Final report

Project title:

Pathway to carbon neutral – whole orchard recycling in almond orchards

Project leader:

Professor Paul Petrie

Delivery partner:

South Australian Research and Development Institute

Report author/s:

Paul Petrie, Nigel Fleming and Kavitha Shanmugam

Project code:

AL21000

Disclaimer:

Horticulture Innovation Australia Limited (Hort Innovation) makes no representations and expressly disclaims all warranties (to the extent permitted by law) about the accuracy, completeness, or currency of information in this final report.

Users of this final report should take independent action to confirm any information in this final report before relying on that information in any way.

Reliance on any information provided by Hort Innovation is entirely at your own risk. Hort Innovation is not (to the extent permitted by law) responsible for, and will not be liable for, any loss, damage, claim, expense, cost (including legal costs) or other liability arising in any way (including from Hort Innovation or any other person's negligence or otherwise) from your use or non-use of the final report or from reliance on information contained in the final report or that Hort Innovation provides to you by any other means.

Funding statement:

Levy funds – R&D projects

This project has been funded by Hort Innovation, using the Almond research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN <Hort Innovation to add>

Published and distributed by: Horticulture Innovation Australia Limited
ABN 71 602100149

Level 7
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

Contents

SARDI AS21000 summary

Almond trees accumulate significant amounts of carbon (as trunks, branches and roots) during their lifecycle. When an orchard reaches the end of its commercial life, however, this resource is traditionally managed through burning as part of the orchard redevelopment. While burning rapidly clears debris from the site and can reduce the pathogen load, it also releases a significant amount of carbon. This carbon could potentially be sequestered or at least incorporated to improve soil organic matter, fertility and help with the establishment and productivity of the new orchard. The alternative to burning the trees prior to replanting is known as whole orchard recycling. This involves the pulverisation of the almond trees and incorporation into the soil before replanting. This project assessed the impact of whole orchard recycling on orchard establishment through to the end of the third growing season. The trial was established in a commercial orchard near Merbein in the Sunraysia region of Victoria. The existing orchard was removed and processed into chips using a horizontal grinder. Wood chips were broadcast onto the soil surface, then tree mounds drawn up, moving the bulk of the chip material into the tree row. As an alternative treatment an almond hull and shell based compost (compost) was applied to the soil and mounded in a similar manner. The control treatment was mounded, but without any organic amendments. Measures included tree growth (canopy height, light interception and trunk circumference), soil nutrition, soil water analysis, soil moisture, greenhouse gases, soil diseases and nut yield. Despite initial slow growth, trees in the orchard recycling treatment caught up to the other treatments by the second season. The amendments (recycled trees or compost) increased soil organic carbon by about 30% but had limited impact on the other soil physical parameters by the end of the three-year study. The trees in the whole orchard recycling treatment had reduced nitrate concentrations in soil water sampled from below the root zone. Initially the soil beneath the whole orchard recycling treatments released more carbon dioxide and nitrous oxide greenhouse gases, but there was no difference between treatments after the first year. There was no difference in yield between the treatments for the harvest in the third season, this was not unexpected as experience in California suggests it may take up to seven years before whole orchard recycling results in a productivity improvement. Use of whole orchard recycling under the management at Merbein resulted in good tree growth and light interception and no yield penalty compared to other treatments. There was no indication of adverse environmental effects, either through nitrate leaching or greenhouse gas emissions. Soil organic carbon levels were elevated by whole orchard recycling, but improvements in other soil parameters were not observed.

Keywords

Almonds, *Prunus dulcis*, compost, orchard recycling, soil carbon, irrigation, nitrous oxide

Introduction

Almond trees accumulate significant amounts of carbon (as trunks, branches and roots) during their lifecycle. When an orchard reaches the end of its commercial life, however, this resource is traditionally managed through burning as part of the orchard redevelopment. While burning rapidly clears debris from the site and can reduce the pathogen load, it also releases a significant amount of carbon. This carbon could potentially be sequestered or at least incorporated to improve soil organic matter, fertility and help with the establishment and productivity of the new orchard. The alternative to burning the trees prior to replanting is known as whole orchard recycling. This involves the pulverisation of the almond trees and incorporation into the orchard soil before replanting. In California whole orchard recycling has been adopted as a practice to meet clean air regulations and manage the disposal of biomass when the orchard is removed as well as reducing carbon emissions. Under North American conditions whole orchard recycling has been shown over the long term to enhance soil health, increase soil organic carbon (SOC), nitrogen, water retention, and overall fertility. Whole orchard recycling may also stimulate microbial activity, potentially increasing CO_2 and N_2O emissions. The long-term balance between carbon storage and emissions depends on soil type, climate, irrigation, and fertilizer use (Culumber *et al.* 2025).

The utility of whole orchard recycling has not been demonstrated under Australian conditions. This study aims to improve our understanding of how whole orchard recycling affects tree productivity, soil chemistry and carbon sequestration in a replanted almond orchard in Merbein, Victoria to determine its viability as a long-term conservation practice. The project aims to quantify the impact of whole orchard recycling on the establishment of an almond orchard, including the impact on carbon storage in the soil and soil greenhouse gas emissions. Information from this project will support growers to integrate whole orchard recycling into their redevelopment programs with clear expectations around orchard establishment, carbon farming, changes in soil health, irrigation use efficiency and productivity improvements. It will also support almond processors and sellers (the wider industry) to improve their sustainability credentials, with the potential for whole orchard recycling to underpin practices that will allow the production of carbon neutral almonds

Methodology

Broad methodology is described here, more detail is provided in Appendix 1.

Chipping and amendment

Trees from the previous orchard were pulled out, pushed into heaps and chipped into pieces to pass through a 75 mm screen (Figure 1). Wood chips were broadcast onto the soil surface, then tree mounds drawn up, moving the bulk of chip material into the tree row. The organic amendments (either wood chips or compost) were applied at the same rate as the removed orchard (around 60 t/ha).

Figure 1. Tree chipping with a) Tana Shark Waste Shredder, b) Morbark Wood Hog, and spreading with c) Penta Manure Spreader. Photos D. Jaensch, Almond Board of Australia.

Trial layout

The new orchard was laid out with rows of Non-pareil trees alternating with Shasta and Pyrenees pollinators. Six replicates of three treatments (18 plots) were applied to 9 Nonpareil rows. The three treatments were recycled wood chips (recycle), almond-based compost (compost) and control treatment with mounded tree rows but no amendment (control). Figure 2 shows the trial layout.

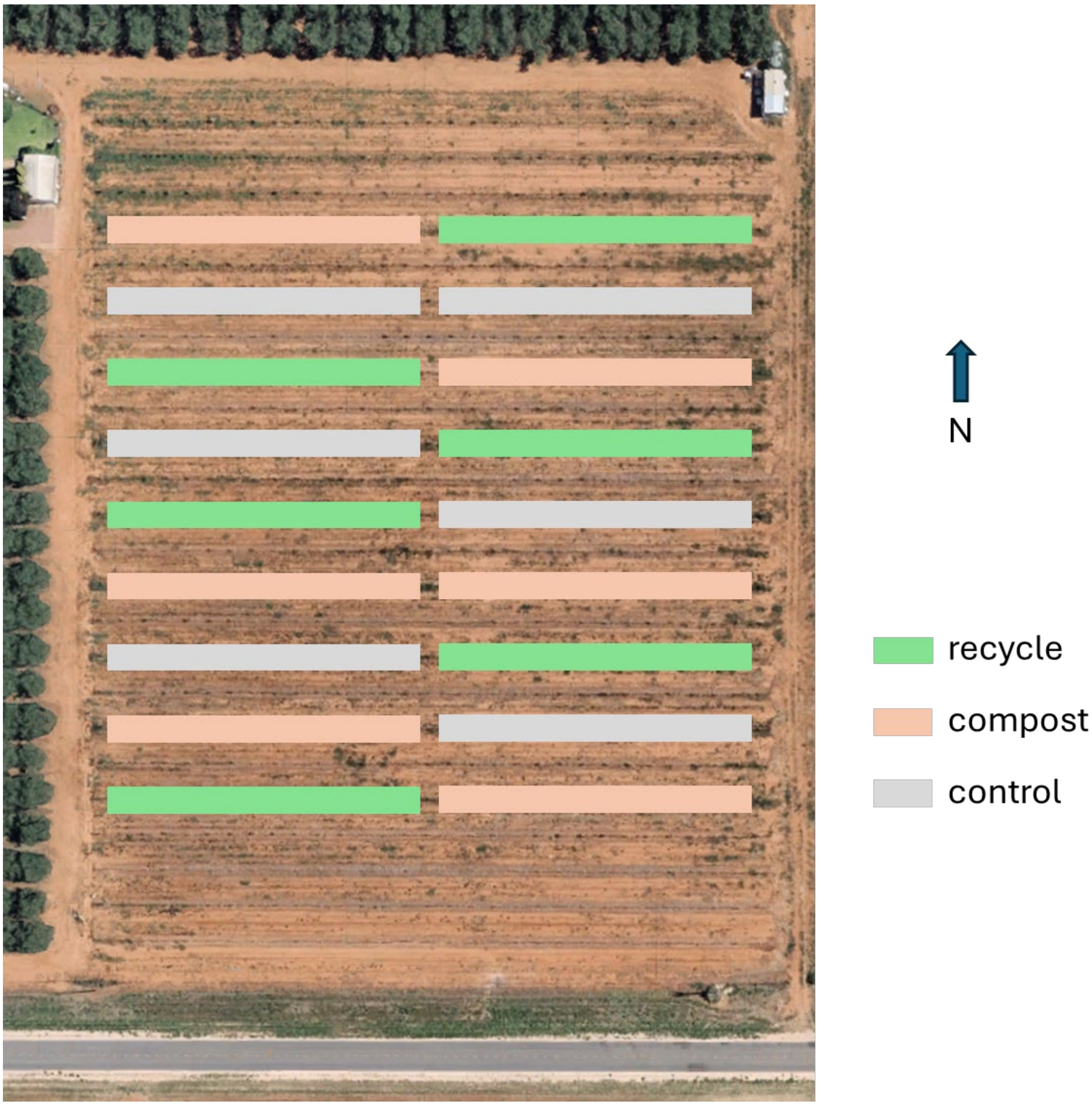

Figure 2. Layout of Merbein trial. Unmarked trees and rows are buffer areas.

Figure 3. Tree rows in a) October 2022, b) May 2023, c) January 2024 and d) March 2025 (harvest)

Irrigation, soil water and greenhouse gas monitoring

Trees were planted and irrigation applied in August 2022. A nest of soil water samplers (30 cm, 60 cm and 90 cm depths) was installed in the tree row at each of nine monitoring sites in November 2022. A capacitance soil moisture probe was also installed at each site. A pressure sensor was installed in the dripline to record irrigation run times. In February 2023 sampling collars for greenhouse gas measurement were installed in the tree row and in the midrow of each of the nine sites and sampling for greenhouse gases (GHG) commenced. A separate exercise tested temporal changes in GHG emission by sampling at 2-hourly intervals from 8 am to 6 pm on a single day.

Soil sampling

Annual soil cores were taken before and during the trial for assessment of soil carbon levels and bulk density. Annual soil samples were also taken to determine the rate of breakdown of wood chips in soil. Undisturbed soil cores (Figure 4, Figure 6a) were taken in November 2022 and September 2024 for measurement of bulk density, saturated hydraulic conductivity and soil moisture release curves.

Figure 4. Collection of undisturbed soil cores a) digging pits, b) preparing site, c) collecting and d) bagging samples.

Regular soil, soil water and greenhouse gas sampling

Regular sampling (2-3 monthly) of extractable soil water, soil carbon and nitrogen, and greenhouse gas emission (Figure 5) was carried out. DNA analyses of soil for soil borne pathogens were carried out before and during the trial to assess the risk of disease carry-over from the previous orchard.

