Integration of Tree Density & Minimal Pruning for Efficient Almond Production

Project No.:

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A. Summary

This is the final summary of a large, twenty-three-year field trial which chronicled the performance of commercial almond trees planted at various in-row spacings and pruned with one of four pruning strategies and compared on two rootstocks. The trial encompassed 37 acres within a large commercial almond growing operation. Yields were very good through most of this trial, often exceeding 3500 kernel pounds per acre during the peak production years. The pruning treatment portion of this trial was terminated at the end of 2018 (19^{th} leaf) but harvest data collection continued for the in-row spacing portion through 2021.

Throughout the duration of this trial, data have consistently shown that annual pruning done to preserve the lower canopy or maintain long-term yields did not improved yield in the short-term or long-term compared to trees that were essentially unpruned for 19 years. In general, pruned trees had lower cumulative yields than unpruned trees, although differences were often insignificant within a given year. Based on the nut value during the period of this trial, annual pruning would have cost the grower between $7,500 and $14,000 per acre in cumulative pruning costs and loss of production, depending on variety and rootstock.

In-row tree spacing affected yield, but not as much as anticipated. Nonpareil trees on Nemaguard rootstock planted 10 or 14 feet apart down the row had almost identical cumulative yields over the 22-year period of the trial, and accumulated about 2,300 pounds per acre more than trees planted 18 feet apart and more than 4,900 pounds more than trees planted 22 feet apart. Closer spacing improved yield more for the smaller Carmel variety. Carmel on Nemaguard planted 10 feet apart yielded 4,638 pounds per acre more than trees 18 feet apart and 7,852 pounds per acre more than trees 22 feet apart. For the most vigorous trees (Nonpareil on Hansen rootstock), yields tended to be a little higher at 18'. The biggest advantage to closer tree spacing was a smaller tree size and increased tree longevity. Closely planted trees are smaller (less canopy volume, smaller trunk circumference but similar tree height), shake more easily, have less cumulative shaker injury on their trunks, have fewer mummies per acre, and have lost far fewer trees compared to the most widely spaced trees, regardless of rootstock. It appears that orchards with trees planted closely down the row may be easier to maintain, be more productive and profitable, and may have a longer productive lifespan than more widely, (conventionally) spaced orchards.

B. Objectives

To evaluate the long-term effects of three key management factors on orchard production and longevity: tree spacing (planting density), rootstock, and training/pruning strategies.

C. Annual Results and Discussion

Effects of Pruning

- Yield data for the pruning component of this trial were collected annually (with two exceptions) from the 4th leaf through the 19th leaf (Table 1). Nonpareil trees that were trained to three scaffolds and pruned annually for the life of the trial had almost identical cumulative yield compared to trees that were initially trained to three scaffolds and then left essentially unpruned. Pruning reduced yield in Carmel. Untrained and unpruned Carmel trees accumulated 4,423 more kernel pounds per acre than trees that were traditionally trained and then pruned annually thereafter, an increase of about 11%. Untrained, unpruned Nonpareil trees accumulated 952 more pounds per acre through the 19th leaf than trees pruned annually (+2.3%). Trees that were originally trained to three scaffolds and then left unpruned had similar cumulative yields as untrained trees that were also unpruned for the duration of the trial.
- At average almond prices and labor costs during this trial, conventional training and annual pruning would have reduced cumulative net income by $7,500 - $14,000 per acre, including pruning, stacking & shredding costs plus lower cumulative yield.
- Although untrained & unpruned trees tended to have the highest yields, they were more prone to scaffold failure, especially in widely spaced trees.
- In this trial, “minimally” pruned trees often had the lowest yields. This was likely because when pruners were allowed only three cuts per tree, they tended to make larger saw cuts instead of smaller pruning shear cuts.
- Annual pruning did not improve light interception within the canopy as measured by a PAR meter (see Lampinen, et. al. annual reports). Annually pruned and unpruned trees both reached their maximum light interception during years 10–12 and both began declining beginning approximately the same year and at about the same rate.
- Unpruned trees were the same height as annually pruned trees after 23 years.
- The most economic and trouble-free strategy was to train the tree to be structurally strong during the first two years and then prune only if necessary, for safety or equipment access thereafter.

