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Project No.: 04-BL-01 Spur Dynamics and Almond Productivity

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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. Questions such as how long almond spurs live, how regularly they fruit and how these parameters are influenced by orchard management practices have not been addressed. We hypothesize that management variables such as N fertilization and irrigation rates, which are know 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 N 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.

Objectives:
The objectives of the proposed study are 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, N and irrigation application rates.

Materials and Methods:
Plot establishment: A 5 year old, 146 acre orchard 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 [irrigate to maintain mid-day stem water potentials in the range of -0.7 to -0.9 Mpa (-7 to -9 bars)]

2.) Moderate N application rate* and high irrigation.
3.) High N application rate and moderate irrigation rates [irrigate at mid-day stem water potentials of -1.2Mpa (-12 bars)]
4.) Moderate N application rate and moderate irrigation rates.
*Apply N at one-half of normal rate when July leaf N concentration gets as low as 2.0%.

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. These more detailed measurements were done 7, 9 and 6 times during the season in 2001, 2002 and 2003 respectively.

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, 2003, 2004 and in 2005 nitrogen was applied to T2 and T4 on every other nitrogen application for a total of half the nitrogen applied to the high nitrogen treatments. In 2003, leaf nitrogen samples were 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..

Spur dynamics. The dynamics of shoot growth, spur renewal, fruitfulness, and spur mortality will be quantified using annual assessment of tagged spurs as well as by monitoring the generation of new spurs from previous year's growth. Although initial plans called for monitoring 10 limbs per treatment, due to difficulty in selecting 10 representative limbs of a manageable size, the procedures were changed. Instead, 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 and 2005 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 monitored trees. In July 2005, adjacent spurs were sampled from 2 tree per replications for a total of 8 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 and 2004, midday canopy light interception was measured 5 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, measurements were taken directly beneath the canopy of each monitored tree in 2001, 2002, 2003, 2004 and 2005.

Yield

Yield data were collected in two different ways in 2002, 2003 and in 2004. 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 and 2004, 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

Applied water for the high water (T1 and T2) treatment in 2002 and 2003 was 48.5" and 51.9" respectively. For the moderate water treatments (T3 and T4), applied water in 2002 and 2003 was 38.8" and 41.8" respectively. In 2003, ET_c was approximately 43.4" so applied water was 119 and 96% of ET_c for the high and moderate water treatments respectively.

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 2). 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, the two moderate water treatments had significantly lower midday stem water potentials after mid-May (Fig. 1).

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 1). Therefore, in 2002, nitrogen was applied to these treatments at one-half the rate for T1 and T3. In 2003, 248 lbs/acre were applied to T1 and T3 while 124 lbs/acre were applied to T2 and T4. In 2004, In 2004, 284 lbs/acre were applied to T1 and T3 while 142 lbs/acre were applied to T2 and T4.

Canopy light interception and tree size

As the 2001 season progressed, a significantly lower canopy light interception was observed in T3 and T4 in comparison with T1 and T2 (Fig. 2). In 2002, T2, T3 and T4 all had significantly lower levels of canopy light interception than T1 throughout the season (Fig. 2). In 2003, T1 had significantly higher midday canopy light interception than T2, T3 or T4 at both the June and July sampling dates (Fig. 2). In 2004, T1 had significantly higher midday canopy light interception than T3 or T4 at all dates after the first set of readings (Fig. 2).

The difference in midday canopy light interception varied across the orchard. There were some blocks where the growth in T1 (high water, high nitrogen) looked excessive suggesting future problems with shading, limbs hanging into drive rows etc. In 2003 and 2004, some trees in these most densely shaded blocks died, most likely due to *Phytophthora*.

In 2002, canopy light interception measured underneath the tree canopy on six occasions showed that the low nitrogen treatments had significantly more light penetrating through the tree canopy, or lower canopy light interception (Fig. 4). These differences averaged about 5% over the season. This indicates that light is penetrating farther down into the canopy in these treatments and this may have implications for spur dynamics. In 2003, T3 had significantly lower canopy light interception underneath the tree canopy and only on the June sampling date (Fig. 4). In 2004, T3 and T4 had significantly lower light interception under the tree canopy throughout most of the season.