Figure 5. Regular field sampling of a) soil water, b) soil and c) greenhouse gas

Wood chip breakdown

The amount of wood chips in soil was assessed by the weight of material which was larger than 2 mm (measured during sample analysis) from samples in November 2022 and August 2023, due to the absence of gravel in soil. In August 2023 and September 2024 the amount of wood chips was measured directly (Figure 6b) by passing the sample through a 6 mm sieve, following the method used during development of WOR (Holtz, pers. comm.).

Figure 6. Laboratory analysis of a) undisturbed soil cores and b) wood chip content of soil.

Tree size and light interception

Tree height and trunk diameter were measured annually. Light interception of the tree canopy was first measured 18 months after planting. Trees were too small to cast a useable shadow prior to then, as tree rows were planted in east/west orientation rather than the typical north/south direction. This gave less shadow to work with than at other almond orchard sites. Light interception was measured using a Mobile Orchard Phenotyping Platform (MOPP) in February 2024 and January 2025. Harvest was carried out at the 3rd leaf stage in February 2025.

Results and discussion

Irrigation and fertiliser

Additional irrigation was applied in the first irrigation season in an effort to remedy poor initial tree growth in the WOR treatment (irrigation and rainfall totaled around 80% of evapotranspiration). Following improved growth in the recycle treatment, irrigation was reduced in order to slow tree growth and minimise risk of wind damage. Around 40% of evapotranspiration was applied in 2023/24 and 35% in 2024/25. Figure 7 shows monthly rainfall and irrigation charted against reference evapotranspiration (Bureau of Meteorology).

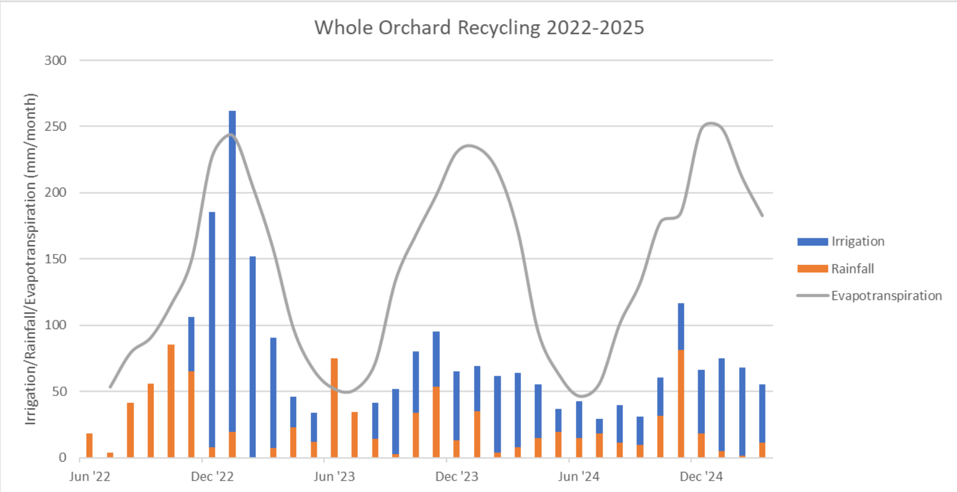

Figure 7. Monthly irrigation, rainfall and reference evapotranspiration at Merbein 2022-2025.

Annual fertiliser applications are shown in Figure 8. A higher rate of nitrogen fertiliser was applied during tree establishment to help counter any nitrogen draw down due to the high amount of carbon incorporated into the soil in the WOR treatment. This is following published recommendations for WOR by Holtz *et al.* (2020), who found that large amounts of added carbon, such as in wood chips, can increase the carbon-to-nitrogen (C:N) ratio in soils. This in turn can cause soil microbes to immobilise available soil nitrogen to satisfy their sudden increase in carbon consumption and induce a temporary deficit of nitrogen available for trees. Higher applications of nitrogen fertiliser during the first year will counter this effect, and this is in line with recommendations for whole orchard recycling from California.

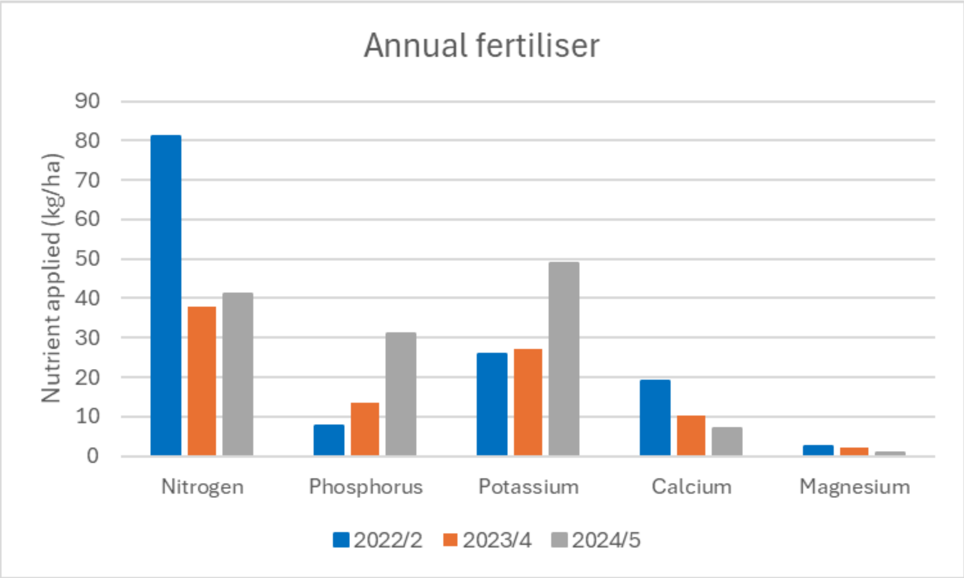

Figure 8. Fertiliser applied at Merbein, 2022-2025.

Tree size, 2023 to 2025

The orchard established well, and tree growth across all of the treatments was strong. While no industry benchmarks are available for almond tree establishment in Australia, tree growth was inline with what is observed for other sites in the region (Figure 9).

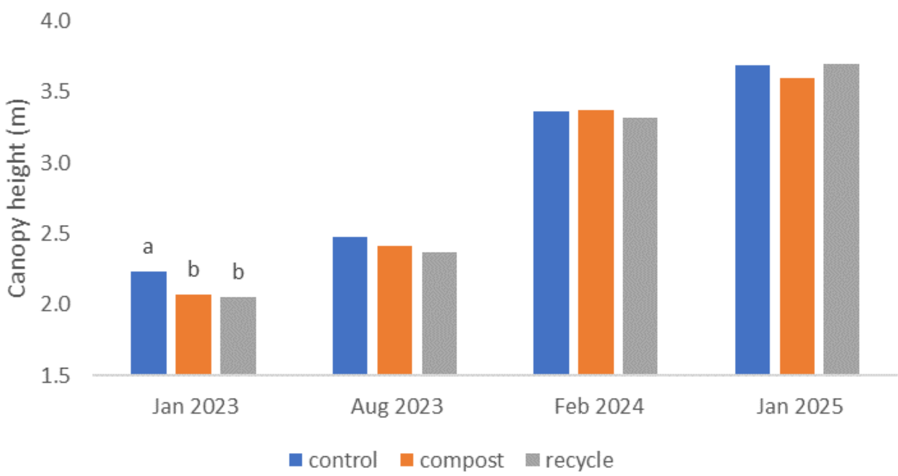

Figure 9. Tree height 2022-2025. Values with different letters are significantly different ($p<0.05$) at each date.

Trees in the control treatment intially grew taller than the others. This proved to be a temporary effect, most likely due to temporary nitrogren deficiency as discussed above, from August 2023 the WOR and compost treatments caught up to the control. Trunk diameters are shown in Figure 10.

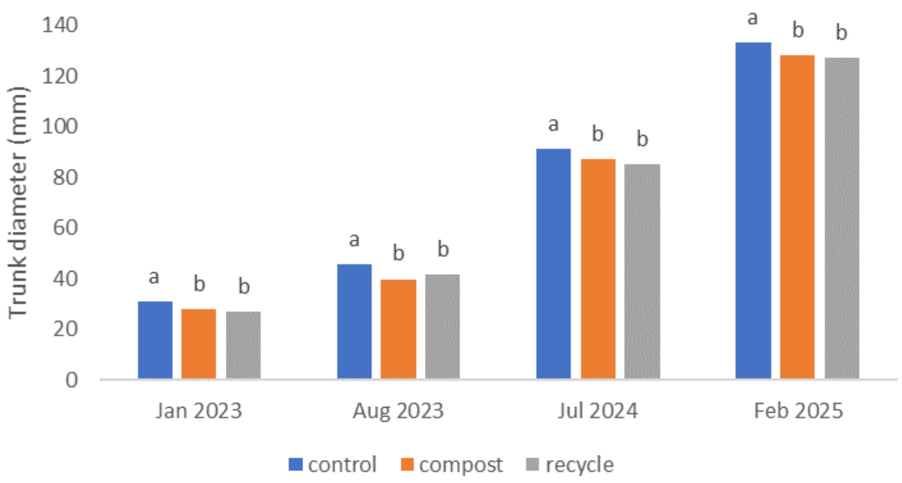

Figure 10. Trunk diameter 2022-2025. Values with the same letter at each date are not significantly different at p<0.05.

Unlike tree height, the trees in the control treatment maintained a larger trunk diameter through the 3 years of the trial. While these differences were statistically different, at between 5 and 10mm, we do not expect them to have a large impact on orchard performance. Trees in the recycle treatment grew less than the others in the first year, but then caught up in the second and third years. This is consistent with the observations of Holtz *et al.* (2018) who pioneered WOR in California.

Light interception

Light interception of the tree canopy is shown in Figure 11.

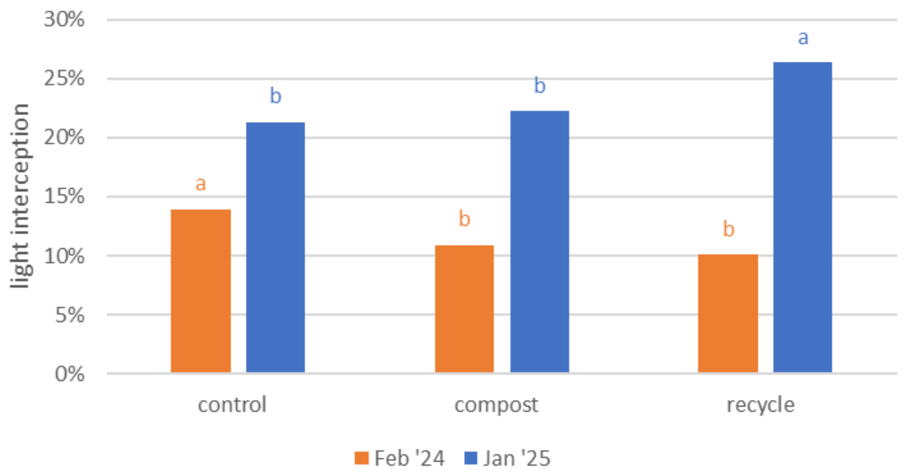

Figure 11. Light interception in 2024 (orange) and 2025 (blue). Values with the same letter are not significantly different at p<0.05.

In February 2024 the control trees intercepted more light than the trees in the other treatments (Figure 11), which aligns with the measurements of tree height (Figure 9). By January 2025, however, trees in recycle and compost treatments had recovered, and the measured light interception was now higher than the control. This is consistent with visual observations but was not expected as the trunks of the control trees had a larger diameter than the trees in the whole orchard recycling treatment and other research in this space did not report improved tree performance until the 7^{th} leaf (Culumber et al. 2025). Larger canopies are related to higher yields, due to greater light interception and increased fruiting spur positions. This increased light interception may be the first indication of the increase in yield observed in other studies (Culumber et al. 2025).

