PFR SPTS No. 24268

National tree crop intensification in horticulture update of Plant and Food Research almond studies – July 2023

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July 2023

1 Project overview

Over the past 50+ years, the prospect of improved economic returns through increased yields and reduced input costs has driven trends to intensify production in a range of horticultural crops, from vegetables and floriculture to perennial tree crops. These trends have not gone unnoticed in the global almond industry, with high density plantings being trialled in commercial and research settings in the major almond-producing countries (the USA, Australia and Spain).

The Plant & Food Research team in Australia is carrying out a number of trials aimed to improve our understanding of the physiological and genetic factors determining orchard light environment, precocity, vigour management, tree architecture, and the development of systems to manage these components in a high-density setting. Results from these research trials will provide Australian almond growers with a better understanding of the performance of intensive almond production systems in Australia.

2 Research trials

2.1 Pruning responses trial, ACE Experimental Orchard, Loxton SA

To identify almond varieties, rootstocks and management strategies better suited to closer plantings and to better understand how tree management/pruning affects the orchard light environment and crop maturation, this trial looked at various young tree management systems with five cultivars (‘Nonpareil’, ‘Maxima’, ‘Carina’, ‘Vela’ and ‘Buralmondtwo’ (BA2; marketed as Shasta®)) budded onto ‘Garnem’ rootstock and planted in July 2018 at 4.5 x 3 m spacing (741 trees/ha).

Starting in the nursery, trees were selected to have a single dominant trunk with multiple side branches, then grown in the field with different training/pruning methods to produce the desired narrow tree shape. An additional “low cost” option included planting trees that were dormant budded in May

2018, planted in July 2018 with a “sleeping eye” bud, then trained during spring and summer to produce the final tree.

‘Garnem’ rootstocks are well known as a vigorous rootstock, so it has been a challenge to manage these trees with minimal pruning within the allocated space in 4.5-m wide rows and without suitable machinery for narrow rows.

The trial has delivered pruning recommendations for growers to maintain high productivity in higher density orchards, together with information on early tree establishment from the nursery to the orchard. The information has been summarized in these publications:

Almond-planting-and-early-tree-establishment-In-the-nursery-Part-1.pdf (australianalmonds.com.au)
Almond-planting-and-early-tree-establishment-In-the-orchard-Part-2.pdf (australianalmonds.com.au)
Almond-planting-and-early-tree-establishment-Establishment-of-canopy-Part-3.pdf (australianalmonds.com.au)

Within each variety and across the four harvests, only minor yield differences were found between pruning methods, i.e. dormant-budded trees had a slight yield advantage over those in other treatments in 2021 (Table 1). Differences in yield between varieties were found over the four seasons. ‘Carina’ and ‘Vela’ showed increasing yield from 2020 to 2023, with ‘Vela’ yielding as high as 4.4 t/ha in this last 2023 season. Yield from ‘Maxima’ was low in 2022 but it almost doubled in 2023 (from 1.75 t/ha in 2022 to 3.32 t/ha in 2023). ‘Nonpareil’ produced very small crops in 2023, possibly owing to the bad weather during flowering. The self-fertile varieties did not seem to have been affected by the weather conditions as much as ‘Nonpareil’. However, Shasta, despite being self-fertile, did show a mild drop in yield in 2023 compared with that in 2022.

Table 1. Kernel yield per hectare of ‘Carina’, ’Maxima’, ‘Nonpareil’, Shasta® and 'Vela’ almond trees planted in July 2018 at 4.5 x 3 m spacing (741 trees/ha) at the Almond Centre of Excellence (ACE) in Loxton. Values in each column followed by the same letter are not significantly different (p<0.05).