Trees in both high water treatments (T1 and T2) had significantly larger trunk circumferences and were significantly taller than those in the moderate water treatments (T3 and T4).

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 5). In 2003, the percentage of flowering tagged spurs was even lower and T2 had significantly less flowering tagged spurs than T1 (Table 5). In 2004, all three deficit treatments had a significantly higher percentage of flowering spurs controlled to T1 (Table 5).

In 2002, approximately 6-8% of the tagged spurs died in all of the treatments and there were no significant treatment differences (Table 6). In 2003, both of the moderate nitrogen treatments (T2 and T4) had significantly fewer tagged spurs that died compared to T1 (Table 6). In 2004, T2 had significantly less tagged spurs that died compared to T1. 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 was significantly higher in T2 (low nitrogen, high water) and T3 (high nitrogen, moderate water) for positions in the middle and interior of the canopy 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 not significantly different from each other (Fig. 4).

Bloom was advanced in T1 compared to all other treatments when measured on February 15, 2005 (Fig. 5). In fact, bloom stage on this date followed treatment numerical order with all treatments being significantly different from one other.

Yield and Quality

Individual tree harvest 2002-2004

The yield data by individual tree indicated that T1 had the significantly higher yields than any of the other treatments followed by T3, T2 and T4 respectively (Table 3). If the yield data is adjusted for the canopy light interception (Table 3), there T1 and T3 kernel yields were not significantly different (Table 3). This suggests that if these treatments were imposed slightly later (perhaps by one year), after the canopies had filled in more completely, the treatment differences between T1 and T3 may have been less.

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 2 versus Table 3) 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.

Whole plot harvests 2001-2004

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 4). 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 4). For the Woods 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, and this same trend occurred when yields were adjusted for canopy light interception (Table 3). In 2004, yields for T2 and T3 were not significantly different than those for T1 while those for T4 were significantly lower (Table 3). However, when yields were adjusted for canopy light interception, all three deficit treatments tended to yield higher per unit canopy compated to T1 (Table 3).

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).

Preliminary conclusions

All of the moderate water and nitrogen application treatments have had significant negative impacts on canopy light interception and yield until 2004. 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, yields for T2 and T3 were not significantly different than those for T1 and when yields were adjusted for canopy light interception, all three deficit treatments tended to yield more per unit canopy light intercepted compared to T1 (Table 3).

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 became more pronounced in 2003. 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 appear to be producing good yields per unit light intercepted. This suggests that by planting the trees at a higher density and then imposing these treatments, 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.

The relatively low leaf nitrogen levels (2.02% in 2002 in T1) and midday stem water potentials even on the high nitrogen (248 lbs/acre), high water (119% ET_c) application rate treatments suggest that the efficiency of application of water and nitrogen is not high in the orchard. It is possible that nitrogen and water are being pushed below the root zone.

The lack of differences in leaf nitrogen levels in T2 (high water, moderate nitrogen) and T3 (moderate water, high nitrogen) suggest that there is an interaction of irrigation and nitrogen. It is possible that the limited water in T3 is limiting the ability of the root system to utilize nitrogen effectively.

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. For the first time in 2004, all three deficit treatments produced higher yields per unit midday light interception compared to the high water, high nitrogen control.

Project duration

The proposed duration of the study is 6 years, but the time frame is subject to continuing review. The intent is that the study should be long enough to follow a cohort of spurs from formation to death to assess treatment effects on this process. At the end of this season, we will have completed 5 of 6 years.

Table 1. Leaf nitrogen for 2001-2003 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 Number	Treatment Description	Leaf nitrogen 2001	Leaf nitrogen 2002	Leaf nitrogen 2003*	Leaf nitrogen 2004
1	+nitrogen, +water	2.20a	2.02a	2.39a	2.48 a
2	-nitrogen, +water	2.00b	1.74c	2.17b	2.15 b
3	+nitrogen, -water	2.11a	1.91b	2.19b	2.23 b
4	-nitrogen, -water	1.96	1.67c	2.00c	1.96 c

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

Table 2. Average seasonal midday stem water potential by treatment for the 2001-2004 seasons. Measurements are for a total of 12 trees per treatment taken over the season.

