Almond Board of California
Annual Report
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Project No.: 02-BL-01 Spur Dynamics and Almond Productivity

Project Leader: Bruce Lampinen, Dept. of Pomology, UC Davis

Cooperating Personnel: Ted DeJong, Steve Weinbaum, Sam Metcalf (UCD), M. Viveros (Kern County), Nadav Ravid, Marcos Rodriquez and Rob Baker (Paramount Farming Company).

Problem and its Significance:

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. Spur longeveity, 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 influence the dynamics of spur renewal, fruitfulness and persistence and are likely to impact yield. 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.

Plans and Procedures:

A. Plot establishment: The following treatments will be replicated four times:

1.) Low N* (withhold N fertilization) and moderate irrigation rates [irrigate at mid-day stem water potentials of -1.2Mpa (-12 bars)].
2.) Low N 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)].
3.) High N (200 pounds N/ acre) and high irrigation rates.
4.) High N and low irrigation rates.

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*Apply N at rate of 100 pounds N/ acre when July leaf N concentration gets as low as 2.0%. Apply 30 pounds with the last pre-harvest irrigation and 70 pounds during the period of shoot growth (mid-March).

B. Data collection. Two types of data will be collected:

1.) Productivity. The effects of treatments on orchard yields will be determined. We anticipate that treatments will influence yields significantly within three years.

2.)Spur dynamics. The dynamics of shoot growth, spur renewal, fruitfulness, and spur mortality will be quantified using annual assessment of previously-tagged spurs as well as by monitoring the generation of new spurs from previous year's growth. These analyses will be directed primarily at the treatment extremes (low N / low irrigation vs. high N / high irrigation). The rationale behind this strategy is that collection of these data is labor intensive, and differences will appear earliest at the treatment extremes. Because of tree-to tree variability, alternate bearing and pollination variables, etc., we will monitor 600 spurs per treatment.

C. 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.

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, one fully irrigated tree and one moderately irrigated tree was 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 at a rate of 200 pounds per acre and application began in March and was continued throughout the season. Leaf samples were taken for nitrogen analysis in July. No nitrogen was applied to T3 or T4 in 2001 and in 2002, nitrogen was applied to the moderate nitrogen treatment at 50% the rate applied to the normal nitrogen treatments.

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 feet.

In July 2001 and July 2002, the number of leaves per tagged spur were counted and leaf sizes were rated. In addition, in 2001 a similar spur from a location nearby each tagged spur (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. In 2002, a similar spur was sampled for leaf area and leaf specific weight from on tree per treatment. 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 will be used to count the number of leaves and to calculate the leaf area for each spur from the digital photographs. The image analyses are partially completed. The leaf area and leaf dry weights will be used to calculate leaf specific weight. The leaf specific weight (dry weight per unit area) acts as an integrator of the total light exposure of the spur. In March 2002 and 2003, number of flowers per tagged spur were assessed.

Canopy light interception

Canopy midday light interception was measured twice during July and twice during August using a Decagon Ceptometer (80 cm bar with light sensors mounted on it). 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. Measurements were made near each tagged tree for a total of 48 measurements. Full sun measurements were taken periodically as a reference. In addition to these measurements, just before harvest, 20 measurements were taken directly beneath the canopy of each monitored tree in order. This measurement would show whether any changes in light interception by a treatment were due to changes in overall tree growth or to differences in canopy density.

Leaf nitrogen

Approximately 50 leaves from non-fruiting spurs per tree were sampled for leaf nitrogen analysis in July 2001 and July 2002..

Yields

In 2001, yield data for the first year of the study was collected as one composite sample for each treatment. The entire crop for each treatment and variety was collected and weighed in the field. Then, the entire yield for each treatment was followed through the hulling process to obtain a per acre kernel yield for each treatment and variety combination. In 2002, yield data was again collected as one composite sample for each treatment. In addition, in 2002, single tree yields were obtained from each of the 48 trees (12 per treatment) that were monitored for water potential over the season.

Results and Discussion

Irrigation

Differential irrigation treatments began in early May 2001. The control treatment midday stem water potentials were below (more negative than) the target values during much of the season due to problems with the water distribution system. However, overall there was about a 2 bar difference between the fully irrigated and moderate irrigated treatments through the season in both years (Table 1). Although there was a tendency for the midday stem water potentials for the moderate irrigation treatments to be lower than the control, there were no significant treatment effects on midday stem water potential for the large orchard sample until 25 July (the period when water was cutoff to prepare for harvest) when both of the water moderate treatments were significantly more stressed than the fully watered control (data not shown). In 2002, seasonal average midday stem water potentials were near target levels for all treatments (Fig. 1).

