Tree Architecture and Development of New Growing Systems

Project No.: **18-HORT30-Thorp (COC)**

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Objectives:

This program of research in California is following a similar structure to research underway in Australia, with six main research objectives.

1. Commercial high density orchards: To validate management systems for new almond orchards planted at high density
2. Pruning responses: To optimize pruning systems for current and future almond varieties to be planted at high density
3. Architectural studies: To develop techniques to accelerate the identification, breeding and commercialization of almond varieties suitable for high density orchards
4. Nursery production: To develop new production methods to provide low cost single axis almond trees suitable for high density orchards
5. Trunk girdling: To optimize use of trunk girdling to reduce the time taken for almond trees to produce their first commercial crop
6. Light interception: To determine the best canopy dimensions to optimize light utilization and yield in high density almond orchards.

Interpretive Summary:

Almond orchards of the future will need to be more efficient, with more cost effective and sustainable growing and harvesting systems. The New Zealand Institute for Plant and Food Research Limited (PFR) scientists are researching almond tree architecture and the development of advanced production systems in Australia. A similar program is being established in California, funded by the Almond Board of California (ABC), with the aim of establishing multi-year collaborative research projects between PFR and Californian researchers. This report covers Year 3 activities in this program, from August 2018 to December 2019.

In 2018/19 (Year 3) of this project, data collection has continued from trees planted in field trials in winter 2018 at CSU Fresno at Clovis, Burchell Nursery in Fowler and at UC Davis at Wolfskill. Genotypes included eight advanced selections from the UC Davis breeding program, three from the Burchell Nursery breeding program and five commercial varieties ‘Nonpareil’, ‘Monterey’, ‘Wood Colony’, ‘Winters’ and BA2 (Shasta®). New data collected in Year 3 contains architectural data, including tree stature, branching and propensity of trees to develop a strong central leader.

New research trees planted in winter 2019 were established at the Burchell Nursery in Fowler with a focus on spur bearing genotypes from the UC Davis and Burchell Almond Genetics breeding programs. This is a new direction for the research. The “high productivity” model we were working with was based on trees that produce numerous dard-type shoots, as with the variety ‘Winters’. We found that genotypes with this growth habit can be sensitive to cold temperatures during winter and just by the sheer number of shoots produced can weaken the terminal shoot being trained as a central leader. Hence, we have now included in our program more examples of strong spur bearing types, which have persistent spurs that are productive even in relatively low light environments.

One trunk girdling treatment was applied on 10 October 2017 to Shasta trees planted in January 2015. The crop was harvested in August 2018. While we recorded a modest reduction in tree vigor/size, there was no difference in crop yield, confirming previous results regarding the potential benefits of girdling from projects with ‘Nonpareil’ in Australia.

The spacing between rows and trees in new growing systems needs to be evaluated, to develop systems that will capitalize on the opportunity to increase yield without compromising nut quality and mixed maturity issues. Preliminary data on temperature, relative humidity and light interception (PAR) are being collected from blocks of closely planted trees to record the effect of growing/planting system on the micro-climate within orchards and trees. Low temperature and high humidity conditions are likely to be found in heavily shaded blocks, which will probably delay fruit ripening/drying and contribute to mixed maturities at harvest. This is an important consideration when designing new growing and harvesting systems.

Background:

The Australian and Californian almond industries are undergoing a period of rapid growth with the establishment of new orchards and conversion of existing orchards over to new varieties and rootstocks. This is an ideal time to take a fresh look at almond orchards and to challenge current paradigms around almond production and harvesting.

To remain profitable and meet current and future regulatory requirements, almond orchards of the future will need to be more efficient with more “cost effective” and “sustainable” growing and harvesting systems based on the best new variety and rootstock combinations for each site.

