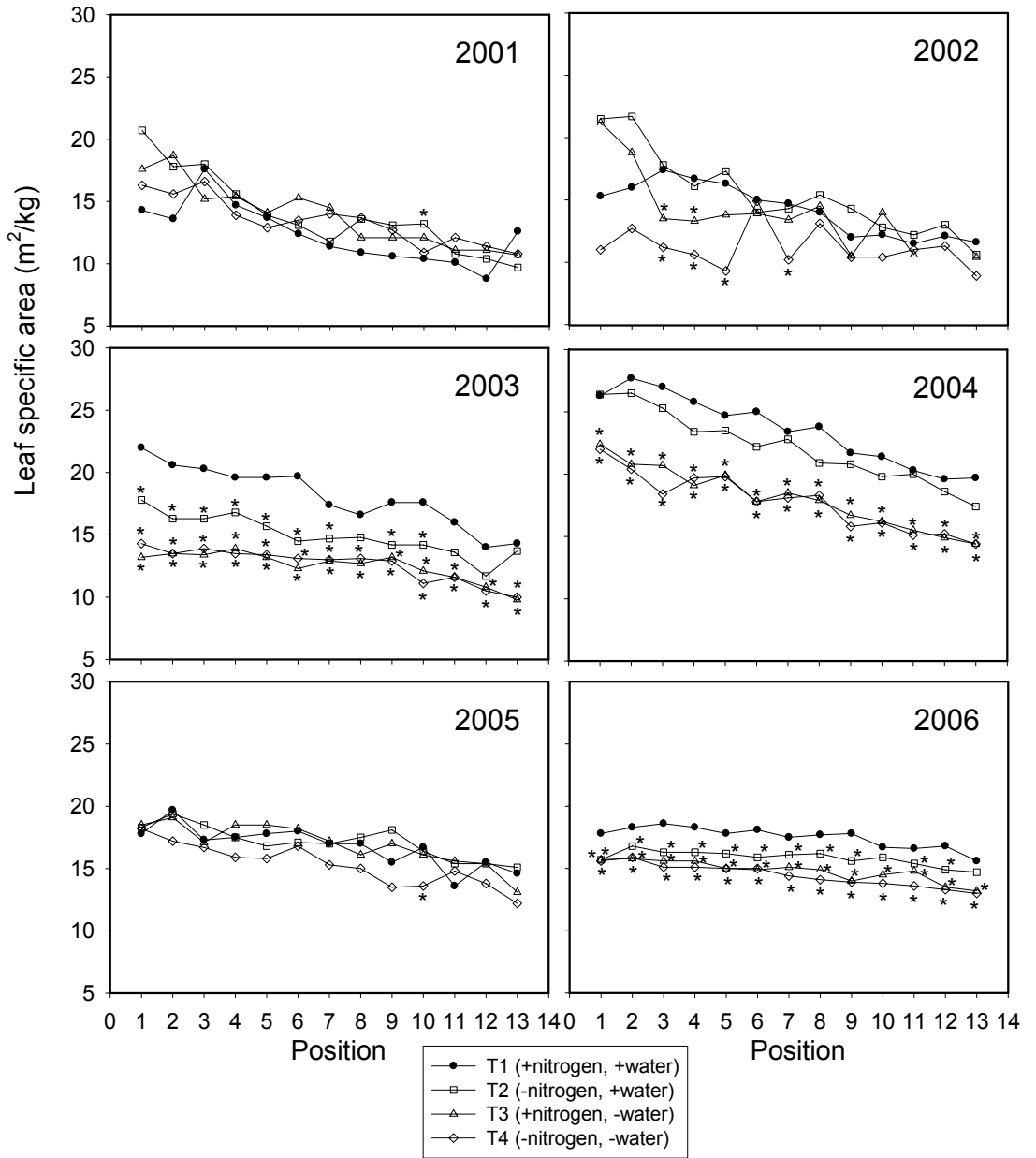


Fig. 5. Seasonal average midday light interception versus yield for Nonpareil (top) and Monterey (bottom). Light interception was measured between Nonpareil and Monterey rows.