Part of the reason for the large variability in water potentials within a given irrigation treatment was due to the fact that the experiment encompasses three different irrigation sets. Therefore, on any given day, trees being monitored for water potential in any treatment had been irrigated anywhere from 0-4 days previous. The differences in midday water potential across the irrigation sets within one treatment tended to be fairly consistent over the course of the season (Fig. 2). These consistent differences were partially due to the differences in days since irrigation (since water potential measurements were generally done at the same point in an irrigation cycle) but there were also consistent differences across the irrigation sets most likely due to soil variability.

We will be able to factor the impacts of the irrigation variability into our data analysis since we have midday stem water potential data for each of our monitored trees throughout the season.

Canopy light interception

After late July, the two moderate irrigation treatments led to a significant decrease in canopy light interception in 2001 (Fig. 3). This is probably because the water potentials in these treatments were consistently below –12 bars which is generally the level at which vegetative growth is impacted. In 2002, all three of the deficit treatments had significantly lower light interception than the control at all times during the season.

Measurements of light interception under the tree canopy indicated that some of the treatment differences could be due to increased light penetration through the tree canopy rather than decreased radial growth of the canopy (Table 2, Fig. 4).

Spur dynamics

In 2001, leaf dry weight per spur increased from about 0.1 to almost 0.2 grams from the interior canopy spurs to the most exterior ones (Fig. 5). There were generally 5 to 6 leaves per spur and there were no significant treatment differences in leaf dry weight per spur at any canopy position in the 2001 season (Fig. 6). There were no significant treatment differences in number of leaves per spur although there was a tendency towards increasing number of leaves per spur as you move outward in the canopy.

There were no significant treatment differences in the percentage of flowering spurs, the number of flowers per spur, or the numbers of fruit per spur in 2002 (data not shown).

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. 7). 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. The large difference in the patterns in 2001 versus 2002 indicate that cumulative effects are occurring. These data suggest that the treatments are likely to impact spur dynamics over time.

Leaf nitrogen

All of the nitrogen and water deficit treatments had significantly lower leaf nitrogen at the July sampling date compared to the control in 2001 and 2002 (Table 3). Leaf nitrogen analysis in July 2001 indicated the trees in T2 and T4 were right near the point where nitrogen applications should begin (Table 3). Therefore, in 2002, nitrogen was applied to these treatments at one-half the rate for T1 and T3. However, the July 2002 leaf nitrogen samples indicated that all of the treatments were below the desired levels of nitrogen although the grower had applied 200 lbs N/acre. Leaf nitrogen will be sampled throughout the growing season in 2003 so that adjustments can be made during the growing season.

Yields

In 2002, yield data for the overall plots were again collected as one composite sample for each treatment. 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. When difference in canopy light interception are accounted for, yield difference between T1 and T2-T3 were still significantly different while those between T1 and T3 were not (Table 5).

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).

Preliminary conclusions

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 water 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. However, even with these negative confounding factors, the results suggest that T3 (high nitrogen, moderate water) may have potential as a tool to manage vegetative growth without serious impacts on yield. Differences in light interception among treatments and as well as alterations in spur characteristics that have started to appear in 2002, suggest that treatments are impacting canopy light penetration, and hence will likely impact spur longevity and quality in the following years.

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.

Table 1. Average seasonal midday stem water potential by treatment for the 2001 and 2002 seasons. Measurements are for a total of 12 trees per treatment taken over 7 days during the season in 2001 and 10 days in 2002.

Treatment	Description	Average 2001 seasonal midday stem water potential (bars)	Average 2002 seasonal midday stem water potential (bars)
1	+nitrogen, +water	-11.9a	-9.8ab
2	-nitrogen, +water	-11.6a	-9.7a
3	+nitrogen, -water	-13.8b	-11.4c
4	-nitrogen, -water	-13.0b	-11.0bc

Table 2. Percent light interception under the tree canopy at midday on August 10, 2001.