	Yield (t/ha)			
Cultivar	2020 (2nd leaf)	2021 (3rd leaf)	2022 (4th leaf)	2023 (5th leaf)
‘Carina’	0.12	2.12 c	2.72 b	3.32 b
‘Maxima’	0.30	3.50 a	1.76 c	3.32 b
‘Nonpareil’	0	2.30 b	3.46 a	2.47 c
Shasta	0.24	1.61 d	2.34 b	2.10 c
‘Vela’	0	2.39 b	3.71 a	4.45 a

The general observations from this trial were as follows:

1. Unpruned (Control) trees and the narrow-pruned trees produced trunks with scaffold branches evenly spaced over a zone from 70 to 120 cm above the ground.
2. Small, late-budded trees had a more condensed zone of scaffold branches over a zone from 70 to 90 cm above the ground, as these trees were relatively small when planted.
3. Bare pole trees also produced scaffold branches evenly spaced over a zone from 70 to 120 cm above the ground, but these branches were more horizontal than those on the unpruned trees.
4. Dormant-budded trees grew well but practically all the scaffold branches developed from or in close proximity to the “sleeping eye” bud, which will be a point of weakness as the trees age.

2.2 Architectural studies trial, Almond Centre of Excellence (ACE) Experimental Orchard, Loxton SA

This trial aimed to identify cultivars that are inherently more amenable to intensive production systems, naturally forming the desired tall “slender pyramid” shaped trees.

The project comprised 15 genotypes, including the six new cultivars released from the University of Adelaide breeding programme. ‘Nonpareil’ was used as the control variety. Apart from removing lower branches, up to 60 cm on the trunk, the trees were left to grow over three seasons with no pruning, so that the natural growth and fruiting habit of each genotype could be observed.

Third- and fourth-leaf yields are presented in Table 2 below.

Table 2. Kernel yield in 2021 and 2022 of 15 genotypes of almond trees in the Architectural study at Almond Centre of Excellence (ACE) Experimental Orchard in Loxton. Trees were spring-budded onto ‘Garnem’ rootstock in 2017 and planted in 2018. Trees were planted with a central leader and then left without pruning. Values in each column followed by the same lower-case letters, are not significantly different ($p<0.05$).

Genotype	Kernel weight[1] (kg/tree)		Kernel weight (t/ha; 741 trees/ha)	
	2021 (3rd leaf)	2022 (4th leaf)	2021 (3rd leaf)	2022 (4th leaf)
‘Rhea’	2.41 def	4.06 a	1.78	3.01
R30a T25	3.48 bcd	3.62 ab	2.58	2.68
R8b T58	5.65 a	3.57 ab	4.19	2.65
R19a T166	1.76 ef	3.11 bc	1.31	2.30
‘Carina’	2.27 def	2.97 bc	1.68	2.20
‘Nonpareil’	3.11 bcde	2.94 bc	2.30	2.18
R52 T204	4.39 ab	2.85 bc	3.25	2.11
‘Mira’	4.14 abc	2.73 c	3.06	2.02
‘Vela’	2.84 bcdef	2.69 c	2.10	2.00
R36 T212	2.66 cdef	2.32 cd	1.97	1.72
R20a T101	1.93 def	1.90 de	1.43	1.41
‘Capella’	3.31 bcde	1.37 ef	2.45	1.01
‘Maxima’	5.36 a	0.79 fg	3.97	0.59
R52 T202	1.45 f	0.58 g	1.07	0.43
R36 T195	4.33 ab	0.33 g	3.21	0.25
p-value	*<0.001*	*<0.001*		

In 2022, the most productive genotypes were ‘Rhea’, R30a T25 and R8b T58, each of which produced more than 2.6 t/ha on fourth-leaf trees. While ‘Rhea’ and R30a T25 had only modest crops in 2021, with 1.34 and 1.94 t/ha (respectively), the R8b T58 genotype was also one of the highest yielding genotypes in 2021, with 3.14 t/ha. Tree shape with this genotype is very flat with strong, horizontal scaffold branches that easily support high crop loads. While highly productive, it is unlikely to be suitable for high-density plantings systems unless trained as an espalier.

The most promising genotype in this study was R36 T212, which naturally produced a narrow tree shape with relatively few, upright scaffold branches, each with a mix of spurs and short to medium shoots. Although the trees produced moderate crops of 1.72 t/ha on fourth-leaf trees, they had a relatively small footprint, which means that yield per ha could be increased by planting trees at 2-m spacing and thus increasing the number of trees per ha. Trees of this genotype have been propagated for planting in a new high-density, intensively managed “fruiting wall” type growing system at ACE in Loxton.