New “22nd Century Agronomics” will include improvements in tree architecture and growing systems to enable a shift away from the current, inefficient “large tree” orchards, where young trees are pruned to produce an inverted pyramid shape with several large scaffold branches. These new growing systems will work with the natural growth habit (tree architecture) of specific varieties to produce trees with a narrow, slender pyramid tree shape. This slender pyramid tree shape will be more efficient at harvesting sunlight and converting this sunlight into commercial crops thus increasing orchard yields (lbs per acre) and grower profits. Additional benefits from growing slender pyramid almond trees planted at high density will include:

- Reduced time for new orchards to produce their first commercial crop
- Tree shape suitable for “shake and catch” harvesting with more uniform crop maturity and improved nut quality
- Smaller trees for more efficient pest and disease management
- Improved water use efficiency by smaller trees in terms of water requirements per lb of harvested kernel.

The key research hypothesis is that orchard yields and grower profits can be doubled by planting trees at high density and growing these trees with a slender pyramid tree shape that optimizes orchard light interception.

Ancillary questions to achieve this outcome include:

- How will different varieties respond to the various training/pruning regimes required to produce slender pyramid trees for high density plantings?
- Will slender pyramid trees increase crop value by reducing variability in crop maturity and improving kernel quality?
- Can current nursery practice be improved to produce a better tree structure more amenable to high density planting and to reduce tree cost which is often a barrier to growers wanting to plant high density orchards?
- Will trunk girdling increase yields on young almond trees and reduce the time taken for trees to produce their first commercial crop?
- Can the breeding cycle for trees with high productivity be accelerated by screening for desired architectural traits in 1st leaf trees budded onto clonal rootstocks and by screening for desired fruit bearing traits in 2nd and 3rd leaf trees?

Project Activities Year 3:

A total of 2212 almond trees were propagated by Burchell Nursery and planted during winter 2018 in field trials at CSU Fresno in Clovis, Burchell Nursery in Fowler and UC Davis in Wolfskill. Genotypes included eight advanced selections from the UC Davis breeding program, two from the Burchell Nursery breeding program and six commercial varieties ‘Nonpareil’, ‘Monterey’, ‘Wood Colony’, ‘Winters’, BA2 (Shasta) and BA3 (Pyrenees®).

Pruning responses

Eleven genotypes budded in June 2017 on container grown Cornerstone rootstock were planted at the Burchell Nursery in Fowler in February 2018 in a high density block with trees at 7.5 x 15 ft spacing (387 trees per acre), with one variety per row.

All trees have been trained as central leader trees with three pruning treatments applied from Year 2:

i) **Control** — trained as central leader in Year 1 (2018), then narrow pruned in January and May 2019 (Year 2).
ii) **Bare pole** — trained as central leader in Year 1 (2018), then all side shoots trimmed to approximately 1½ inches in January 2019, followed by a single round of pruning in May 2019 (Year 2).
iii) **Scaffold branches** — trained as central leader in Year 1 (2018), then a set of strong scaffold branches selected in Year 2 (2019).

Pruning treatments were applied to three trees each with three of these experimental blocks per variety for each of the three pruning treatments (nine trees per treatment). The trial extends across 11 rows (one variety per row) with 27 trees per row (297 trees) in a randomized complete block design along each row. External rows and one tree at the end of each row are guard trees.

Trees were approximately 3 ft tall when planted as central leader trees with a single trunk. Management of these trees in Year 1 has involved gradual removal of any side branches below 2 ft as the central leader has increased in height. Some additional pruning was required to remove competing lateral shoots (congestion) just below the terminal bud on the central leader to promote extension of the terminal shoot to become the central leader. Control trees were narrow pruned in winter and summer (dormant and in-season pruning, respectively). Bare pole trees were cut back in winter Year 2 to create the bare pole effect then an in-season narrow pruning treatment applied in summer. Scaffold trees were pruned during summer of Year 2 to select a set of strong scaffold branches as the fruiting framework.

The first commercial crop is expected to be harvested from these trees in summer 2020.