Treatment	Description	PAR interception (%)
1	+nitrogen, +water	89.3a
2	-nitrogen, +water	87.7a
3	+nitrogen, -water	87.3a
4	-nitrogen, -water	84.8a

Table 3. Leaf nitrogen for 2001 and 2002 seasons. Approximately 50 leaves were sampled from non-bearing spurs about half way up the canopy on 12 trees (the trees that were monitored for water potential) per treatment.

Treatment Number	Treatment Description	Leaf nitrogen 2001	Leaf nitrogen 2002
1	+nitrogen, +water	2.20a	2.02a
2	-nitrogen, +water	2.00b	1.74c
3	+nitrogen, -water	2.11a	1.91b
4	-nitrogen, -water	1.96	1.67c

Table 4. Average pounds of kernel yield per acre by variety. Weight is for the total plot.

2001

Treatment Number	Treatment Description	Nonpareil	Monterey	Wood Colony	Average 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	Average 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

Table 5. 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

Fig. 1. Midday leaf water potential by treatment over the 2002 season.

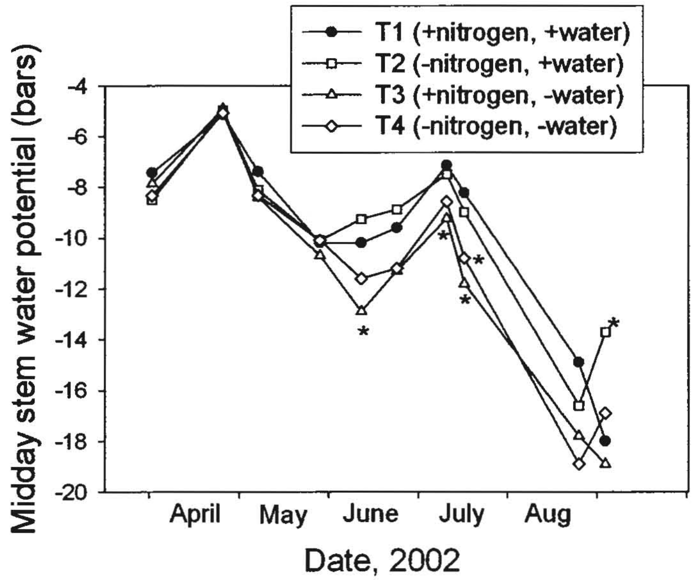


Fig. 2. Midday water potential over the 2001 season for treatments 4 broken down by irrigation set. Leaves were sampled by wrapping a shaded leaf in damp cheesecloth and immediately taking a water potential reading.

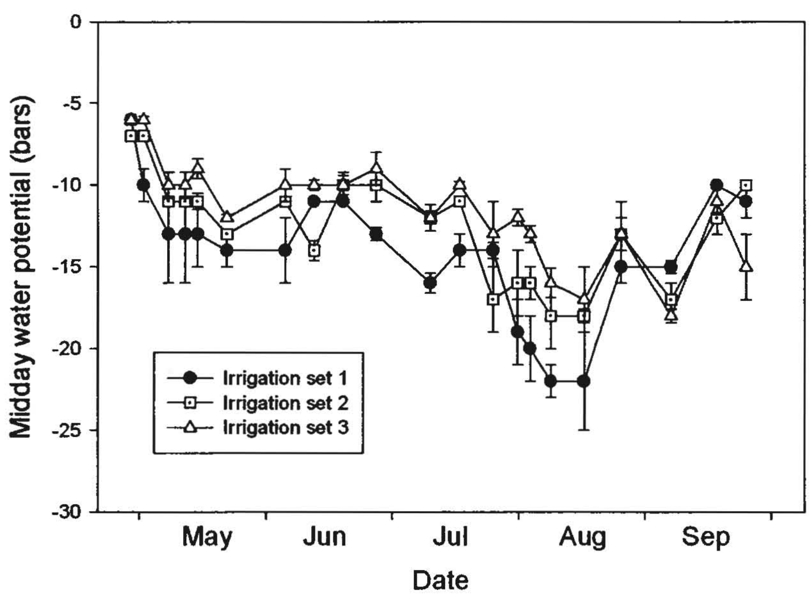


Fig. 3. Canopy light interception measured between the Nonpareil and Monterey rows by taking 100 measurements in a grid pattern in 2001 and 2002. Asterisks indicate significant difference from T1.