R36 T195 also has the desired narrow, upright tree shape and was one of the most productive genotypes in 2021, producing 2.41 t/ha. However, yields in 2022 were among the lowest with just 0.25t/ha. A similar, surprising drop in productivity was found with 'Maxima', which produced 2.98 t/ha in 2021 but just 0.59 t/ha in 2022.

One of the key messages from these results is that genotypes need to be appraised over more than three seasons to be confident of their productive potential.

The data collected have been used to identify a genotype that naturally forms and maintains a strong central leader growth habit (deemed essential to form a tall "slender pyramid" shaped tree). This trial will be used to collect casual observations on genotype growth habits and to showcase field performance of different genotypes when grown in similar conditions, as a demonstration site for the industry.

2.3 High density planting, ACE Experimental Orchard, Loxton SA

This trial has been designed to test growing systems with different tree planting densities. The approach has been to take a fresh look at almond orchard design and i) increase the planting density by reducing the row and tree spacing; ii) plant new cultivars with architectural attributes that are more suited to closer planting; and iii) adopt new pruning/training systems. The combination of the three resulted in a 1.6-ha block, established in July 2018 with the new self-fertile cultivars BA2 (Shasta®) and 'Vela' on 'Nemaguard' rootstock. These two varieties were chosen based on their different growth habits: Shasta has an upright, narrow growth habit and 'Vela' a spreading and weeping growth. Four planting densities are compared: 513 (6.5 x 3 m), 769 (6.5 x 2 m), 741 (4.5 x 3 m) and 1,111 trees per ha (4.5 x 2 m). Trees are grown as tall, narrow "slender pyramid" shaped trees with minimal pruning to maintain a 2.0-m wide gap between the rows for machinery access (Figure 1). Pushing densities to as high as 1,111 trees/ha in a large-scale experimental planting is intended to demonstrate and assess the limits of intensification and the challenges associated with canopy management, rootstock/scion combinations, machinery access and resource requirements.

Figure 1. High-density almond planting trial at the Almond Centre of Excellence (ACE) Experimental Orchard in Loxton with 4.5 m wide rows, showing Shasta® on the left and 'Vela' on right. Images were taken during summer in February 2022. Trees were planted in winter 2018.

The images below were taken in February 2023 and show the Shasta and 'Vela' trees at their maximum of canopy width for the season in both the 6.5-m rows (left) and 4.5-m rows (right) (Figure 2).

Figure 2. High-density almond planting trial at the Almond Centre of Excellence (ACE) Experimental Orchard in Loxton, with 6.5 (left) and 4.5 (right) m wide rows. Both figures show Shasta® on the left and 'Vela' on right. Images were taken during summer in February 2023. Trees were planted in winter 2018.

Yield results (Figure 3) so far show that Shasta produced a small crop already in 2020 (planted in 2018). For this variety, when grown in 4.5-m rows, there was an increase in yield over those in 6-m rows from 2022 onwards. The 2023 yield results took the cumulative yield of Shasta to values as high as 7.9 t/ha for the 4.5-m rows and 5.2 t/ha for the 6.5-m rows.