Table 1. The Effects of Training and Pruning on Cumulative Yield Through the 19th Leaf (final test harvest).

	Nonpareil		Carmel	
Training & Pruning Strategy	Cumulative Yield (lb / acre)	Difference from Standard Annual Pruning	Cumulative Yield (lb / acre)	Difference from Standard Annual Pruning
Trained to 3 scaffolds; Annual moderate pruning	41,326	--	38,851	--
Trained to 3 scaffolds; Unpruned after 2nd year	42,237	+ 911	41,732	+ 2881
Trained to multiple scaffolds; Three annual pruning cuts	39,739	- 1587	40,780	+ 1929
No scaffold selection; No annual pruning	42,278	+ 952	43,274	+ 4423

Tree Spacing

- Yields were exceptionally low for all planting densities, especially for the Carmel variety, in the final year of harvest for this trial (22nd leaf) and were not representative of previous years. Nonpareil yield for trees on Nemaguard were similar for all planting densities in 2021 (Table 2). Yield of Nonpareil on Hansen rootstock was lowest for the widest spacing (22' x 22') but statistically similar for the other tree spacings. 2021 yield for Carmel on Nemaguard was statistically lower for trees planted ten feet apart than 14 feet apart, but yield was statistically similar for trees planted 14', 18', or 22' apart. Yields were very low but similar for Carmel on Hansen rootstock in 2021, regardless of tree spacing.
- Cumulatively, yields are highest at the closest tree densities (10' & 14' spacing) regardless of variety or rootstock, with the exception of Nonpareil on Hansen rootstock which is highest at the 18' tree spacing. The largest yield impact of closer spacing (higher yields) is most obvious in the less vigorous Nemaguard rootstock, especially with the smaller Carmel variety.
- Cumulatively, Carmel trees on Nemaguard planted ten feet apart yielded 7,852 pounds per acre more than trees planted 22 feet apart over 22 years. There was a direct relationship between tree spacing and yield; the closer the trees were planted, the higher the cumulative yields.
- Tree spacing did not affect tree height (tree height was similar at all tree spacings after 23 years) (Table 4).
- Closely planted trees have smaller canopies and trunks than widely spaced trees (Table 3, Figs 2-4). As a result, more densely planted trees are easier to harvest, resulting in less shaker injury and fewer mummies per acre than widely spaced trees. Large, widely spaced trees have also suffered more scaffold breakage and tree blowover, leading to substantially more replants in widely spaced trees than closely spaced trees (Fig 1). In the first 20 years of the 37-acre trial, a total of 42 trees in the 10' x 22' spaced sections needed to be replaced compared to 175 trees in the 22' x 22' spaced areas. This represents a loss of 9,240 ft^2 of canopy in the closely spaced trees vs. 84,700 ft^2 in the most widely spaced trees.
- Canopy light interception peaked in the 11th leaf and was higher in the more closely spaced trees (10') and declined at the same rate as moderately spaced trees (14'-18'). PAR declined earlier and faster in the most widely spaced trees (Fig. 5). The reason for this was likely related to more shaker injury, more scaffold failure and more trees falling over in the larger, widely spaced trees. This may indicate that higher density orchards may be productive longer than low density orchards, even without dwarfing rootstocks, a hypothesis counter to previous assumptions.
- These data indicate that a yield advantage from tightly spaced trees is highly dependent on inherent tree vigor. Lower vigor trees (small varieties, less vigorous rootstocks, poor soil) will benefit most from tight spacing. However, even though vigorous trees may not have a substantial yield increase if planted at high density, the risk of yield loss due to overly close planting may be overstated.
- There are advantages to tighter spacing other than yield. Trees planted closer together are smaller. This results in less need for training & pruning, less tree structural failure, easier harvest, less trunk injury, fewer mummies, and perhaps a longer lasting orchard.