Shasta®' pruning trial

Shasta is a new self-fertile variety released by Burchell Nursery. In this project we are evaluating five pruning treatments on Shasta trees spring budded onto field grown Nemaguard rootstock and planted at Fowler in February 2018 in a high density block with trees at 7.5 x 15 ft spacing (387 trees per acre). The pruning treatments are:

Control: Trees headed/trimmed in nursery before planting in February 2018, then narrow pruned in June 2018 (Year 1), and again January and May 2019 (Year 2).
Central leader: No pruning before planting in February 2018, then narrow pruned in June 2018 (Year 1), and again in January and May 2019 (Year 2).
Central leader — bare pole Year 1: Side shoots trimmed to 1½ inches before planting in February 2018, then narrow pruned in January and May 2019 (Year 2).
Central leader — bare pole Year 2: Trees left unpruned when planted in February 2018, narrow pruned in June 2018 (Year 1), then all side shoots trimmed to 1½ inches in January 2019 (Year 2), followed by a single narrow prune in May 2019.

Central leader — hedging: No pruning before planting in February 2018, then narrow pruned in May 2019 (Year 2).

There are eight experimental blocks of three trees each per pruning treatment extending across four rows with 30 trees per row (120 trees) in a randomized complete block design with each pruning treatment represented twice in each row.

As well as the above pruning treatments, all trees were pruned as required to remove any new branches formed on the trunk below 2.5 ft in to maintain a clean trunk for the tree shakers. Terminal dominance of the central leader trees was also maintained as required, by thinning out competing subterminal shoots.

The first commercial crop is expected to be harvested from these trees in summer 2020.

Architectural studies

As with many *Prunus* spp., almond trees generally exhibit a strong basitonic growth habit that produces a set of very large scaffold branches near the base of the tree. With heavy cropping varieties this can result in unstable fruiting canopies that require considerable pruning and training to maintain productivity. While this growth habit is suited to current large-tree growing systems, it is not suited to more intensive small-tree growing systems. At the same time as we redesign almond orchards, we need to select new almond varieties that have different traits to those previously sought.

Our objective here is to work with almond breeders and develop techniques that will help them to accelerate identification, breeding and commercialization of new almond varieties better suited to high density orchards than current varieties.

In a series of short-term studies we are characterizing desirable architectural traits in current and future almond varieties, starting with “unpruned” trees in their first leaf budded onto clonal rootstocks. All trees were trained as central leader trees in Year 1 and then left to develop for 2 years with no pruning so that the true natural growth habit of each genotype could be observed.

The first set of trees were planted in February 2018, with a range of standard commercial varieties planted alongside a number of advanced selection genotypes from the UC Davis and Burchell breeding programs, which had been identified to have an upright dard type growth habit with numerous side shoots similar to the variety ‘Winters’.

All trees were budded on container grown Cornerstone rootstock in June 2017 and planted in February 2018 in a high density block with 7.5 x 15 ft spacing (387 trees per acre). There are five experimental blocks of two paired trees each per genotype extending across five rows, with 30 trees per row (150 trees) in a randomized complete block design. Each row includes one pair of trees per genotype. The first commercial crop is expected to be harvested from these trees in summer 2020.

A second set of trees was planted in 2019 with the focus on having more spur bearing genotypes. Trees had been nursery grown in 2018 then field planted and budded in February 2019 with trees at 7.5 x 15 ft spacing (387 trees per acre). There are five experimental blocks of two trees each per genotype extending across two rows with 30 trees per row (60 trees) in a randomized complete block design. Each row includes one pair of trees per genotype. No data will be collected from these trees until 2020.

Both quantitative and qualitative attributes have been identified for breeders to use when screening breeding populations in their first- or second-leaf for desired architectural traits for high density growing systems. Important considerations are:

- A compact, upright tree with excurrent branching will be easier to manage in high density blocks than trees with wide, spreading canopies and decurrent branching. These differences are obvious within the first two years of growth.
- Tree architecture among breeding populations can easily be observed in years 1 and 2. Would it accelerate the breeding pipeline if trees with negative architectural traits were eliminated before the trees produced their first crop?
- Seedlings from breeding populations growing on their own roots typically show large variation in vigor, which is not seen in commercial trees on clonal rootstocks. Would it make the breeding pipeline more efficient if all breeding progeny were budded and evaluated on clonal rootstocks?
- First-leaf trees in the nursery show a range of branching habits typical for each variety. Desired attributes for central leader trees would be to have uniform branching, evenly distributed along the trunk, as tends to happen with ‘Nonpareil’ and Shasta.
- While strong axillary shoot production is important to increase the number of potential fruiting sites, these shoots (dards) need to be robust enough to survive in low light conditions and sustain high productivity. This attribute can be identified in second-leaf trees.
- Strong branching from terminal and subterminal buds can produce long barren sections of wood; this undesirable habit can be observed in second-leaf trees.
- Uniform extension of the central leader is desired at the transition zone between one growth flush and the next; compared with poor central leader development caused by dominant axillary branching or weak terminal bud development.
- Is strong axillary shoot growth in Year 1 at the expense of strong bud and spur development in years 1 and 2, respectively?
- Long-term viability of spurs will be important for sustained high productivity, as will the generation of new fruiting wood. At what stage in the breeding cycle can we predict spur longevity?

Examples of qualitative and quantitative data that can be used when screening breeding populations for desired architectural traits in the first- and second-leaf trees budded on clonal rootstocks have been shared with almond breeders.

Shasta®’ trunk girdling trial

This project is located on a private grower property adjacent to the Burchell Nursery in Fowler. The variety is Shasta, a new self-fertile variety, spring budded on Nemaguard rootstock and planted in January 2015 at 15 x 21 ft spacing (138 trees per acre) in a solid block of Shasta trees.

A complete trunk girdle was applied to 10 trees using a 1/8th inch VACA girdling knife on 10 October 2017, and 10 trees were left ungirdled as a control, in a systematic design with girdled and control trees alternating along the same row. The crop was harvested and canopy dimensions recorded in August 2018.

Tree dimensions were recorded as tree height and canopy volume. Tree canopy volume was determined from digital images taken at right angles to each tree along the row. ImageJ Fiji software (http://imagej.nih.gov/ij) was then used to trace the perimeter of the tree canopy from which to calculate cross-sectional canopy area. This cross-sectional area was then converted to a circle from which it was possible to calculate radius. Canopy volume (V) was calculated as $V = 4/3 * \pi * radius^3$. All trees were isolated and not growing into each other so it was valid to assume a uniform canopy cross-section regardless of the angle at which the digital image was taken.

Yield data were determined on 9 August 2018 by hand harvesting each tree and recording the total fresh weight of whole fruit per tree. A subsample of approx. 2 kg was then taken for each tree. This subsample was weighed before the fruit were hulled, the nut-in-shell was weighed again then shelled to produce the kernel only which was weighed. Moisture content of the kernel was measured in approx. 100 g of kernel using a Dickey-John GAC 2100 Moisture Meter located at Hughson Nut Co. in Modesto CA. Yield data were then converted to kg of kernel at 5% moisture content per tree.

Results:

Tree height and canopy volume were similar for the girdled and not-girdled trees at the start of the project in October 2017 (Table 1). Tree height did not increase as much as expected during the period from application of the girdling treatment in October 2017 until harvest in August 2018. This was because the trees had been machine pruned in early summer 2018 to reduce tree height. However, tree canopy volume did increase substantially from one year to the next.

Control trees had a significantly greater increase in canopy volume than those receiving the trunk girdling treatment (Table 1).

Table 1. Tree height and canopy volume of 3-year-old Shasta® almond trees in October 2017 and August 2018. Treatment trees were girdled in October 2017 with a 1/8th inch wide girdle and nuts were harvested in August 2018.