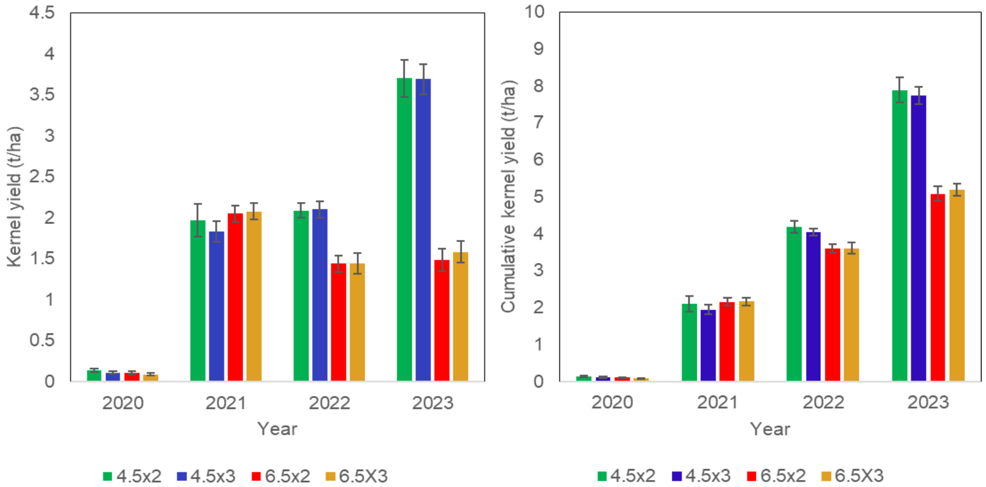

Figure 3. Yearly yield (left) and cumulative yield (right) of Shasta® almond trees planted at the Almond Centre of Excellence (ACE) orchard in Loxton, Australia, at four densities: inter-row spacings of 4.5 and 6.5 m and within-row tree spacings of 2 and 3 m. Trees were planted in winter 2018. Error bars represent the standard errors of the means.

Unlike Shasta, 'Vela' did not produce a yield in 2020. Only in 2022 did yield differ between planting densities, when the 6.5 x 3-m spacing produced a lower yield. The average cumulative yield of 'Vela' in 2023 (8.7 t/ha) was higher than that of Shasta (6.5 t/ha) (Figure 4); however, there were no yield differences between planting densities.

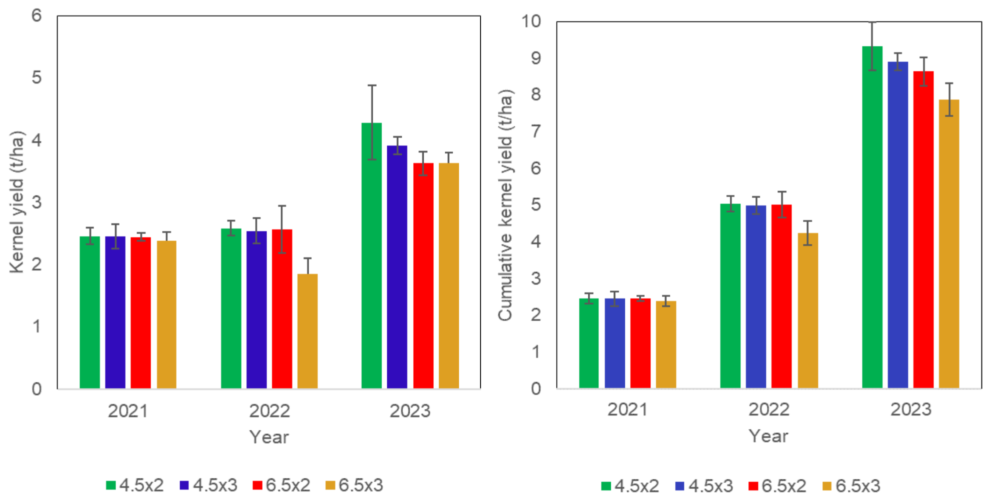

Figure 4. Yearly yield (left) and cumulative yield (right) of 'Vela' almond trees planted at the Almond Centre of Excellence (ACE) orchard in Loxton, Australia, at four densities: inter-row spacings of 4.5 and 6.5 m and within-row tree spacings of 2 and 3 m. Trees were planted in winter 2018. Error bars represent the standard errors of the means.

Although higher yields were expected from the higher-density treatments, there was no difference in the yield per ha among the four spacings in 2021 for either variety. Since the irrigation design was based on the amount of water applied per ha (ML/ha) rather than per tree (kL/tree), trees in the 6.5-m wide rows received more water and hence more fertiliser than trees in the 4.5-m rows. It was probably this difference that negated the benefit of having more trees per ha in the 4.5-m rows. To test this hypothesis, irrigation was adjusted from the 2021/22 season so that each tree received approximately the same amount of water. With the new irrigation design, yields showed a positive trend with irrigation rates per tree. Results so far indicate that irrigation rates per tree are more important than rates per ha in terms of orchard yield for these young, high-density blocks where trees are not crowded and thus not light limited.