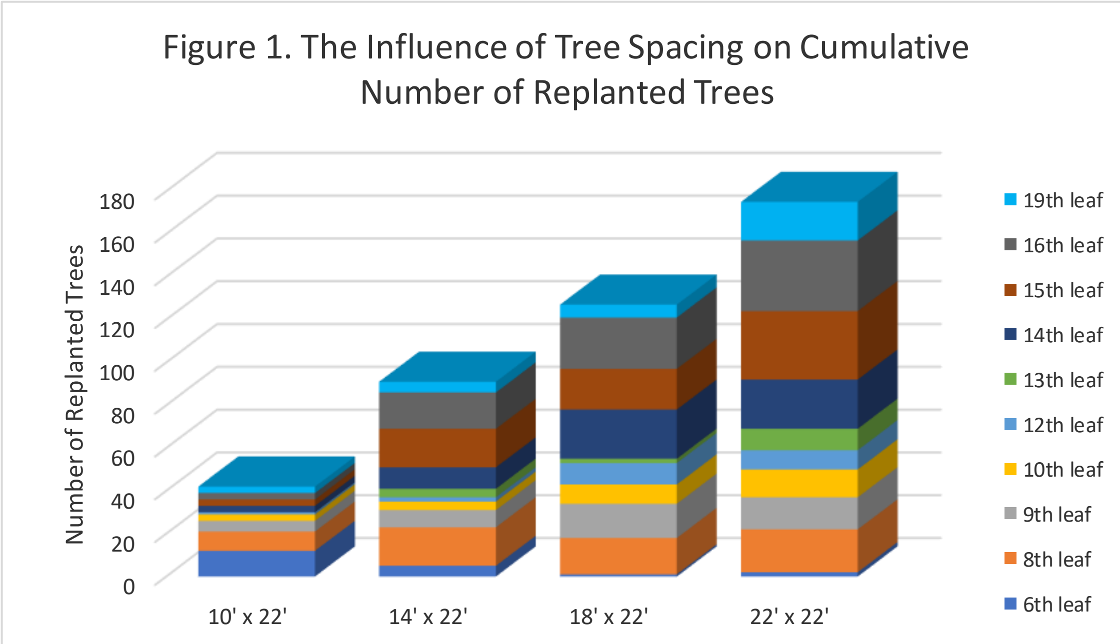

Fig. 1. Closely planted trees are smaller and have significantly fewer replants than widely spaced trees due to less scaffold failure, blow over, and shaker injury.

Table 2. The Effects of In-row Tree Spacing & Rootstock on 2021 (22nd leaf) and Cumulative Yield.				
	Nonpareil			
	Nemaguard		Hansen	
	2021 yield (lb / a)	Cumulative	2021 yield (lb / a)	Cumulative
Tree Spacing				
10' x 22'	1193 a[1]	47,840	1668 ab	49,380
14' x 22'	1342 a	47,775	1345 ab	49,535
18' x 22'	962 a	45,541	1839 a	53,097
22' x 22'	1052 a	42,893	1195 b	48,210
Nonpareil x rootstock	1137 a	46,012	1512 a	46,160
	Carmel			
10' x 22'	699 b	51,953	774 a	41,399
14' x 22'	1104 a	48,840	818 a	41,881
18' x 22'	1069 ab	47,315	798 a	40,686
22' x 22'	862 ab	44,101	630 a	38,661
Carmel x rootstock	934 a	48,052	755 b	40,657

[1]Data followed by the same letter are not significantly different (P< 0.05, DMRT).