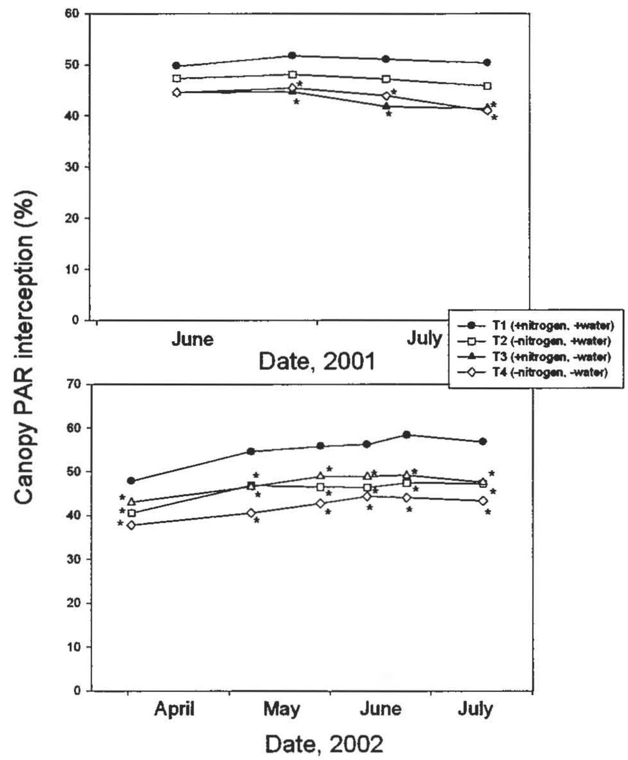


Fig. 4. Canopy light interception for 2002 season under individual tree canopies measured by taking 30 readings distributed evenly under canopy shaded area.

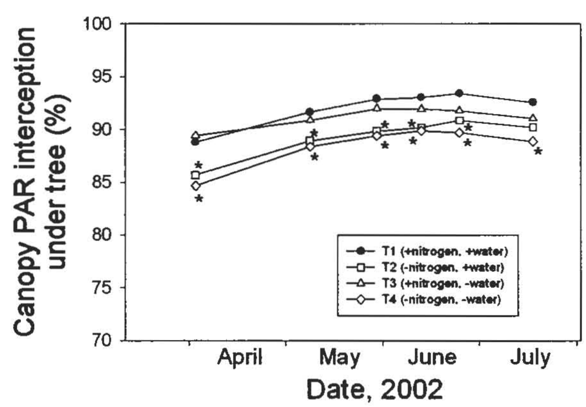


Fig. 5. Spur leaf dry weight as it varies by canopy position and treatment in 2001. Position 1 is the most interior and lowest on the tree and position 13 is the most outward and highest canopy location.

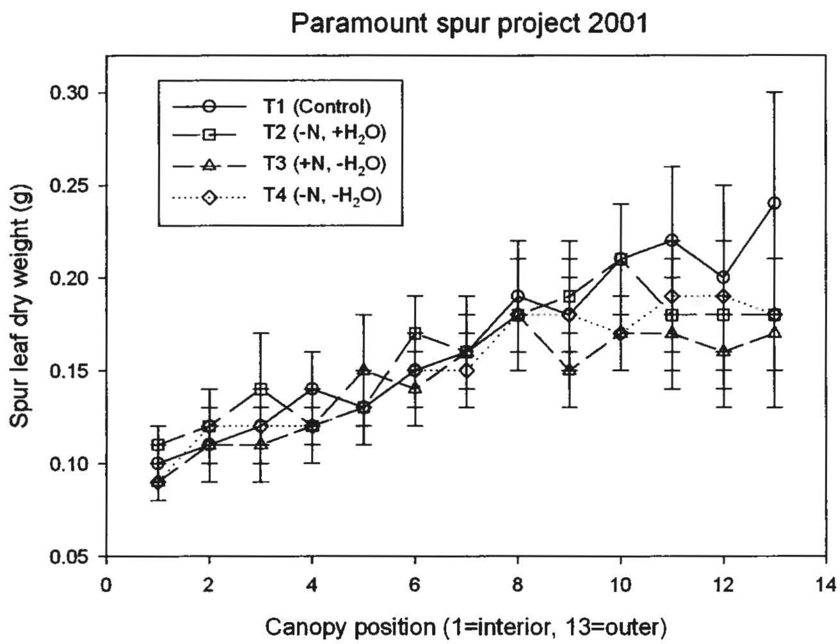


Fig. 6. Number of leaves per spur as it varies by canopy position and treatment in 2001. Position 1 is the most interior and lowest on the tree and position 13 is the most outward and highest canopy location