2.4 Ultra-high-density, ACE Experimental Orchard, Loxton SA

Knowledge, data and observations gathered with the trials described above, together with industry and collaborator consultations, have resulted in Plant & Food Research conceptualizing and planting an ultra-high-density trial in Loxton at the Almond Centre of Excellence.

This trial combines two genotypes characterized by architectural features considered to be better suited to high-density growing systems, high productivity and precocity (a key element for Australian conditions) with vigour-controlling rootstocks. UA102 (R36T212), an unreleased University of Adelaide genotype, exhibits fruiting on 'axillary' or 'lateral' buds on long lengths of one-year-old wood, as well as on short shoots arising from 2- and 3-year-old wood. This results in an open canopy with a 'columnar' type branch habit, which suggests it may suit a planar canopy system (Figure 5).

Figure 5. The natural architecture of UA102 (open canopy with a 'columnar' type branch habit, left) and 'Carina' (spreading and weeping growth, right) almond trees suggests they may suit either a narrow "slender pyramid" shaped tree or a planar canopy system.

Planted in August 2022 with the cultivars 'Carina' on Controller™ 6 rootstock and UA102 (R36T212) on 'Nemaguard', this trial compares two growing systems, each at two densities:

i. tall, narrow "slender pyramid" shaped trees with minimal pruning at densities of 1,111 (4.5 m x 2 m) and 1,428 (3.5 m x 2 m) trees/ha

ii. an informal "planar cordon" type-tree at densities of 740 (4.5 m x 3 m) and 952 (3.5 m x 3 m) trees/ha.

Figure 6 (*right*) describes the trial design for the variety ‘Carina’. The design for the ‘UA102’ trial is identical; however, the two cultivars were planted in two separate blocks (instead of interspersed) owing to the age of the young trees, and hence differences in irrigation requirements. The trial occupies eight rows: rows 1–4 are planted at a distance of 3.5 m and rows 5–8 at 4.5 m. Row 1 and row 8 are used as border rows and all trees are trained as tall, single-trunk trees. The top three trees are used as border trees; from tree 4, the training system changes every block of 5 trees, starting with “slender pyramid” shaped trees planted 2 m apart and alternating with the informal planar system with trees 3 m apart. The trees represented in pink correspond to the data-collection trees. The red circles indicate the location of each soil moisture probe and the fixed camera that takes daily images of each tree.

This trial has been planned with a focus on mechanization of orchard operations. A condition for mechanized harvest, for example, with “shake and catch”-type machines is to have a trunk height above 80–90 cm. The ‘Carina’ trees were all already at least 3 m tall at the time of planting, so that soon after planting the trunks were cleared up to 1 m height. This was also the height where the future “planar trees” were topped (Figure 7). The topping of the planar trees allowed for the selection of the two branches to train to become the future “cordons” of the planar system.