Fig. 2. The Influence of Tree Spacing on Tree Size of Third-Leaf Almond Trees

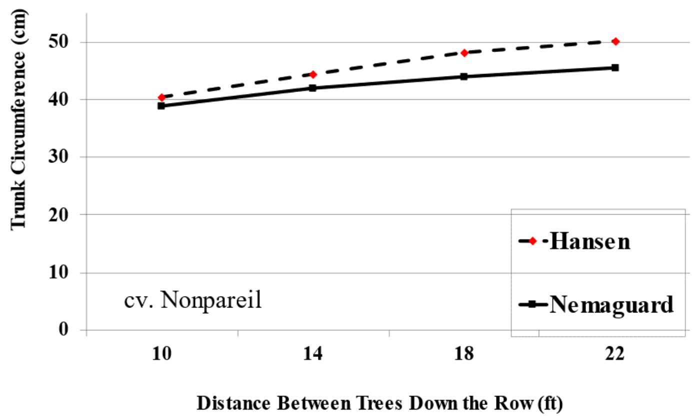

Fig. 3. The Influence of Tree Spacing on Tree Size of Sixth-Leaf Almond Trees

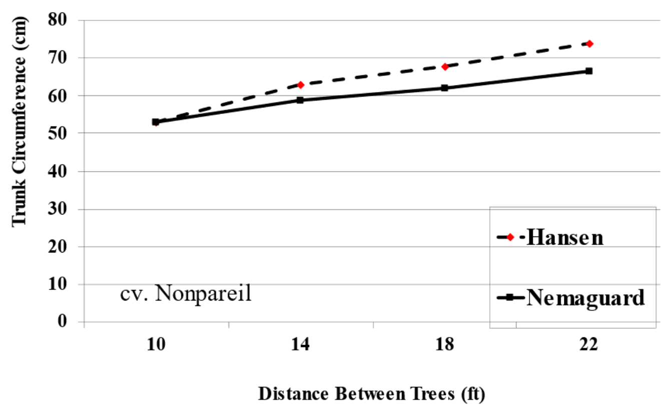

Fig. 4. The Influence of Tree Spacing on Tree Size of 20th -Leaf Almond Trees

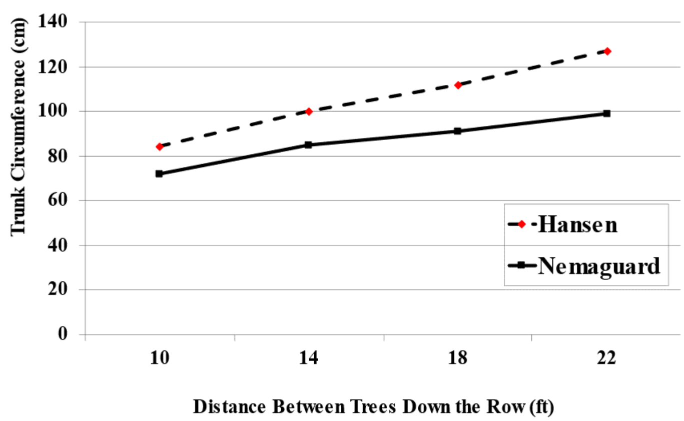

Table 3. Trunk Circumference of Nonpareil, Carmel, and Sonora Almond Trees as Related to Tree Spacing, Pruning, and Rootstock. 2022 (23rd Leaf).			
	Trunk Circumference (cm)		
Spacing	Nonpareil	Carmel	Sonora
10' x 22'	79 c[1]	72 c	92 c
14' x 22'	91 b	81 b	103 b
18' x 22'	102 a	91 a	115 a
22' x 22'	108 a	96 a	120 a
Pruning			
Trained to 3 scaffolds; Annual moderate pruning	86 a	86 a	109 a
Trained to 3 scaffolds; Unpruned after 2nd year	84 a	84 a	107 a
Trained to multiple scaffolds; Three annual pruning cuts	87 a	87 a	108 a
No scaffold selection; No annual pruning	84 a	84 a	109 a
Rootstock			
Nemaguard	86 c	88 a	108 a
Lovell	95 b	86 ab	109 a
Hansen 536	105 a	81 b	105 a

[1]Data followed by the same letter are not significantly different (P< 0.05, DMRT).