Treatment	Description	Average 2001 seasonal MSWP (bars)	Average 2002 seasonal MSWP (bars)	Average 2003 seasonal MSWP (bars)	Average 2004 seasonal MSWP (bars)
1	high water, high N	-11.9a	-9.8ab	-9.0a	-8.4 a
2	high water, mod. N	-11.6a	-9.7a	-8.8a	-9.2 a
3	mod. water, high N	-13.8b	-11.4c	-12.4b	-11.3 b
4	mod. water, mod. N	-13.0b	-11.0bc	-11.6b	-11.7 b

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	Nonpareil yield (lbs/acre)	Nonpareil yield per acre light intercepted
1	+nitrogen, +water	2554a	4652a
2	-nitrogen, +water	1743bc	3797bc
3	+nitrogen, -water	1941c	4103ab
4	-nitrogen, -water	1266c	3007c

2003

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

2004

Treatment Number	Treatment Description	Nonpareil yield (lbs/acre)	Nonpareil yield per acre light intercepted
1	+nitrogen, +water	2339 a	3169
2	-nitrogen, +water	2306 a	3452 (109%)
3	+nitrogen, -water	2143 ab	3607 (114%)
4	-nitrogen, -water	1900 b	3368 (106%)

Table 4. Average pounds of kernel yield per acre by year and variety. Weight is for the total plot. Data for 2004 season is preliminary and subject to change.

2001

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Ave. of all varieties
1	+nitrogen, +water	1926	2380	1989	2098
2	-nitrogen, +water	1898	2208	1874	1993
3	+nitrogen, -water	1979	2073	1834	1962
4	-nitrogen, -water	1992	2060	1714	1922

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

Table 5. Average percentage of total tagged spurs that flowered by treatment and year.

Treatment Number	Treatment Description	2002	2003	2004
1	+nitrogen, +water	18.2 a	16.1 a	20.5 a
2	-nitrogen, +water	18.4 a	10.7 b	26.5 b
3	+nitrogen, -water	17.2 a	16.5 a	23.5 b
4	-nitrogen, -water	15.6 a	13.4 ab	26.8 b

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

Treatment Number	Treatment Description	2002	2003	2004
1	+nitrogen, +water	6.0 a	13.5 a	10.3 a
2	-nitrogen, +water	7.3 a	5.5 c	4.5 b
3	+nitrogen, -water	6.3 a	10.7 ab	8.7 a
4	-nitrogen, -water	8.3 a	7.8 bc	7.3 a

Fig. 1. Midday leaf water potential by treatment over the 2002-2004 seasons.

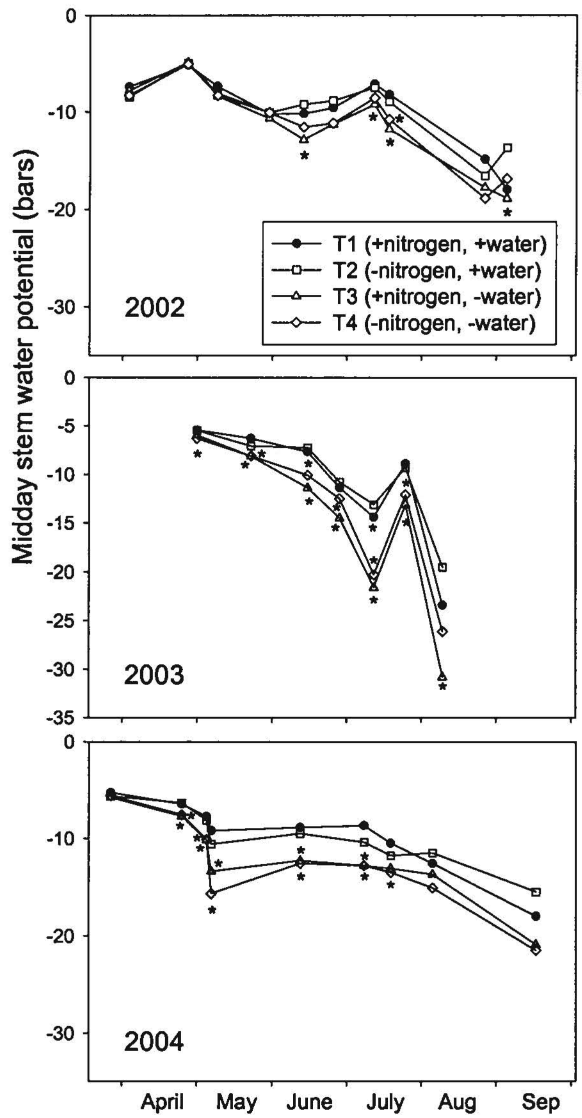


Fig. 2. Canopy light interception measured between the Nonpareil and Monterey rows For 2001-2004 (100 measurements in a grid pattern). Asterisks indicate significant difference from T1.