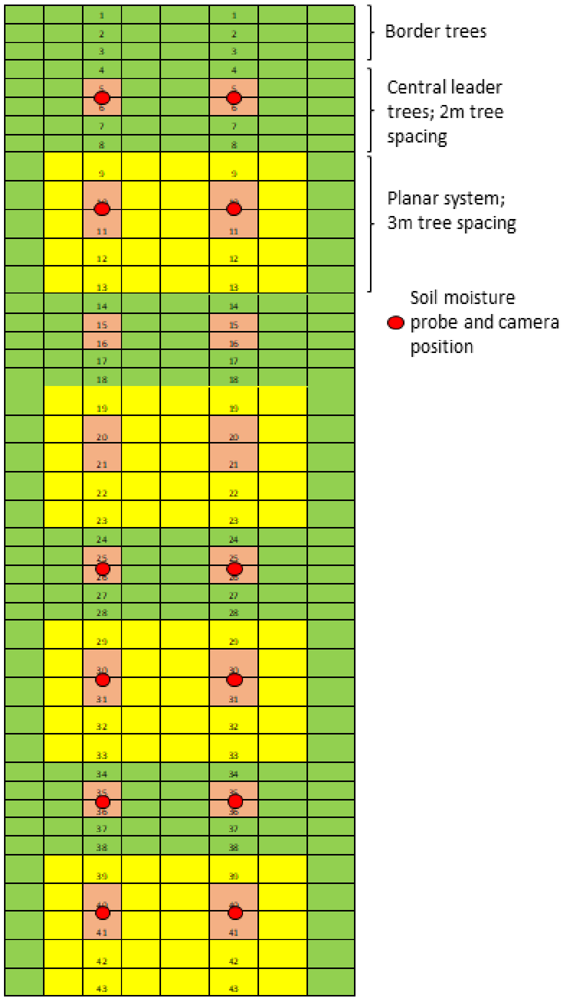

Figure 6. Trial design for the ‘Carina’ almond trees on Controller™ 6 planted in the new Plant & Food Research-designed high-density planting systems at the ACE Experimental Orchard, Loxton SA.

Figure 7. High-density planting of ‘Carina’ almond on Controller™ 6 rootstock at the Almond Centre of Excellence (ACE) orchard in Loxton, Australia. Left: tall, narrow “slender pyramid” shaped tree with minimal pruning with the trunk cleared up to 1 m. Right: informal “planar cordon” tree with the trunk topped at 1 m height. Images were taken during summer, in February 2023. Trees were planted in winter 2022.

The next step in the training process was to determine a suitable method to ensure the desired position, angle and growth of the two "cordons" of the planar system without relying on a trellised structure with posts and wires. The use of bamboo stakes and twine was trialled, as shown in Figure 8. This system has so far ensured the growth of the cordons at the desired angle; this has been obtained by wrapping the twine loosely around the shoots. The shoots have lignified and, for most trees, in January 2023, they had grown to almost the full length required to fill the space between two trees (Figure 8).

Figure 8. High-density planting of 'Carina' almond on Controller™ 6 rootstock at the Almond Centre of Excellence (ACE) orchard in Loxton, Australia. Left: informal "planar cordon" tree with the trunk topped at 1 m height, showing the use of bamboo stakes and twine to ensure the growth of the cordons at the desired angle. Middle: the "cordons" were selected and wrapped loosely around the twine. Right: image taken in February 2023 showing lignified shoots that have grown to almost the full length required to fill the space between two trees.

3 Regional trials

Plant & Food Research has established a national network of demonstration trial sites (starting in 2014) aimed at providing local almond producers with opportunities to observe the research directions and outcomes under local conditions, to support the early adoption of new systems.

3.1 Regional trial 1, Victoria. *Lindsay Point, CMV Farms*

Trees at the CMV Farms orchard near Lindsay Point were dormant-budded in March 2015 and grown in the nursery before being field planted in July 2016 at 6.85 x 3 m spacing (487 trees per ha).

The scion varieties were 'Nonpareil', 'Monterey' and 'Price' budded on 'Nemaguard', Bright's Hybrid®, 'Cornerstone' and 'Garnem' rootstocks. Two pruning/training treatments were initially compared:

1. Control: Traditional tree management regime adopted by nurseries/orchards, with a single heading cut applied at 90 cm just before planting, to produce trees with multiple strong scaffold branches from low down on the tree.
2. Central Leader – Narrow Pruned: Trees selected in the nursery to have a single dominant trunk with multiple side branches which were left unpruned in Year 1. Trees were then narrow pruned in Year 2 to remove any strong branches growing out towards the centre of the rows and impeding machinery access.

No yield differences were found, in any year, in response to the original pruning/training system.

The 2023 harvest marked the final season of the trial and the results from this final year are presented below.

Average yields across all rootstocks were 3.9, 2.5 and 1.2 t/ha for 'Monterey', 'Nonpareil' and 'Price', respectively, compared with 4.4, 3.6 and 3.0 t/ha for the same cultivars in 2022. A generally lower yield was harvested in 2023, with 'Price', followed by 'Nonpareil', showing the lowest kernel yields.