Soil organic carbon, nitrate and ammonium levels – repeated sampling

Temporal changes in soil organic carbon, nitrate and ammonium as measured by regular soil sampling are shown below.

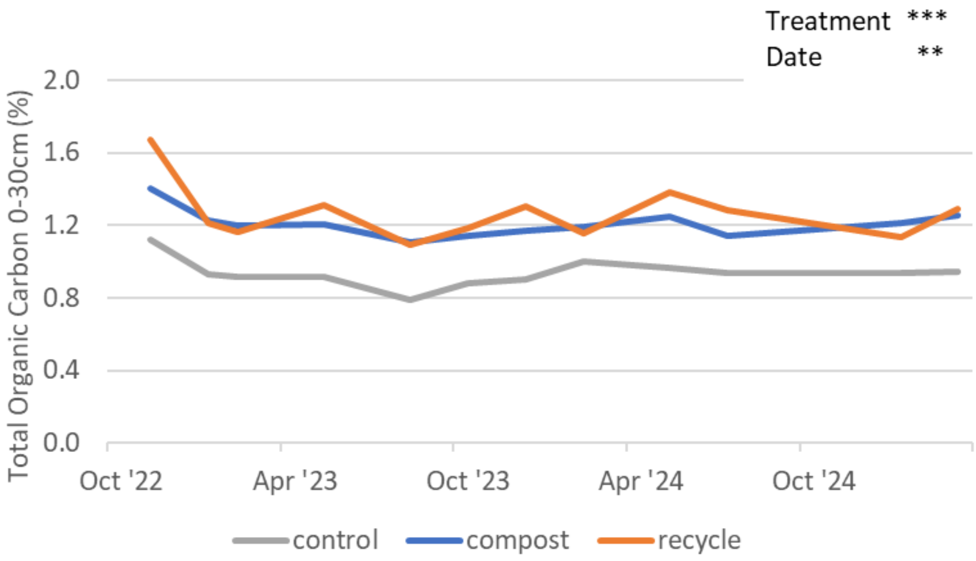

Figure 12. Soil organic carbon in regular samples taken at 0-30 cm depth. Significant effects are indicated at $p<0.01$ (**) and $p<0.001$ (***).

Both of the organic amendment treatments increased soil organic carbon by approximately 30% compared to the control (Figure 12). This higher level of soil carbon has been maintained throughout the 3 years of the trial. Higher levels of soil organic carbon in < 2 mm soil fraction are likely to be maintained in the WOR treatments. This is because the larger pieces of wood (greater than 2mm) are currently removed from the soil samples during preparation for chemical analysis. These larger pieces will continue due to break down into smaller particles which will then be included in the analysed sample. Ongoing maintenance of soil organic carbon levels from WOR has been observed by Culumber *et al.* (2025) in California over a four-year period. Increased soil organic carbon levels are widely recognised as improving soil structure, drainage and nutrient holding capacity and are considered to be a soil improvement.

Soil nitrate-N levels are shown in Figure 13.

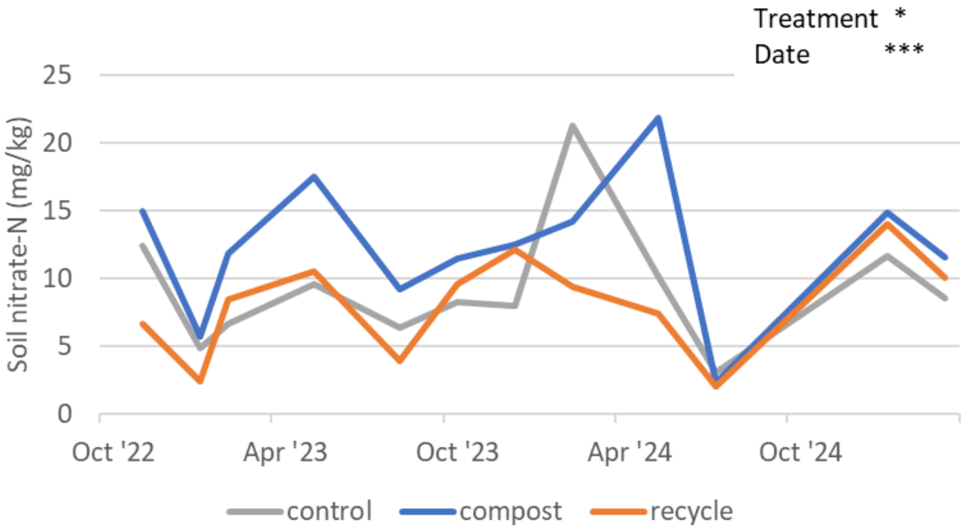

Figure 13. Soil nitrate in regular samples taken at 0-30 cm depth. Significant effects are indicated at $p<0.05$ (*) and $p<0.001$ (***).

Soil nitrate levels were variable, although overall the compost treatment maintained higher nitrate levels than the recycle or control treatments (Figure 13). This is difficult to interpret as soil nitrate levels are influenced by both organic amendments and seasonal fertigation applications.

Soil ammonium-N levels are shown in Figure 14.

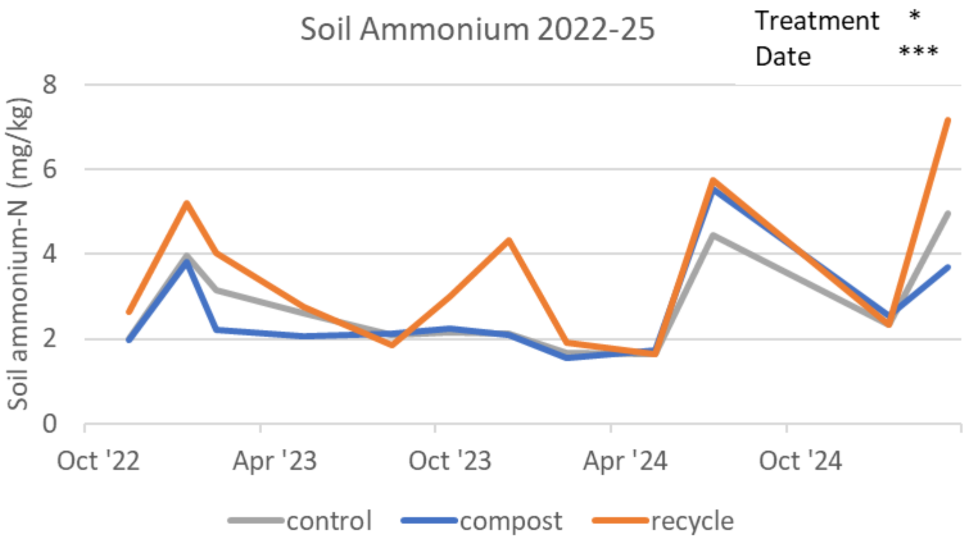

Figure 14. Soil ammonium in regular samples taken at 0-30 cm depth. Significant effects are indicated at $p<0.05$ (*) and $p<0.001$ (***).

Soil ammonium levels were variable across the three years of the trial as they were influenced by both the organic amendments and fertilizer applications (Figure 14). Overall, the recycle treatment had higher levels of ammonium compared to the other treatments.

Soil organic carbon, nitrate and ammonium levels – annual sampling

Annual soil coring was carried out to collect soil samples from 0-30 and 30-60 cm to investigate temporal variation in soil organic carbon, nitrate and ammonium.

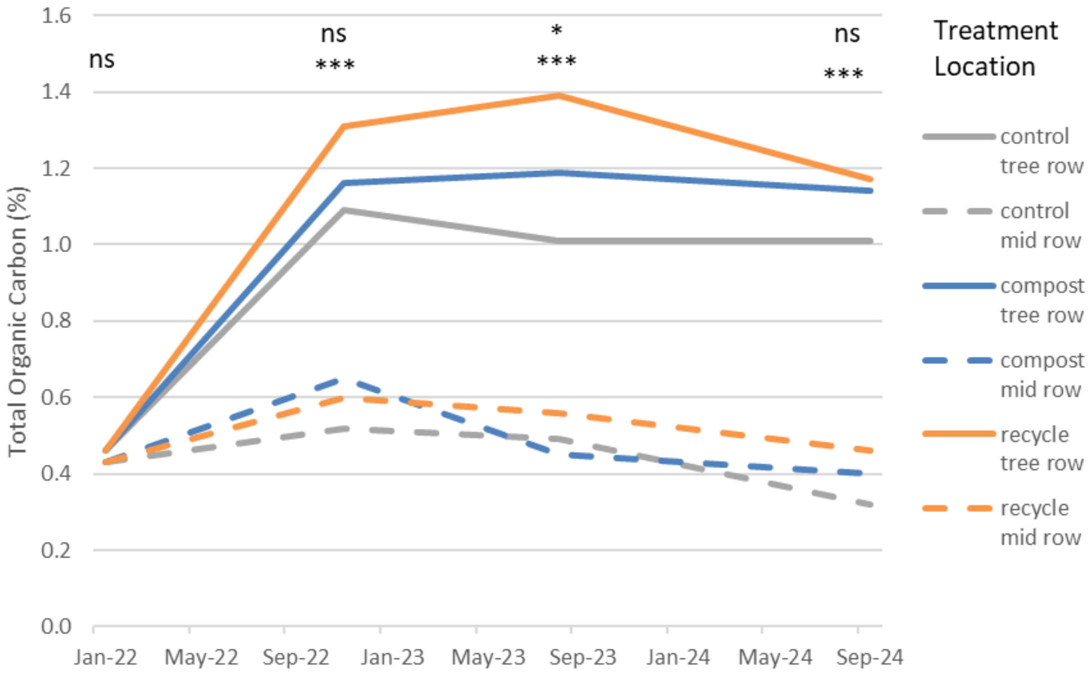

Figure 15. Soil organic carbon in annual samples taken at 0-30 cm depth. Significant effects are indicated at $p<0.05$ (*) and $p<0.001$ (***).

In a very similar trend to the more regular samples collected using an auger (see above) the organic amendment increased soil organic carbon by approximately 30% (Figure 15). There was significantly less soil organic carbon in mid row than in the tree row regardless of the treatment. This is likely due to the removal of topsoil (and associated organic carbon) from the midrow to construct mounded tree rows, and secondly the lack of irrigation and associated plant growth in the midrow.

Soil bulk density is shown in Figure 16.

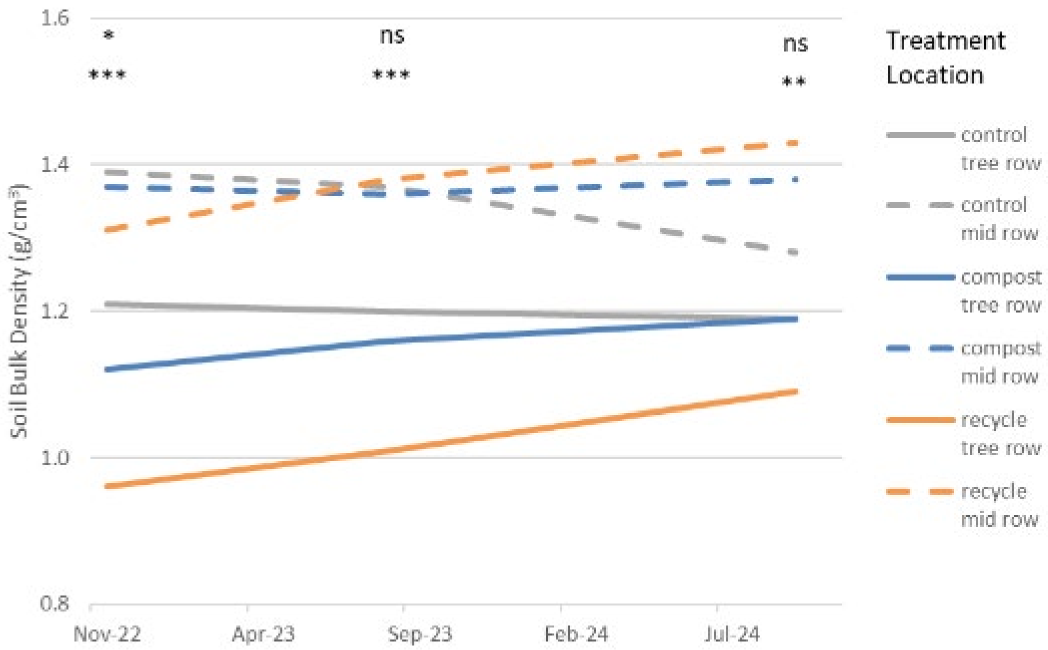

Figure 16. Soil bulk density of annual samples taken at 0-30 cm depth. Significant effects are indicated at $p<0.05$ (*), $p<0.01$ (**) and $p<0.001$ (***).