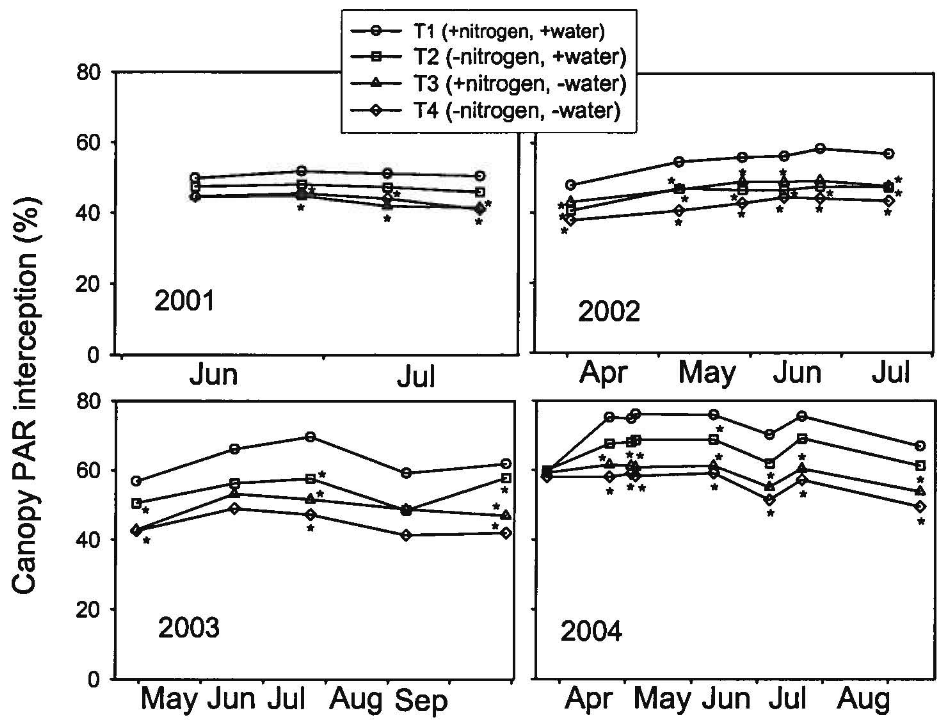


Fig. 3. Canopy light interception for 2002-2004 seasons under individual tree canopies measured by taking 30 readings distributed evenly under canopy shaded area.