	Tree height (ft)	Tree volume (yd^3)	Tree height (ft)	Tree volume (yd^3)
	October 2017		August 2018	
Girdled	10.5 ± 0.3	13.3 ± 1.2	11.5 ± 0.3	18.8 ± 1.7
Not girdled	10.8 ± 0.3	12.9 ± 0.8	12.1 ± 0.2	23.0 ± 0.9
Significance[1]	NS	NS	NS	*

[1] *Significance: NS = not significant; * = $p<0.05$*

The total fresh weight of the crop was less on the girdled than non-girdled trees (Table 2). This was possibly due in part to the crop from the girdled trees being slightly drier at harvest. Although this difference was not significant (*p* = 0.121) there was much greater variation in moisture content between the girdled than non-girdled trees (Figure 1). Nevertheless, when corrected for moisture content, the yield of kernel at 5% moisture content was still slightly less on girdled than non-girdled trees. These data need to be taken with some degree of caution as moisture content values over 10% are not particularly reliable and could have exaggerated sample variability within treatments. To mitigate this, moisture readings were repeated three times for each sample and the average value used in these analyses.

Table 2. Total fresh weight per tree; proportions of hull, shell and kernel; kernel moisture content; and kernel weight per tree corrected to 5% moisture content of the crop harvested in August 2018 from Shasta® almond trees. Treated trees had been girdled in October 2017, when trees were 3-years-old, with a 1/8th inch wide girdle.

Treatment	Total fresh weight (lb)	Hull	Shell	Kernel	Kernel moisture content (%)	Kernel weight (lb) corrected to 5% moisture content
		% of total fresh weight				
Girdled	34 ± 1.5	64 ± 10	16 ± 3	20 ± 8	14 ± 0.9	6.2 ± 0.3
Not girdled	41 ± 2.2	64 ± 6	16 ± 3	19 ± 4	16 ± 0.4	7.0 ± 0.3
Significance[1]	*	*NS*	*NS*	NS	*NS*	(*)
P =	*0.016*	*0.496*	*0.847*	*0.439*	*0.121*	*0.056*

[1] *Significance: NS = not significant; (*) = p<0.10; * = p<0.05*

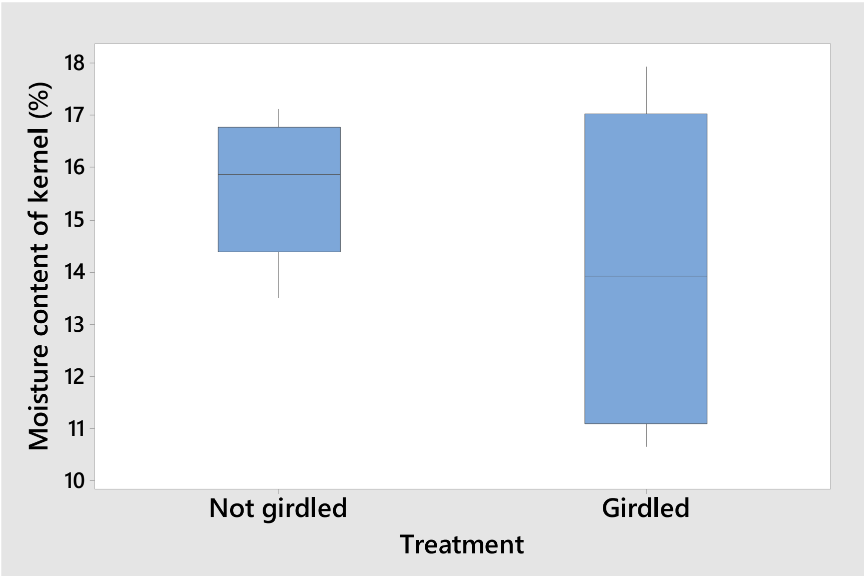

Figure 1. Box plot showing the moisture content (%) of almond kernel harvested from girdled and non-girdled Shasta® almond trees. Treated trees had been girdled in October 2017, when trees were 3-years-old, with a 1/8th inch wide girdle and harvested in August 2018. The median value is visible as a horizontal line within each block. The first quartile marks one end of the box and the third quartile marks the other end of the box. The "whiskers" extend from the ends of the box to the smallest and largest data values.

Environmental studies

Increasing planting densities within the orchard has highlighted an area of research that has historically been overlooked in nut production. As trees are planted closer and closer together, high rates of transpiration combined with closed canopies that limit airflow will produce zones of high humidity and low drying capacity. While improving orchard design and increasing productivity, we must not create problems down the track with growers' ability to dry the crop. This means that we must better understand the microclimates we are creating within the orchard with new varieties and growing systems.