Soil bulk density was higher in the tree row than in the midrow for all treatments. This is also likely due to transfer of topsoil during mounding of the tree row. Although recycle treatment had the lowest absolute bulk density values, there was no significant effect of treatment. Bulk density values were not available for January 2022 (pretrial) as soil was very dry when sampled and cores did not retain sufficient integrity to provide reliable bulk density data.

Soil nitrate-nitrogen levels are shown in Figure 17 .

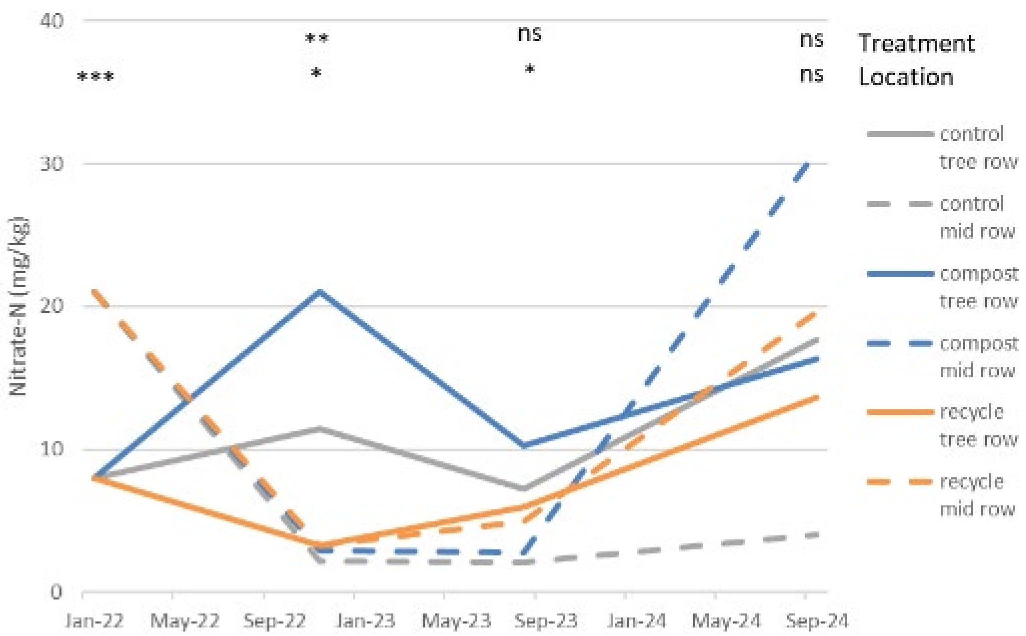

Figure 17. Soil nitrate in annual samples taken at 0-30 cm depth. Significant effects are indicated at $p<0.05$ (*), $p<0.01$ (**) and $p<0.001$ (***).

There were varying effects of treatment and location on soil nitrate-nitrogen levels. This is most likely due to the interplay of nitrogen fertigation, plant uptake, and the presence or absence of leaching by rainfall (especially in the midrow).

Soil ammonium-nitrogen levels are shown in Figure 18.

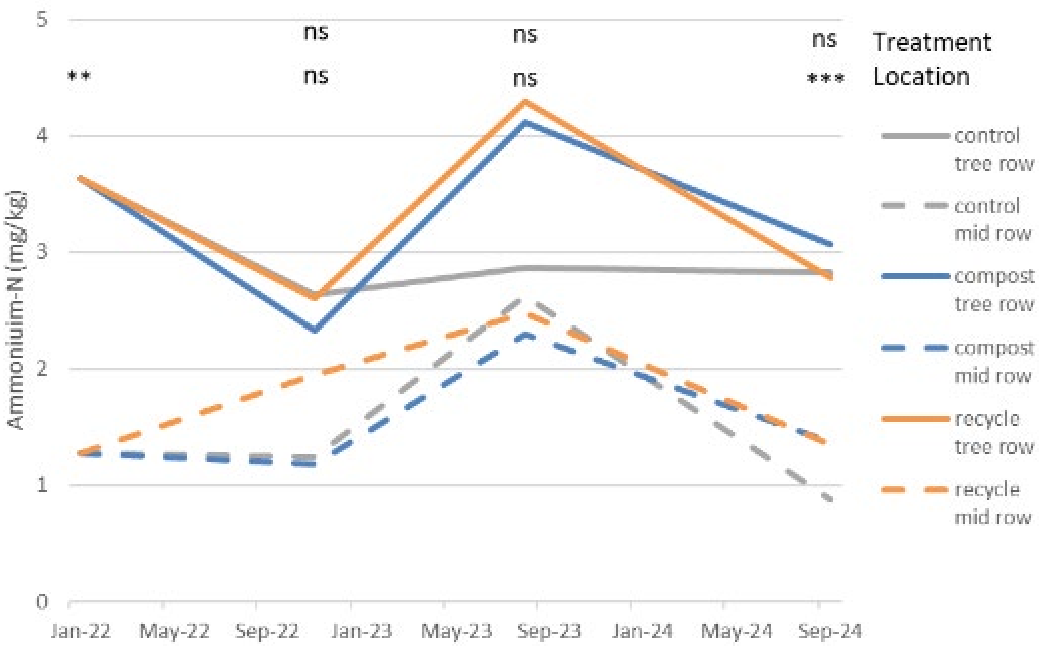

Figure 18. Soil ammonium of annual samples taken at 0-30 cm depth. Significant effects are indicated at $p<0.01$ (**) and $p<0.001$ (***).

Soil ammonium-nitrogen levels were also variable, with generally higher levels in the midrow (aligning with the movement of the topsoil into this region) than in the tree row and limited impact of the soil amendment treatments.

Soil sampling for nitrogen can help estimate the amount available in the root zone prior to the start of a fertiliser program; however, this sampling has challenges and the results need to be interpreted carefully (Brown *et al.* 2020). Soil nitrogen is very unevenly distributed in the soil, and it is difficult to collect a representative sample, especially under drip irrigation. This is one reason why nitrogen status of almond trees is generally determined by leaf tissue analysis, while the amount of fertiliser required is determined by tree requirement, nutrient removal and all sources of supply, including the soil (Brown *et al.* 2020).

Soil cores collected at 30-60 cm depth were analysed for the same range of nutrients as 0-30 cm samples. There were few significant differences between treatments or locations, other than soil organic carbon (Table 1). There was no effect of the organic amendment treatments on soil organic carbon, but a significant effect of location was observed (higher levels in the tree row). This was likely due to the transfer of topsoil (and added amendment) from the midrow to the tree row at the beginning of the experiment. By creating a mound around 40 cm high in the tree row, the existing soil surface effectively became a part of the 30-60 cm sampling layer.

Table 1. Soil organic carbon, bulk density, nitrate-N and ammonium-N of samples taken at 30-60 cm depth.

date	Soil organic carbon, 30-60 cm (%)				p value, $LSD_{0.05}$
	location	control	compost	recycle	
January 2022	tree row	0.32			-
	midrow	0.24			-
	p value ($LSD_{0.05}$)	0.17 (ns)			-
November 2022	tree row	0.503	0.442	0.395	0.97 (ns)
	midrow	0.125	0.207	0.225	
	p value ($LSD_{0.05}$)	0.003 (0.11)			
September 2024	tree row	0.3	0.41	0.4	0.42 (ns)
	midrow	0.18	0.19	0.17	
	p value ($LSD_{0.05}$)	0.003 (0.17)			
date	**Soil bulk density, 30-60 cm (g/cm^3)**				**p value, $LSD_{0.05}$**
	location	**control**	**compost**	**recycle**	
November 2022	tree row	1.4	1.38	1.38	0.57 (ns)
	midrow	1.37	1.35	1.3	
	p value ($LSD_{0.05}$)	0.23 (ns)			
September 2024	tree row	1.31	1.39	1.35	0.29 (ns)
	midrow	1.47	1.55	1.33	
	p value ($LSD_{0.05}$)	0.15 (ns)			
date	**Soil nitrate-N, 30-60 cm (mg/kg)**				**p value, $LSD_{0.05}$**
	location	**control**	**compost**	**recycle**	
January 2022	tree row	13.5			-
	midrow	34.8			
	p value ($LSD_{0.05}$)	0.004 (13.8)			
November 2022	tree row	12.4	7.7	4.7	0.53 (ns)
	midrow	5.1	24.4	10.8	
	p value ($LSD_{0.05}$)	0.44 (ns)			
September 2024	tree row	9.5	9.5	4	0.023 (17.0)
	midrow	21.1	64.5	24.7	
	p value ($LSD_{0.05}$)	0.0009 (13.9)			
date	**Soil ammonium-N, 30-60 cm (mg/kg)**				**p value, $LSD_{0.05}$**
	location	**control**	**compost**	**recycle**	
January 2022	tree row	1.53			-
	midrow	0.64			
	p value ($LSD_{0.05}$)	0.004 (0.57)			
November 2022	tree row	1.62	0.98	1.2	0.53 (ns)
	midrow	0.83	2.82	2.97	
	p value ($LSD_{0.05}$)	0.17 (ns)			
September 2024	tree row	2.98	1.45	1.2	0.27 (ns)
	midrow	1.18	1.3	0.8	
	p value ($LSD_{0.05}$)	0.16 (ns)			

Breakdown of recycled wood chips in soil

Two methods were used to determine the amount of wood chips remaining in soil at each sampling time. The initial method used soil cores collected for analysis as per Carbon Farming Initiative requirements, the subsequent method used large soil samples and assessed wood chips after Holtz (pers. comm.). These methods are described in Appendix 1. The woodchip content of soil samples is shown in Figure 19.