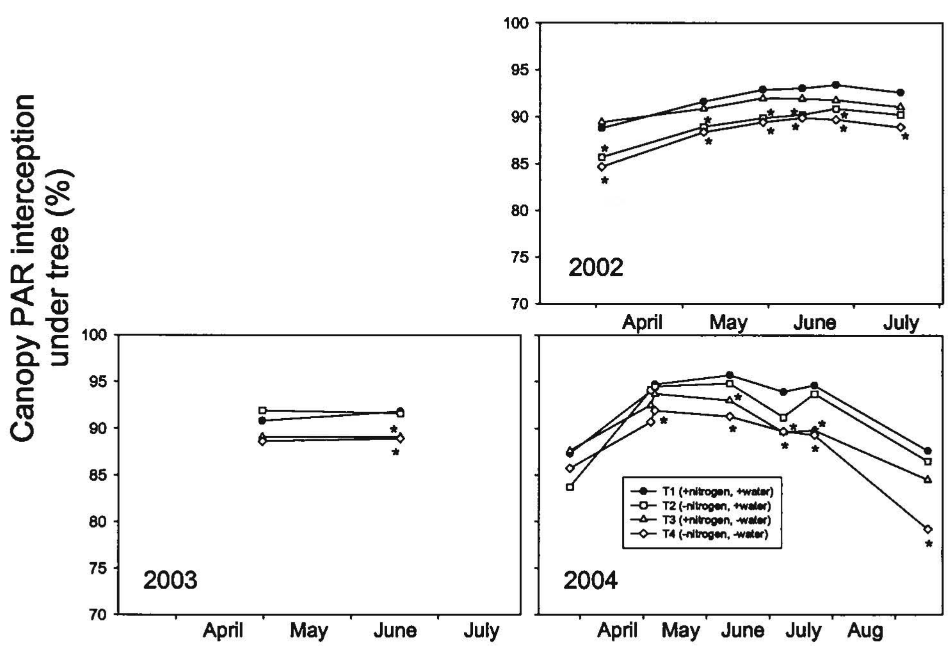
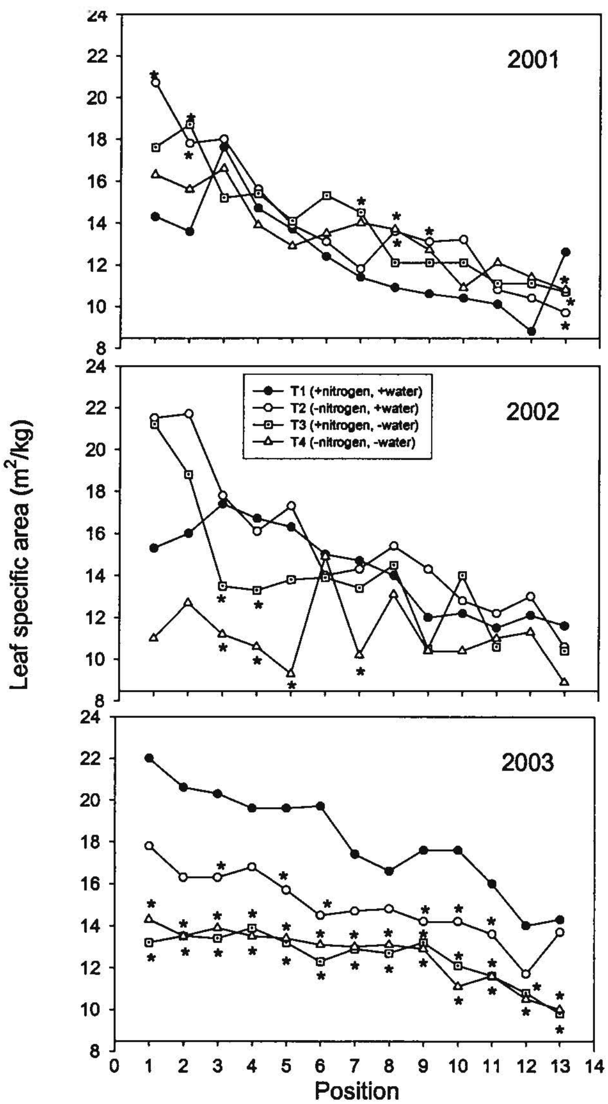


Fig. 4. Leaf specific area for spurs adjacent to tagged spurs from one tree from each treatment. Position #1 is in the innermost position, low in the canopy near the trunk, while position 13 is in the outer exposed canopy at approximately 8-10 foot height. Tables to right give average seasonal midday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



2001 *Treatment*	*Seasonal average midday stem water potential (bars)*	*Leaf nitrogen at July sampling (%)*
1	-9.1	2.33
2	-16.7	1.77
3	-15.8	1.96
4	-10.7	2.21

2002 *Treatment*	*Seasonal average midday stem water potential (bars)*	*Leaf nitrogen at July sampling (%)*
1	-7.1	2.24
2	-8.9	1.55
3	-15.2	1.70
4	-13.9	1.80

2003 *Treatment*	*Seasonal average midday stem water potential (bars)*	*Leaf nitrogen at July sampling (%)*
1	-8.8	2.57
2	-8.5	2.40
3	-15.1	2.37
4	-12.2	2.00

Fig. 5. Bloom stage on Feb. 15, 2005 by treatment.