Temperature and relative humidity are linked such that as ambient temperatures rise during the day, relative humidity decreases and the opposite happens at night, as temperatures cool relative humidity increases (Figure 2). The same pattern is found within trees with heavily shaded parts of the canopy having lower daytime temperatures and thus higher relative humidity and the reverse at night. These daytime conditions will delay fruit development and ripening compared with fruit in more exposed locations.

With poor drying conditions, moisture stays in the fruit. When air is not constantly replenished by the wind, moisture has nowhere to escape. Trees then begin to show variable maturities where the upper canopy fruit is ready to harvest while the lower canopy fruit is still green and sometimes 2–3 weeks away from being ready for harvest. The combination of these factors is a challenge to growers in gauging the perfect time to harvest, especially with shake and catch harvesting systems.

An experimental system to record temperature (T), relative humidity (RH), light interception (PAR) and eventually air velocity data within almond orchards is in development. Comprised of a scalable number of wireless nodes, sensors transmit T, RH and PAR data to a central location or base station that logs the data. The system is designed to be small and transportable to make rollout and implementation seamless and easy. Ultimately the system will be used to set up an array of sensors to produce a grid of environmental conditions within the orchard to be compared with rates of fruit maturation and kernel quality.

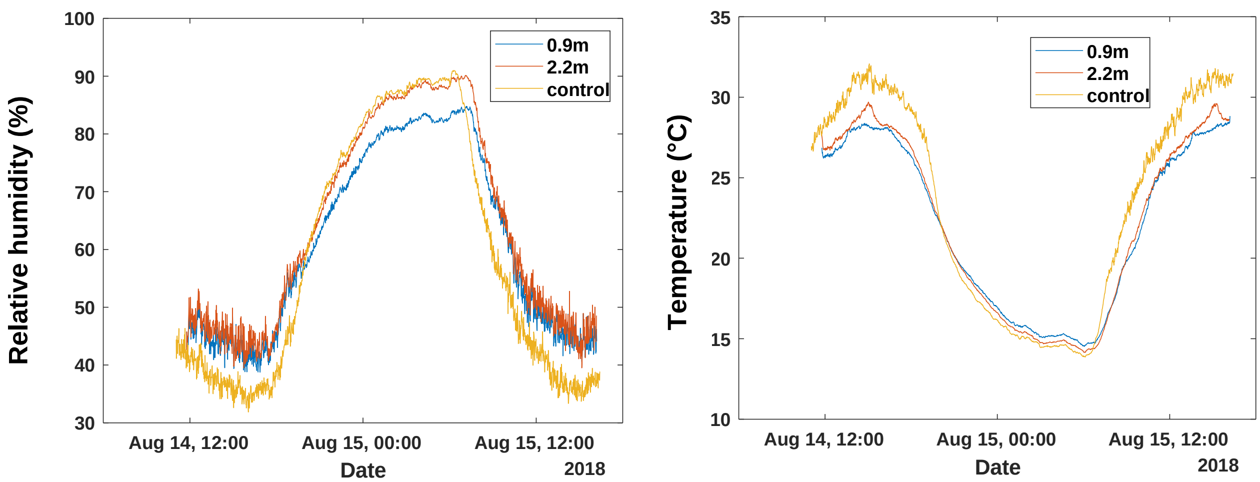

Figure 2. Relative humidity and temperature above the canopy (control) and at two heights (0.9 and 2.2 m) within the canopy of 'Nonpareil' trees planted in a traditional design. Data were recorded on 15 August 2018.

Project presentations and publications:

Grant Thorp 2018. Tree architecture and development of new growing systems. Poster presented to the Almond Board of California Annual Conference in Sacramento, 4–6 December.

Grant Thorp and Ann Smith 2019. Tree architecture – important traits for new almond varieties. Poster presented to the Almond Board of California Annual Conference in Sacramento, 10–12 December.

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