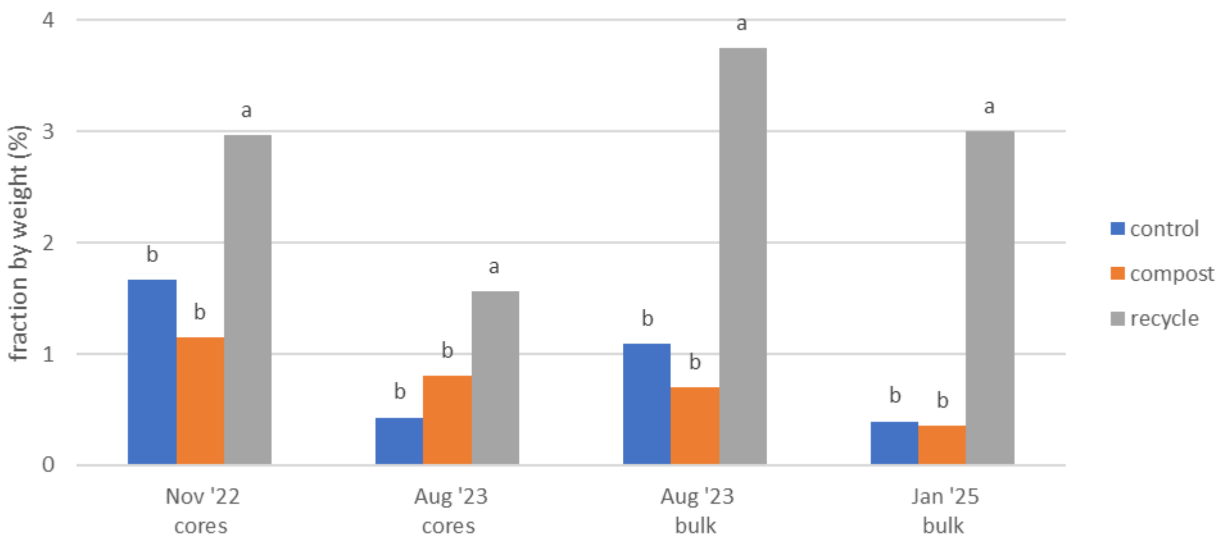

Figure 19. Woodchip content of soil samples taken at 0-30 cm depth estimated as weight of material > 2 mm (cores) or weight of woodchips retained by a 6 mm sieve (bulk). Values with the same letter are not significantly different at $p<0.05$ within each sampling date.

As expected the wood chips appear to be gradually breaking down in the soil. Culumber *et al.* (2025) estimated that 49% of wood chips remained in soil after four years. They predicted that around 23% would remain after 10 years and 7% after 20 years (when the average orchard is replaced), while recognising that modelling may not account for all factors involved in wood chip decomposition. At this stage it is not known how closely decomposition rates at the Sunraysia trial will relate to those in California.

Soil physical measures

A soil moisture release curve (SMRC) is the volumetric soil water content measured over a range of soil water potentials and indicates how much energy is needed by plants to extract water across a range of water contents. Soil moisture curves change with soil type and the range of pores in soil. Sandy soils tend to release water easily, but then hold less water in drier conditions. Clay soils may hold a lot of water in small pores, but this water is less available to plants because it is held more tightly.

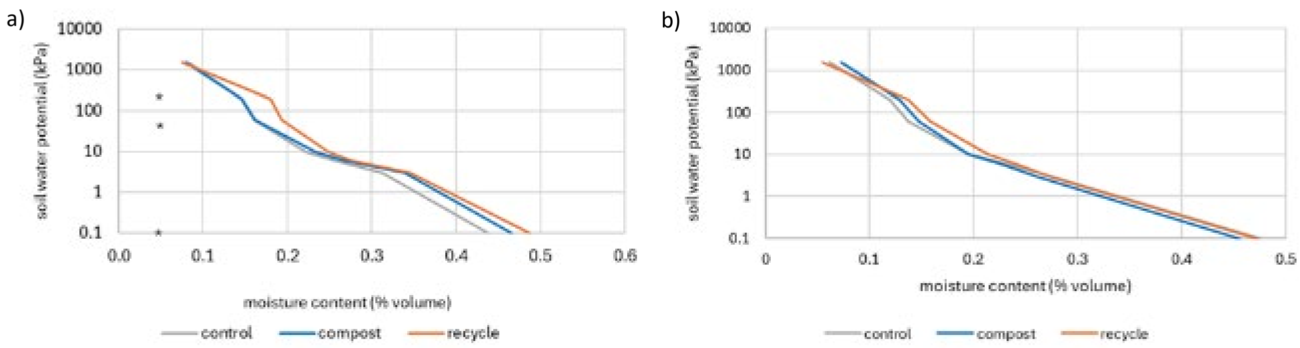

Figure 20. Soil moisture release curves of 0-30 cm samples in a) 2022 and b) 2024. Significant differences between treatments are indicated at p<0.05 (*).

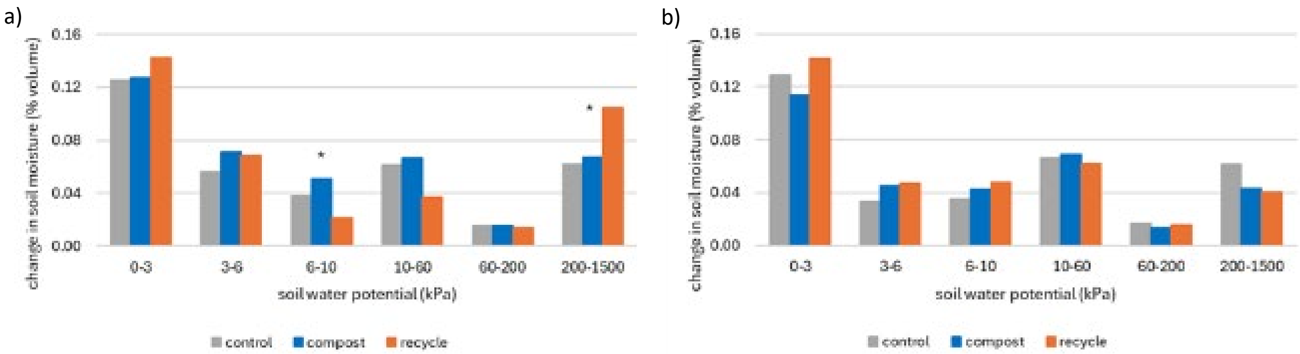

Figure 21. Changes in soil moisture of 0-30 cm samples in a) 2022 and b) 2024. Significant differences between treatments are indicated at p<0.05 (*).

There were some indications that 0-30 cm soil moisture release curve of recycle treatment was different to the other treatments in 2022, but by 2024 there were no differences between treatments (Figure 20) . There were no consistent differences in available soil water between treatments in 2022 or 2024 (Figure 21).

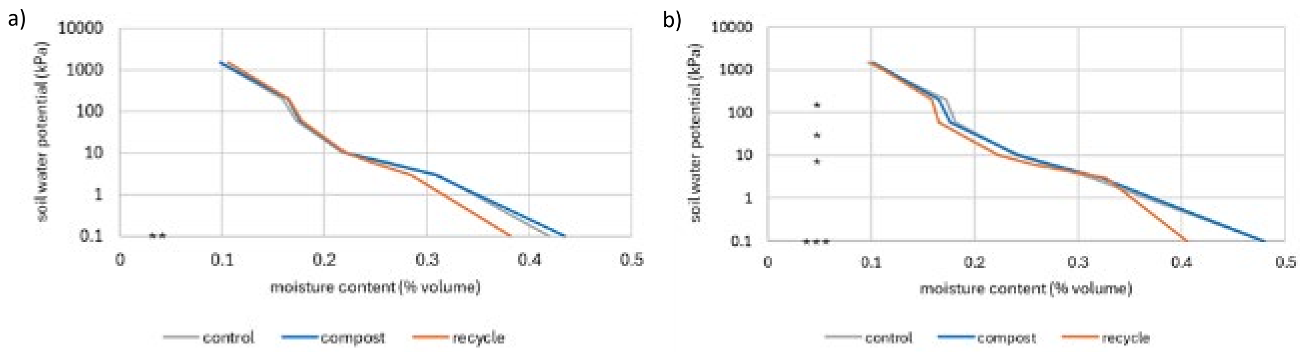

Figure 22. Soil moisture release curves of 30-60 cm samples in a) 2022 and b) 2024. Significant differences between treatments are indicated at p<0.05 (*), p<0.01 (**) and p<0.001 (***).

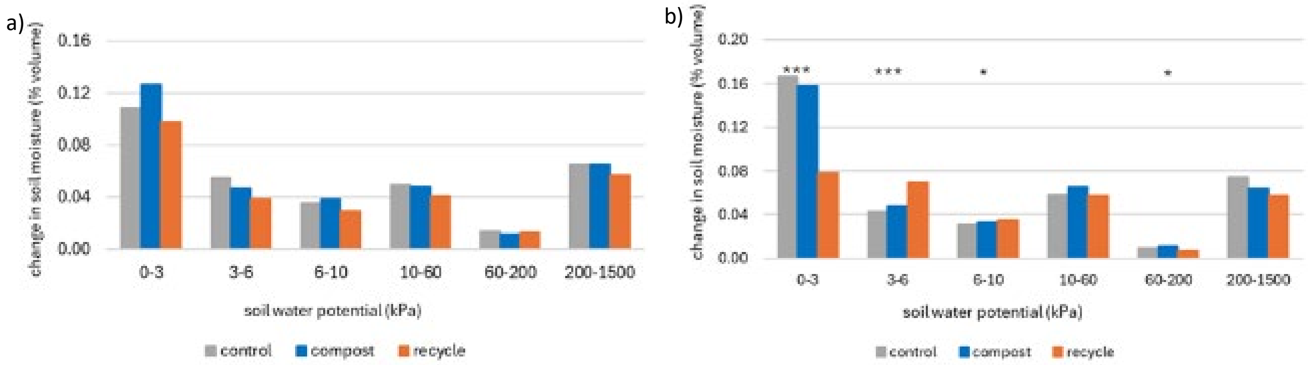

Figure 23. Changes in soil moisture of 30-60 cm samples in 2022 and 2024. Significant differences between treatments are indicated at p<0.05 (*) and p<0.001 (***).

At the 30-60 cm depth there were some differences between treatments, particularly with soil moisture between saturation and 3 kPa (very wet), where recycle treatment had a lower soil moisture content (Figure 22). Although the 30-60 cm samples were taken below the soil surface, they were still within the amendment soil zone as samples were taken from tree mounds around 45 cm high. There were no significant differences in available soil water at 30-60 cm depth in 2022, but there were in 2024 (Figure 23). The treatment differences at 30-60 cm were unexpected. Examination of raw data showed acceptable agreement between duplicate samples across the soil moisture curves (generally less than 20% difference) and there were no consistent differences in soil texture (data not shown).

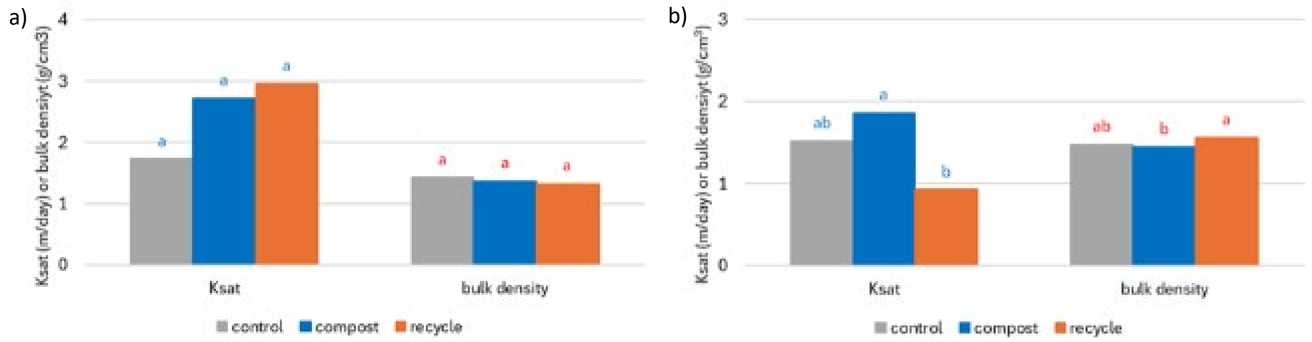

Figure 24. Saturated hydraulic conductivity and bulk density of a) 0-30 cm and b) 30-60 cm samples in 2022. Values with the same letter are not significantly different at p<0.05.

The organic amendments had no significant effect on Ksat or bulk density at 0-30 cm depth, but, WOR treatment resulted in a statistically lower Ksat at 30-60 cm (Figure 24). The differences in bulk density between treatments at 30-60 cm depth were statistically significant, but they are unlikely to have any practical impact.