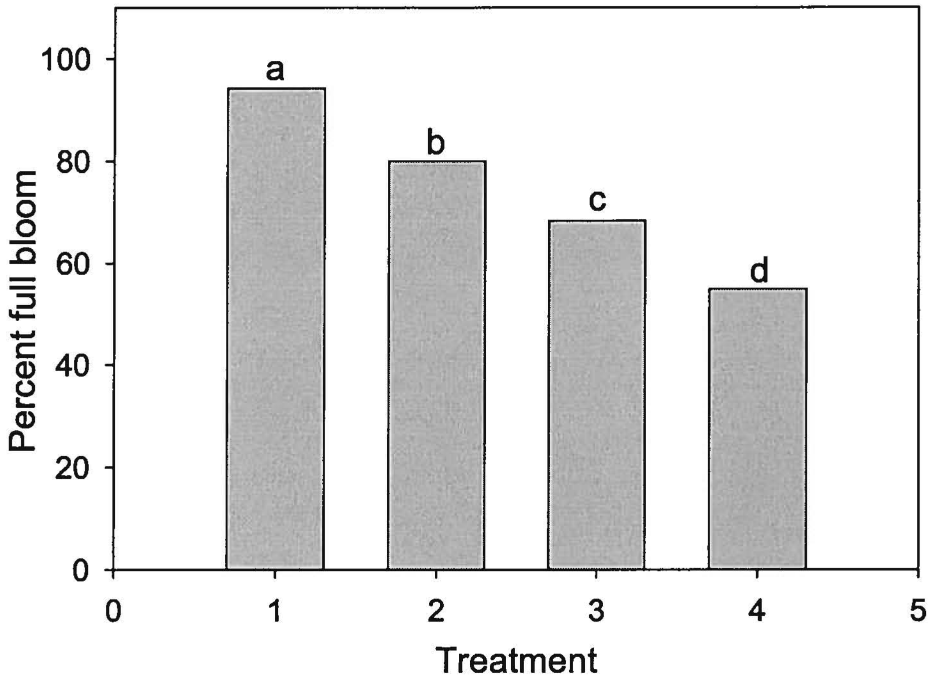


Fig. 6. Nonpareil yield by year and treatment.

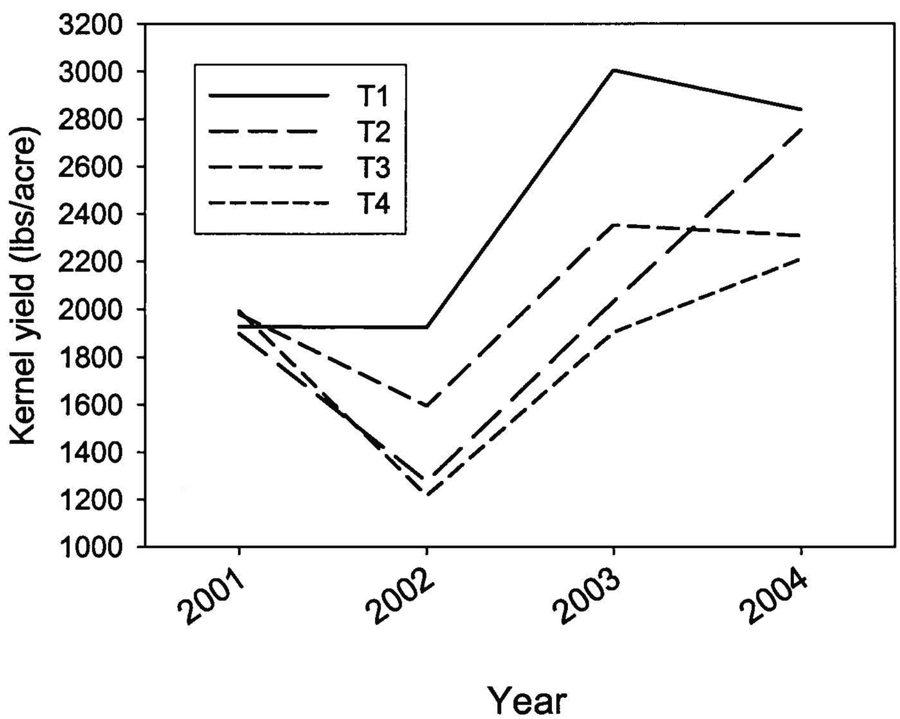


Fig. 7. Trunk circumference, tree height and tree width on February 26, 2005 by treatment.