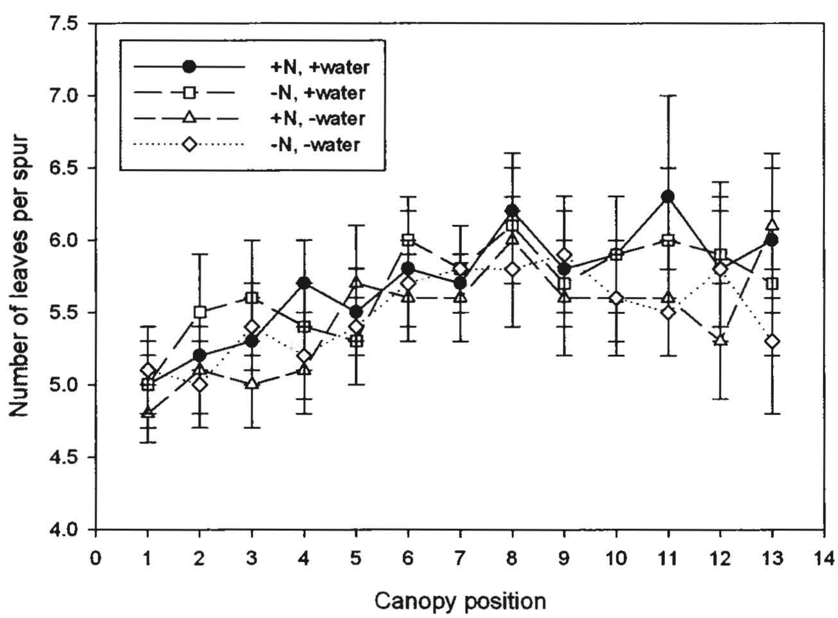
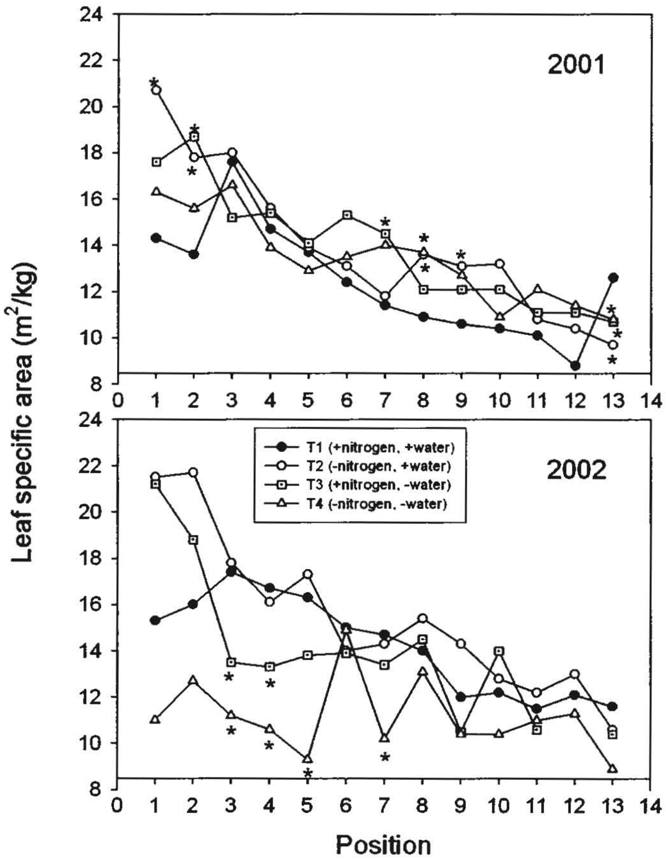


Fig. 7. Leaf specific area for spurs adjacent to tagged spurs from one tree from each treatment. Position #1 is in the innermost position, low in the canopy near the trunk, while position 13 was in the outer exposed canopy at approximately 8-10 foot height. Tables to right give average seasonal midday stem water potential and leaf nitrogen for the individual trees for which data is presented in the adjacent graph.



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

Treatment	*Seasonal average midday stem water potential (bars)*	*Leaf nitrogen at July sampling (%)*
1	-7.1	2.24
2	-15.5	1.55
3	-15.2	1.70
4	-8.9	1.80