Rootstock had no effect on yield for 'Monterey' or 'Nonpareil'; however, 'Price' on 'Cornerstone' rootstock achieved a greater yield than on other rootstocks (Figure 9).

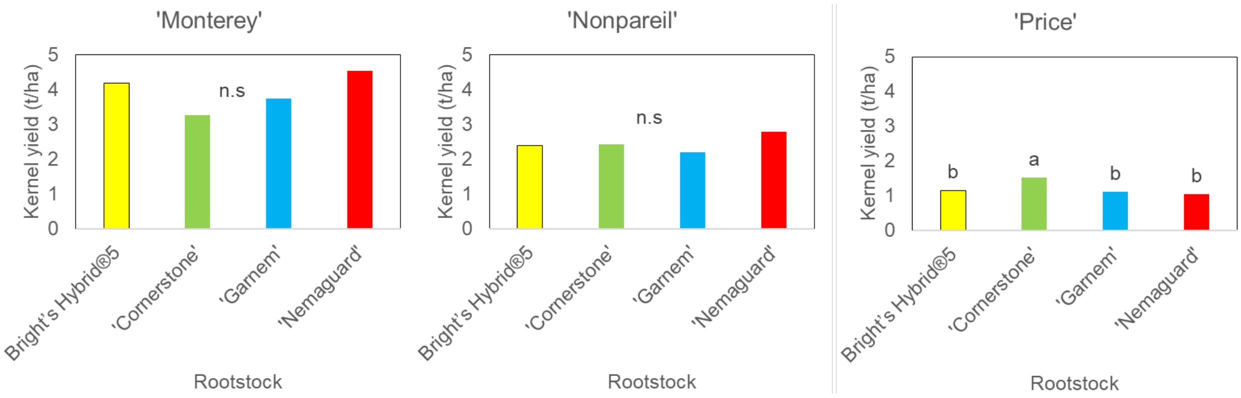

Figure 9. Effect of rootstock on kernel yield of 'Monterey', 'Nonpareil' and 'Price' almonds at CMV Farms, Lindsay Point in 2023. Trees were planted in July 2016 at 6.85 x 3 m spacing (487 trees per ha). Values are treatment averages (n = 8 trees). Bars with different letters were significantly different (p<0.05). n.s.= not significant.

For more information visit the link: Vol 20.3 Spring 2020 (cld.bz)

3.2 Regional trial 2, Victoria. Robinvale, Select Harvests Ltd

Trees were planted in 2018 at 4.5 x 2 m spacing (741 trees/ha). The trial examined the performance of four cultivars; 'Carina', 'Nonpareil', 'Vela' and Shasta budded onto 'HBOK 27' (Controller™ 6), 'HBOK 32' (Controller™ 7) and 'HBOK 50' (Controller™ 9.5) rootstocks. All trees had been dormant-budded in March 2017 and grown for a full season in the nursery before planting into the field in winter 2018 as unpruned central-leader trees.

Early yields from this block were impressive, with significant crops harvested from second-leaf trees in 2020 and a substantial increase recorded in 2021 (Table 3). In 2022, while some scion/rootstock combinations had substantially higher yields than in the previous year, there were examples of only small increases and even decreased yields for other combinations. Only 'Carina' showed an increase in yield across all rootstocks in 2023. No differences among rootstocks were measured in 2023 across all cultivars.

Table 3. Kernel yield per hectare of 'Carina', 'Nonpareil', Shasta® and 'Vela' almond trees budded onto Controller™ 6, Controller™ 7 and Controller™ 9.5 rootstocks at Carina Farm in 2020, 2021, 2022 and 2023. Trees were budded in March 2017 and planted in August 2018 at 2 m x 4.5 m spacing (1,111 trees per ha). Significance: NS = not significant; ** = $p<0.01$, *** = $p<0.001$. Values within cultivar in each column with the same letters are not significantly different ($p<0.05$).