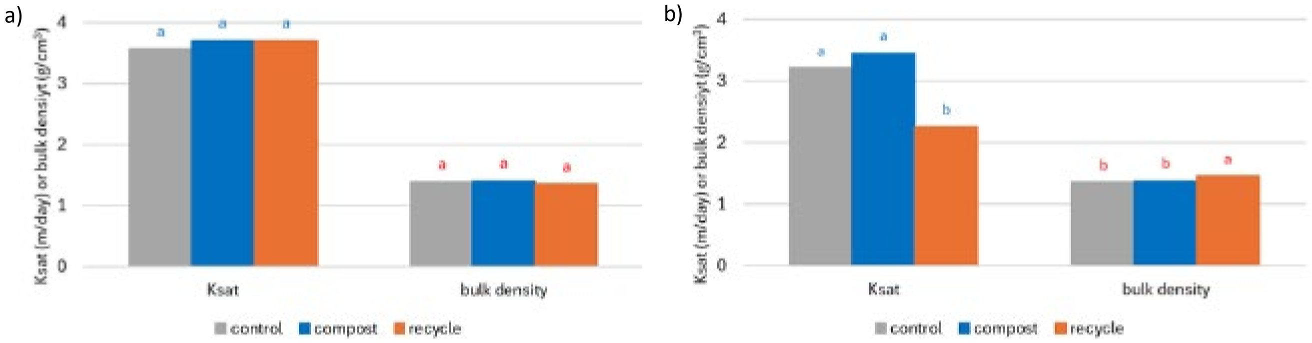

Figure 25. Saturated hydraulic conductivity and bulk density of 0-30 cm and 30-60 cm samples in 2024. Values with the same letter are not significantly different at $p<0.05$.

There were no significant differences between treatments at 0-30 cm depth in 2024, but the WOR treatment had lower Ksat in the 30-60 cm samples (Figure 25). While this result was unexpected, it is consistent with the 2022 sampling and may be a real effect. The recycle treatment also showed lower saturated soil moisture content (Figure 22) and available soil water (Figure 23) at the same depth. The only bulk density differences between treatments were slightly higher values in the recycle treatment at 30-60 cm depth. Examination of raw data showed that duplicate samples varied by less than 10%. It is difficult to explain the soil physical results from recycle treatment at 30-60 cm depth. The movement of fine organic material from the WOR treatment deeper into the soil profile could potentially both reduce Ksat and increase bulk density, but the observations could also be due to natural variation in soil type across the trial site. Hydrological soil attributes, and especially saturated hydraulic conductivity, are known to be overly spatially variable (Soares *et al.* 2023). While it is likely that WOR will improve the soil parameters measured, this is a long-term process. Culumber *et al.* (2025) found that measurable improvements in soil condition were not realised for several years.

Intact soil cores were also taken from 0-30 cm and 30-60 cm depths of midrow locations in 2024. There were no consistent differences between treatments in physical parameters other than lower soil moisture contents in recycle treatment at 30-60 cm depth. This is similar to the tree row results and may indicate a soil type effect such as depth to topsoil. Data from midrow locations is shown in Appendix 1.

Soil-borne disease assessment

The removal and burning of orchard trees (including roots) helps to disinfect the orchard and prevent the carryover of disease into any new plantings. Whole orchard recycling maintains all this material in the orchards which has the potential to harbor a range of diseases. Orchards can be fumigated to help manage the risk of soil pathogens, but this was not carried out in this case. Soil samples were taken pre-trial (to assess the likely disease pressure) and in September 2024 for DNA-based analysis which quantified amounts of soil-borne pathogen DNA. Samples were collected from locations close to trees and analysed using the Hort/Veg Test Panel by the SARDI Molecular Diagnostics Group. The test panel is shown below (Table 2) and also includes a test for almond root DNA, which was present in all samples.

Table 2. Species screened by Hort Veg Test Panel, SARDI Molecular Diagnostics

Common name	Target species
Aphanomyces root rot	*Aphanomyces euteiches*
Blackleg	*Leptosphaeria maculans*
Black dot	*Colletotrichum coccodes*
Black root rot	*Thielaviopsis basicola*
Cavity spot of carrot	*Pythium sulcatum*
	Pythium violae
Charcoal rot	*Macrophomina phaseolina*
Common scab	*Streptomyces scabies*
	(test targets the Streptomyces txtA gene)
Clubroot	*Plasmodiophora brassicae*
Fusarium basal rot of onion	*Fusarium oxysporum, F. sp. cepae*
Onion white rot	*Sclerotium cepivorum*
Pink root	*Setophoma terrestris*
Pythium	*Pythium Clade F*
	Pythium Clade I
Rhizoctonia	*Rhizoctonia solani AG2.1*
	Rhizoctonia solani AG2.2
	Rhizoctonia solani AG3
	Rhizoctonia solani AG4
	Rhizoctonia solani AG8
Root knot nematodes	*Meloidogyne arenaria, M. incognita, M. javanica*
	(test cannot distinguish between the 3 species)
	Meloidogyne fallax
	Meloidogyne hapla
Root lesion nematodes	*Pratylenchus crenatus*
	Pratylenchus neglectus
	Pratylenchus penetrans
	Pratylenchus thornei
	Pratylenchus zeae
Sclerotinia rot	*Sclerotinia sclerotiorum, S.minor*
	(test cannot distinguish between the 2 species)
Stem nematode	*Ditylenchus dipsaci*
Verticillium wilt	*Verticillium dahliae*

Most tests returned a zero value for pathogen DNA, both from samples collected before the trial was established (i.e. from the orchard that was recycled) and the second sample in September 2024. There were no detections of root knot or root lesion nematode. Pythium was present with slightly elevated levels of Pythium in Clade I, but these results were not at levels that indicated likely disease issues (M. Rettke, pers. comm.). Generally, all the trees appear very healthy with no disease symptoms.

Soil water nitrate levels

Soil water samples were collected at the same time as regular soil and GHG samples. Soil water nitrate levels are shown in Figure 26.

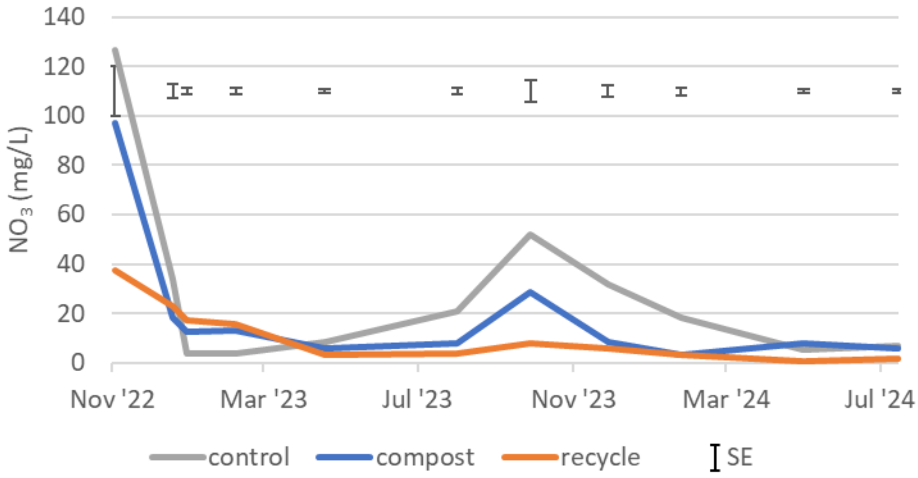

Figure 26. Nitrate in extracted soil solution, averages of all sampling depths. The bars indicate one standard error.

The above chart shows soil water nitrate, averaged across the three sample depths. Elevated nitrate levels at the first sampling were likely due to a combination of the mineralisation and release of nitrogen from organic matter following cultivation and disruption of soil and nitrogen fertigation which was last applied 2 weeks before sampling (data not shown). Nitrate levels tended to be higher in the control than the treatments which had received organic matter. The WOR treatment had the lowest nitrate concentrations, suggesting scavenging of nitrate in soil water by micro-organisms which were decomposing wood chips in soil. Soil water nitrate levels at each depth are shown for each treatment in Figure 27, Figure 28 and Figure 29.

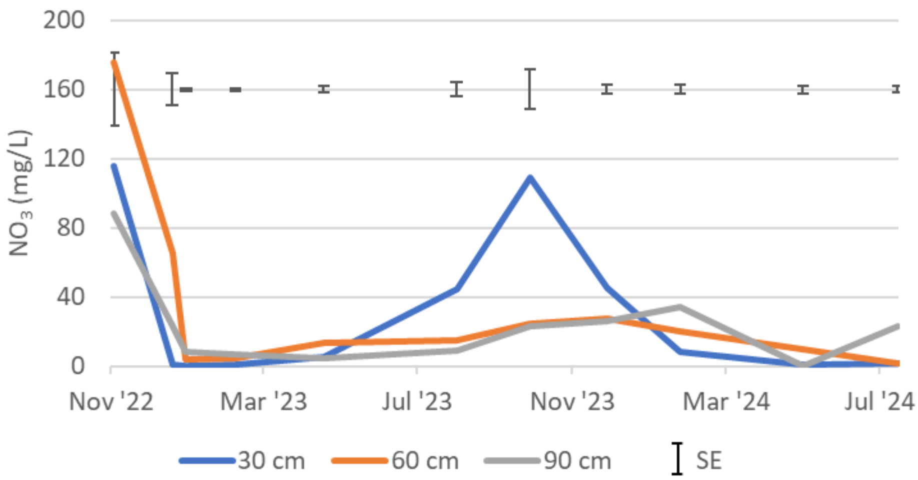

Figure 27. Nitrate in extracted soil solution of the control treatment. The bars indicate one standard error.

The nitrate levels were high at the initial sampling for all three sample depths (Figure 27), this suggests that some nitrogen could have been moving past the rootzone at this time. A spike of nitrate concentration occurred in the 30 cm sample that was collected in October 2023. This was most likely due to fertiliser, as a large application was made during September, just prior to the October sampling. There was small indication of nitrate leaching past the root zone as shown by increased nitrate levels in subsequent samplings from 90 cm in December 2023 and Feburary 2024.

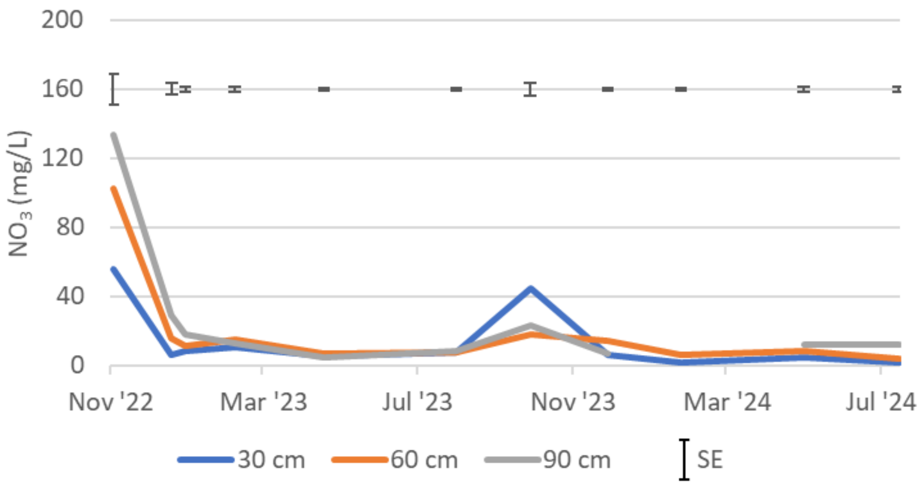

Figure 28. Nitrate in extracted soil solution of compost treatment. The bars indicate one standard error.