Table 4. Tree Height (feet) of Nonpareil and Carmel Almond Trees as Related to Tree Spacing and Pruning. 2022 (23rd Leaf)			
Spacing	Nonpareil	Carmel	
		Nemaguard	Hansen
10' x 22'	25.4 a[1]	22.6 a	21.8 a
14' x 22'	26.7 a	23.6 a	22.2 a
18' x 22'	26.4 a	23.4 a	23.2 a
22' x 22'	25.3 a	22.8 a	23.2 a
Pruning			
Trained to 3 scaffolds; Annual moderate pruning	26.4 a	23.0 a	22.6 a
Trained to 3 scaffolds; Unpruned after 2nd year	26.1 a	23.2 a	23.1 a
Trained to multiple scaffolds; Three annual pruning cuts	25.7 a	23.1 a	22.7 a
No scaffold selection; No annual pruning	25.5 a	22.9 a	22.6 a

[1]Data followed by the same letter are not significantly different (P< 0.05, DMRT).

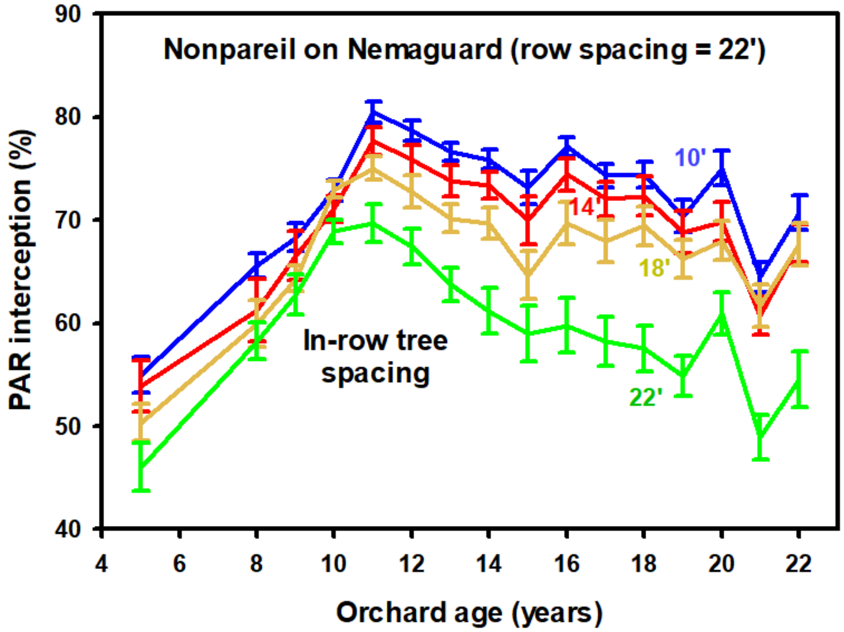

Fig 5. Tree canopy size dynamics, measured as percent photosynthetically active radiation (PAR), from 5th leaf through 22nd leaf for Nonpareil trees on Nemaguard rootstock spaced 10, 14, 18, or 22 feet apart down the row. Percent canopy is positively related to yield potential (higher PAR is associated with higher yield potential). PAR increased more quickly early in the life of the orchard, reached a higher maximum value, and declined more slowly over the second half of the orchard's life in the more closely spaced trees. These data indicate that orchards with more closely spaced trees down the row may reach a higher maximum yield potential earlier in the life of an orchard and maintain a higher yield potential throughout the life of the orchard.

Fig 6. Twentieth-leaf Carmel and Nonpareil almond trees planted at 10' x 22' (left) and 22' x 22' (right). Trees planted closer together down the row have stayed smaller and have required less canopy management than more widely spaced trees. Widely spaced trees are larger (wider canopy, and larger trunks, similar height), are more difficult to shake, have more mummies after harvest, have accumulated more shaker damage through the life of the trial, have four times more missing trees from tree structural failure and trunk canker, may require more corrective pruning including more hedging to dry the nuts faster at harvest, and have lower cumulative yields.

D. Outreach Activities

Information from this trial has been disseminated at multiple events through the years, including three on-site public field days, numerous articles in trade magazines, the UC Almond Production Shortcourses, an Almond Board of California webinar, several Almond Industry Annual Conferences, media tradeshows, numerous North San Joaquin Valley Almond Days (including 2022) and other UCCE county extension events and the UCCE Stanislaus Newsletter, *The Scoop on Fruits & Nuts*.