Cultivar	Rootstock	Kernel weight (t/ha)			
		2020 (2nd leaf)	2021 (3rd leaf)	2022 (4th leaf)	2023 (5th leaf)
'Carina'	Controller™ 6	0.61 b	2.71 b	1.83 b	3.32
	Controller™ 7	0.75 ab	1.52 c	2.48 ab	2.89
	Controller™ 9.5	0.96 a	3.49 a	2.81 a	3.06
	Significance	**	***	**	*NS*
	p-value	*0.001*	*<0.001*	0.007	0.25
'Nonpareil'	Controller™ 6	0.63	2.41 b	3.12 a	2.74
	Controller™ 7	0.39	2.01 b	2.42 b	2.40
	Controller™ 9.5	0.62	3.30 a	3.23 a	2.66
	Significance	*NS*	***	**	*NS*
	p-value	*0.927*	*<0.001*	0.007	0.38
'Vela'	Controller™ 6	0.86	3.33	No data	3.85
	Controller™ 7	0.73	3.60	No data	3.37
	Controller™ 9.5	1.07	3.81	6.00	3.05
	Significance	*NS*	*NS*		*NS*
	p-value	*0.217*	0.208		0.17
Shasta®	Controller™ 6	1.55	2.96	2.84	2.39

For more information: Thorp G, Smith A, Coates M and De Bei, R. 2023. Are almond rootstocks making a difference? In a Nutshell, Summer 23 (4): 38-39. [In a Nutshell IAN Summer 2022 FINAL (joomag.com)]

3.3 Regional trial 3, NSW. Darlington Point, OLAM Kerarbury Farm

Trees at Kerarbury Farm near Darlington Point in NSW were planted in 2017 at 7 x 3 m spacing (476 trees/ha). The trial in 2023 involved two early ripening cultivars (Shasta and 'Nonpareil') and three pruning treatments (1 = unpruned control, 2 = narrow-pruned in July 2018, and 3 = narrow-pruned in July 2018 and July 2019). No yield differences were found in response to the original pruning/training system (Table 4). The 2023 harvest concluded this trial.

Table 4. Kernel yield per hectare in 2020, 2021, 2022 and 2023 from Shasta® and 'Nonpareil' almond trees at Kerarbury Farm. Trees were budded in January 2017 on 'Cornerstone' rootstock and planted in 2017. Trees were planted at 7 x 3 m spacing (476 trees/ha). Values are treatment averages (n = 6–10 trees). Significance: NS = not significant; * = $p<0.05$; ** $p<0.01$. Values within cultivar in each column with the same letters are not significantly different ($p<0.05$).

Cultivar	Pruning treatment	Kernel weight (t/ha) 7 x 3 m (476 trees/ha)			
		2020 (3rd leaf)	2021 (4th leaf)	2022 (5th leaf)	2023 (6th leaf)
Shasta®	Control – no pruning	0.74	1.17	1.39	1.61
	Narrow prune x1	0.94	1.12	1.34	2.02
	Narrow prune x2	0.77	1.01	1.33	2.05
	Significance	*NS*	*NS*	*NS*	*NS*
	p-value	*0.615*	*0.741*	*0.958*	*0.37*
'Nonpareil'	Control – no pruning	0.59	1.17	1.70	1.82
	Narrow prune x1	0.52	1.05	1.48	1.83
	Narrow prune x2	0.48	0.89	1.46	1.71
	Significance	*NS*	*NS*	*NS*	*NS*
	p-value	*0.632*	*0.418*	*0.752*	*0.81*

4 Acknowledgements

This research is funded by the Hort Frontiers Advanced Production Systems Fund, part of the Hort Frontiers strategic partnership initiative developed by Hort Innovation in Australia, with co-investment from The New Zealand Institute for Plant and Food Research Ltd, the South Australian Government and contributions from the Almond research and development levy.

Informal update for:

HIA
Client Project #:AS18000

PUBLICATION DATA

De Bei R, Thorp G, Stanley J, Breen K. July 2023. National tree crop intensification in horticulture update of Plant and Food Research almond studies – July 2023. A Plant & Food Research report prepared for: HIA. Milestone No. 98919. Contract No. 38257 var. Job code: P/415180/01. PFR SPTS No. 24268.

KEYWORDS: high-density planting, tree physiology, tree architecture, rootstock performance, pruning.

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