Initial nitrate levels in the compost treatment were similar to those in the control treatment. The spike of nitrate concentration in October 2023 was comparable to that in the control treatment, but somewhat smaller. This implied some damping of nitrate concentrations through microbial scavenging associated with breakdown of the compost amendment.

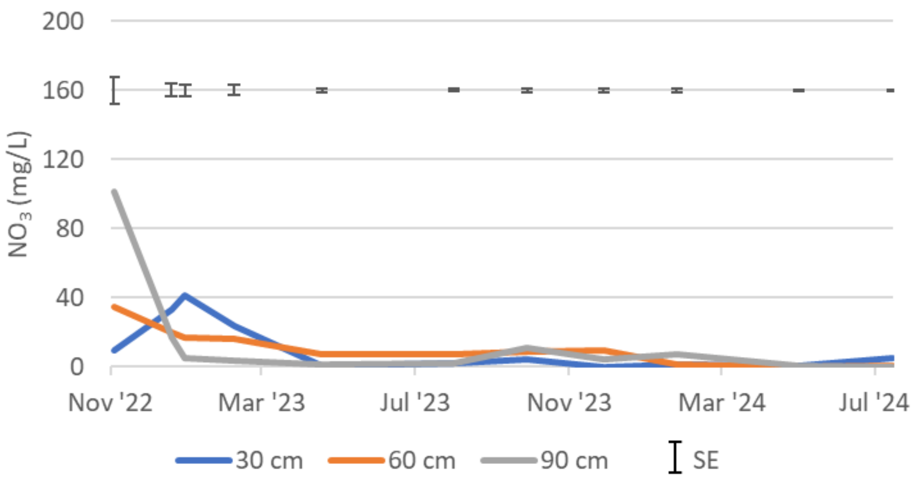

Figure 29. Nitrate in extracted soil solution of Whole Orchard Recycling treatment. The bars indicate one standard error.

Nitrate levels in the WOR treatment were generally lower than those in the other treatments (Figure 29). There was no spike of nitrate concentration in October 2023, implying that all surplus nitrate was scavenged through microbial breakdown of the woodchip amendment. This is consistent with conclusions of Jahanzad *et al.* (2022) who found that WOR both immobilised fertiliser N in the short term and reduced nitrate potential in the long term.

Soil moisture

Soil moisture probes were installed in 2022 and maintained on an ongoing basis. Sensors were installed in three replicates of each treatment, nine in total. Initial measurements were problematic as the irrigation line is moved as the trees grow and the sensors needed to be reinstalled.

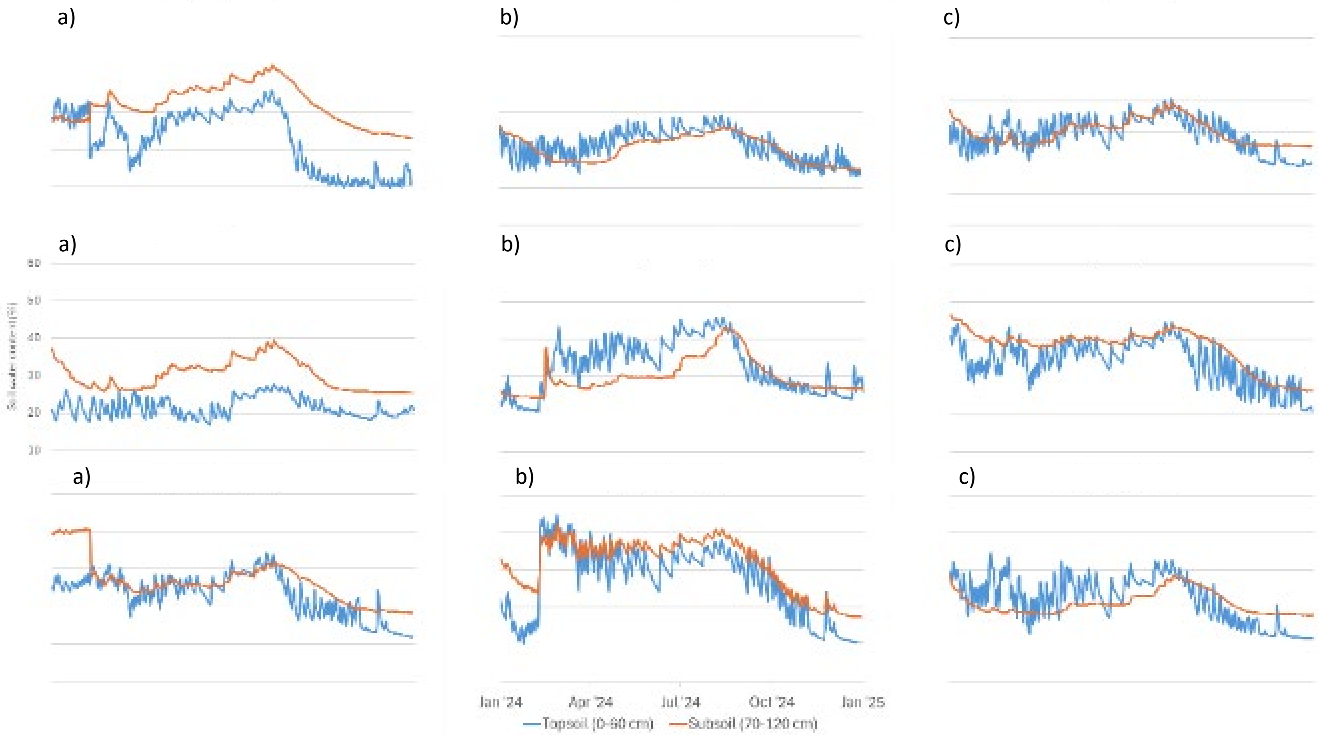

Figure 30. Daily average soil moisture traces from nine monitoring sites in 2024. a) control b) compost and c) whole orchard recycling.

The soil moisture is logged at 15 minute intervals and there were no consistent differences between soil amendment treatments, in the patterns of soil moisture (Figure 30).

Monthly averages of topsoil (0-60 cm) and subsoil (70-120 cm) soil moisture for each treatment are shown in Figure 31.

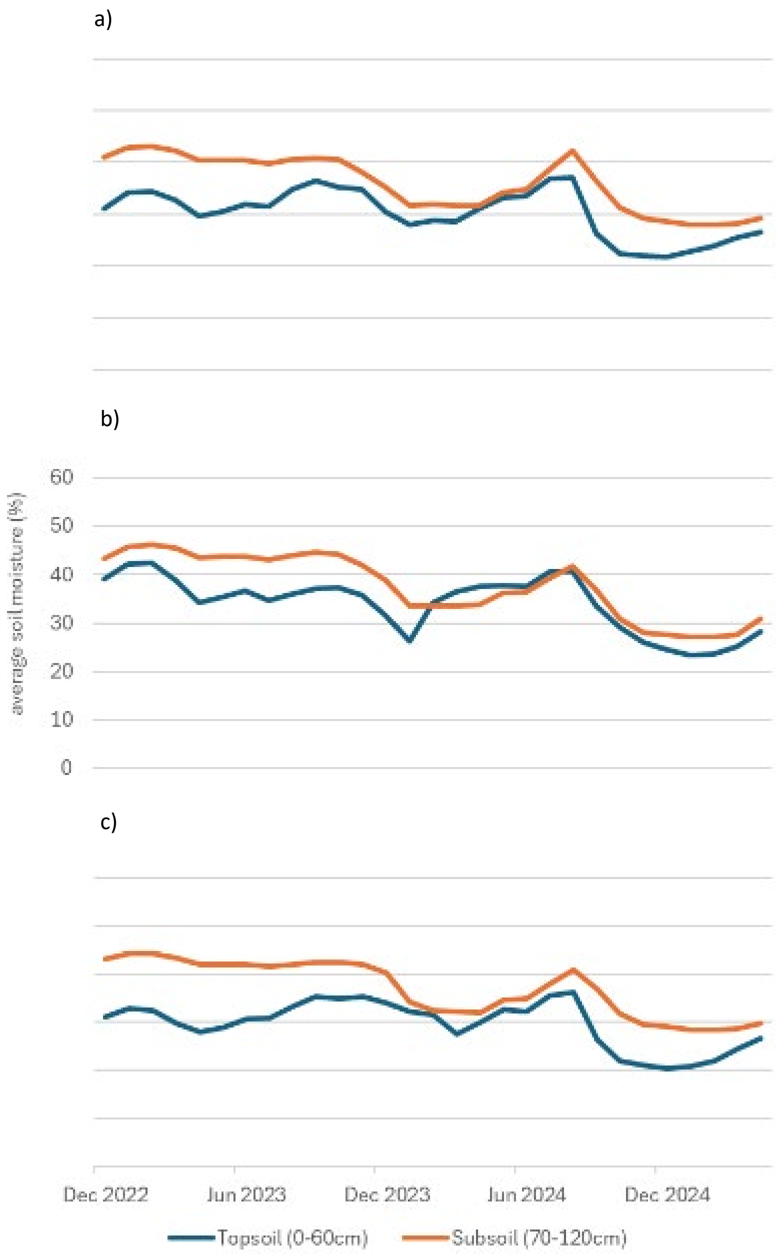

Figure 31. Monthly average soil moisture traces from 2023 - 2025. a) control, b) compost and c) whole orchard recycling

When the soil moisture was averaged on a monthly basis across the three years of the trial there was also no difference between the soil amendment treatments. There was a general slow decline in soil moisture over most sites during the study period (Figure 31). This is consistent with the reduction in irrigation water depth and increase in tree requirement over the three years. Subsoil moisture in most sites was higher than topsoil moisture due to the heavier texture of subsoil and associated higher water retention in the small soil pores.

Greenhouse gas emissions

Spot measurements of greenhouse gas emission from soil were made at 2-3 month intervals from 2022 to 2025, (Figure 32).