E. Materials and Methods

In the fall of 1999, a commercial almond orchard with cultivars ‘Nonpareil’, ‘Carmel’, and ‘Sonora’ was planted on virgin soil on the east side of Stanislaus County. The 37–acre field experiment was arranged in a multi-factorial design with four replications of each treatment for a total of 384 plots. Trees on Nemaguard or Hansen 536 rootstocks were planted at four different in-row spacings: 22 feet, 18 feet, 14 feet or 10 feet down the row. A between-row spacing of 22’ was maintained constant throughout the trial. Beginning at the first dormant period, four training and pruning strategies have been employed in this trial (Fig 7). They are:

- <u>“Standard” training; “standard” annual pruning</u>. Three permanent scaffold limbs were selected during the first dormant pruning. These trees have been “moderately” pruned annually to keep centers open and eliminate crossing branches.
- <u>Minimal training & pruning</u>. Trees were topped twice during the first growing season to stimulate secondary branching. At the first dormant pruning, five to six permanent scaffolds were selected to maintain a full canopy with a minimally open center. These trees are pruned annually by removing a maximum of three limbs on each tree.
- <u>“Standard” training and pruning for the first two years, then no pruning.</u> These trees were pruned the same as in Treatment 1 above for the first two years. Other than occasionally removing branches interfering with farming practices, these trees have not been pruned in fifteen years
- <u>Untrained, Unpruned</u>. No scaffold selection was made during the initial training of these trees except to remove limbs originating too low on the trunk for equipment access. These trees are not pruned except to remove limbs that become problematic for cultural operations and operator safety.

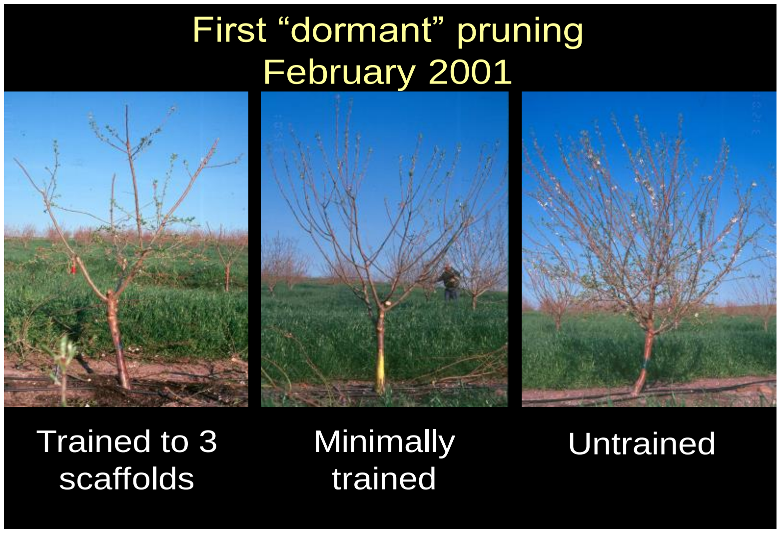

Fig 7. Test trees were initially trained to one of three strategies; conventionally trained to three standard scaffolds (left), minimally trained to 4-6 scaffolds (center), or left untrained (no scaffold selection) except to remove branches originating too low on the trunk to accommodate harvest (right). In successive years, trees initially trained to three scaffolds were either conventionally pruned annually by removing vigorous shoots on the interior of the canopy or they were left unpruned for the next 19 years. Minimally trained trees were “minimally” pruned every year, with no more than three pruning cuts per tree. Untrained trees (whether initially trained or not) were left unpruned for the 19-year duration of the trial.

The same professional pruning contractor was hired to prune this trial throughout most of the life of this experiment. Yields were calculated by harvesting nuts with a commercial pick-up machine as conventionally done and elevating them into conveyer carts with load cells built-in to the axels and tongue. Subsamples were collected from each plot and analyzed for kernel size and quality. Trees were inspected periodically throughout the growing seasons for other treatment effects such as shaker injury, disease incidence, mummies, missing trees, etc.

In 2019, the pruning portion of the field trial was terminated after 19 years. Yield in the tree spacing treatments was monitored through 2021. Other parameters of tree performance were monitored in 2022, including trunk circumference and tree height.