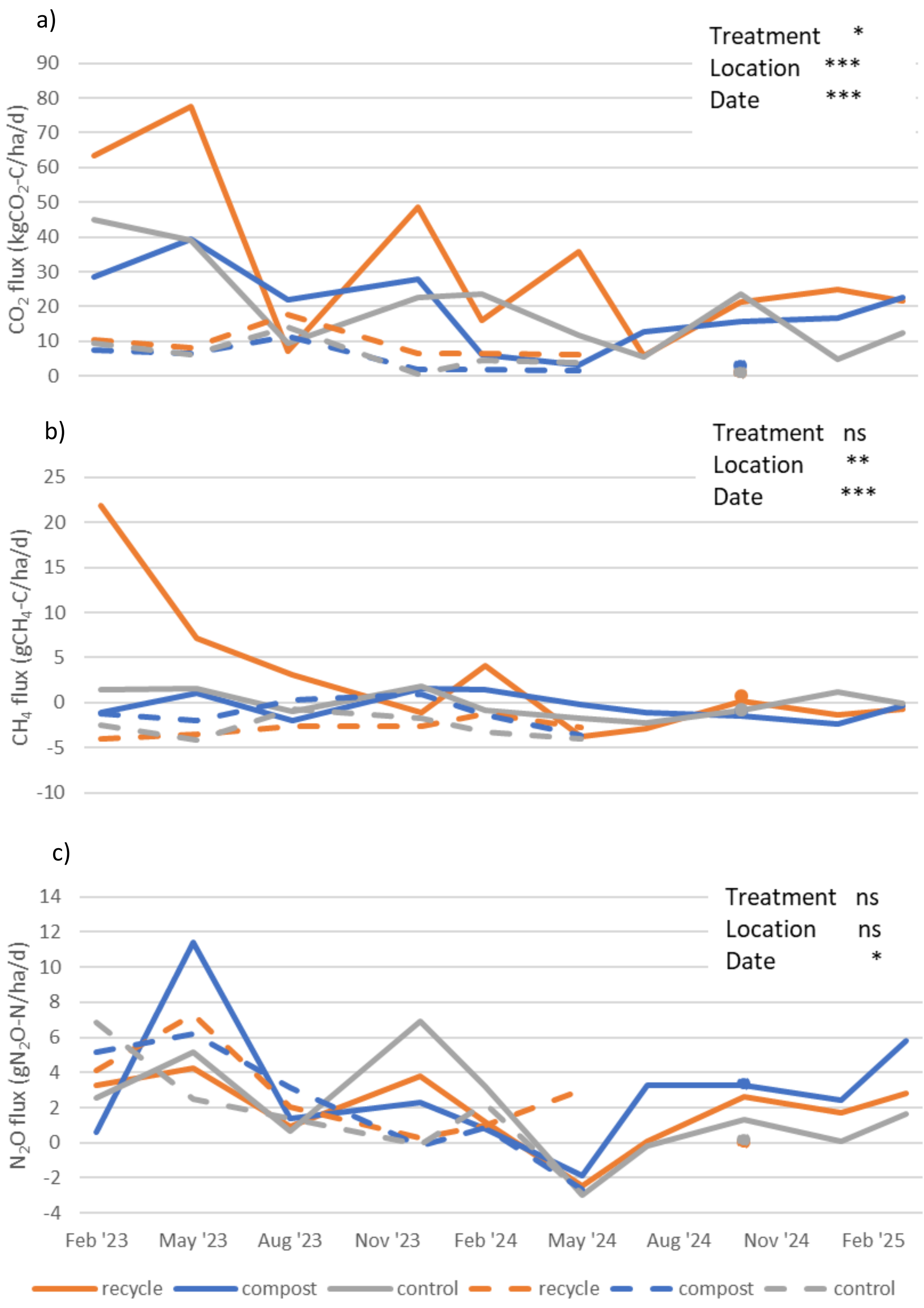

Figure 32. Carbon dioxide, methane and nitrous oxide emissions from 2023-2025. a) CO_2 flux, b) CH_4 flux and c) N_2O flux. Significant differences are indicated at $p<0.05$ (*), $p<0.01$ (**) and $p<0.001$ (***).

Midrow samples were not collected in July 2024 or January 2025, due to the equipment being damage by cultivation and then removal before harvest in February 2025. The effect of location was tested only at sampling times were both the midrow and tree row were sampled. All sampling dates were used to analyse for treatment and sampling date effect.

On average greenhouse gas emissions from the tree rows were higher than from the inter-row. This was anticipated, as more moisture, fertilizer and organic matter was present in the tree line. The carbon dioxide flux was greater from the orchard recycling treatment, likely due to the decomposition of the wood chips. The initial methane flux was also greater from this treatment, but rapidly reduced and became negligible. The nitrous oxide flux was somewhat variable over time but generally reduced. Culumber *et al.* (2025) measured weekly GHG emission from irrigated and non-irrigated locations withing almond orchards that were part of an orchard recycling trial from 2019 to 2022. Their annual GHG emission values have been converted to daily emissions and are shown in Figure 33 (carbon dioxide) and Figure 34 (nitrous oxide). They found methane emissions to be insignificant and did not report them.

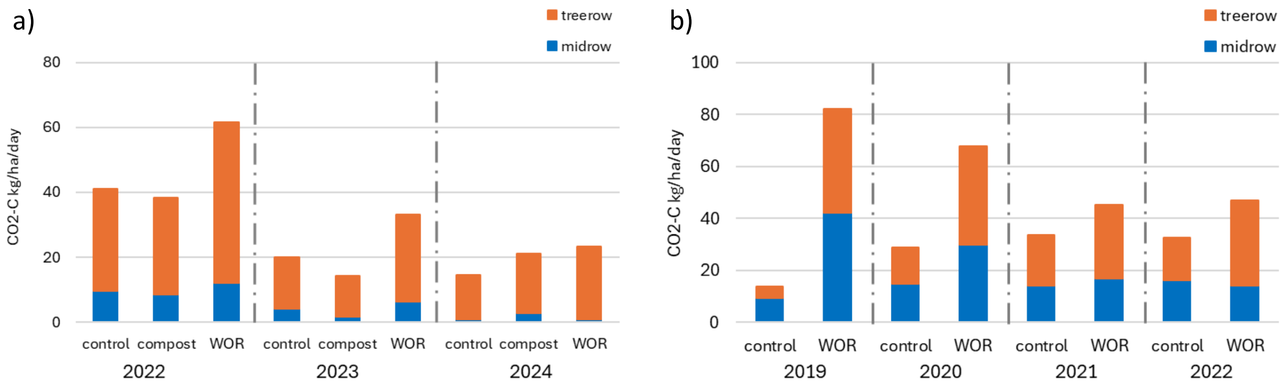

Figure 33. Soil carbon dioxide emissions from orchard recycling trials in a) Sunraysia and b) California (after Culumber *et al.* 2025).

Carbon dioxide emissions from both locations were broadly comparable, and gradually reduced over time.

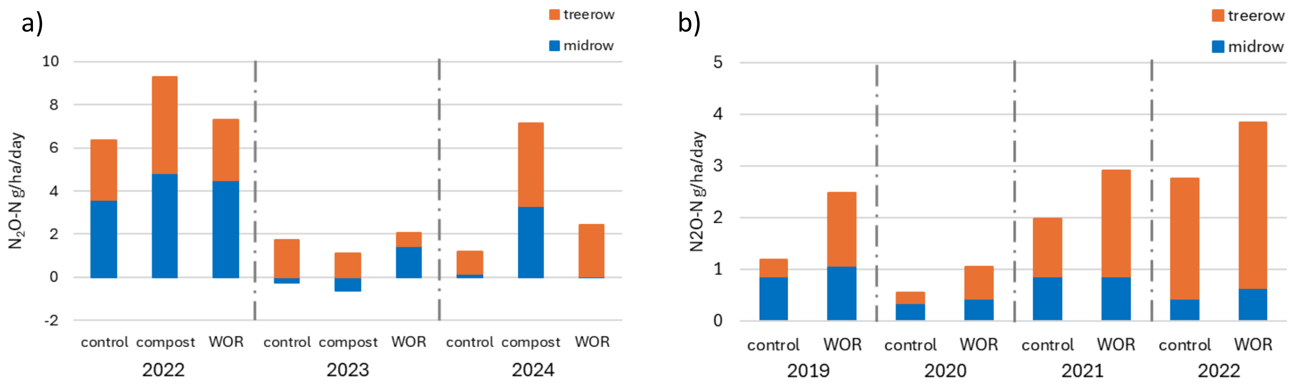

Figure 34. Soil nitrous oxide emissions from orchard recycling trials in a) Sunraysia and b) California (after Culumber et al. 2025).

Nitrous oxide emissions at Merbein were around twice as high as found in California. Direct comparisons between sites may not be warranted, though, given the differences in measurement frequency. Merbein data was calculated from individual sampling times which were 2-3 months apart, while Californian data was calculated from weekly samplings. Nitrous oxide emissions reduced over time at Merbein but were found to increase with time in California.
Culumber *et al.* (2025) attributed the increased nitrous oxide emissions to increases in N fertilisation rates as the orchard was established. At Merbein, however, N fertilisation was highest in the first year (Figure 8) and the reduction in N fertiliser may have contributed to declining nitrous oxide emissions.

Temporal greenhouse gas sampling

To better understand greenhouse gas emission dynamics repeated sampling exercise was carried out to determine whether greenhouse gas emissions varied during the day (Figure 35).

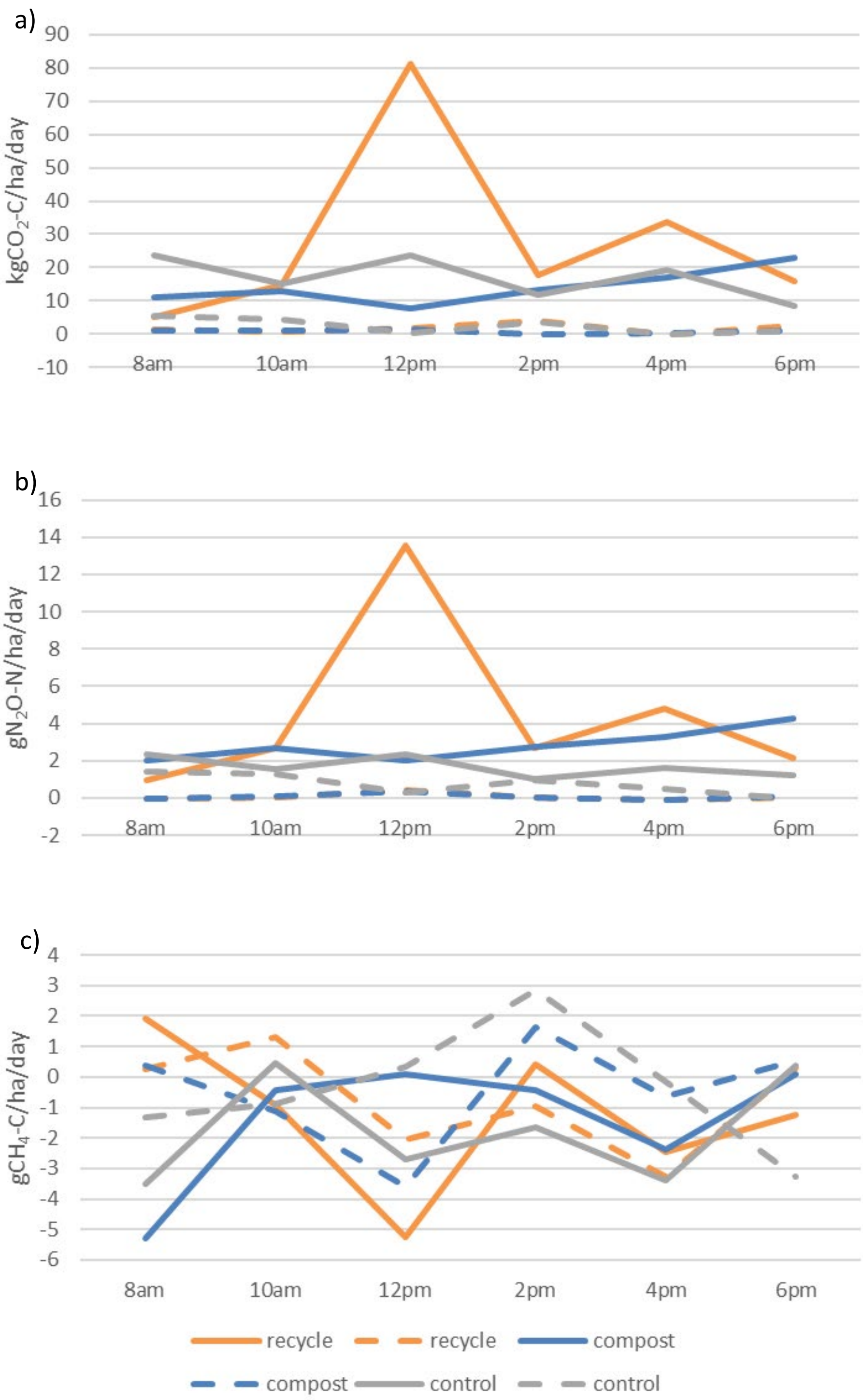

Figure 35. Temporal measures of carbon dioxide, methane, and nitrous oxide emissions in October 2024. Solid lines indicate tree row locations and dashed lines indicate midrow locations. a) CO_2 flux, b) N_2O flux and c) CH_4 flux.

Carbon dioxide and nitrous oxide emission from midrow locations was negligible and unaffected by time of sampling. This was also the case for tree row locations in the control and compost treatments. The orchard recycling tree row location, however, showed a highly elevated nitrous oxide and carbon dioxide emission at the 12 pm sampling. Methane levels were generally unrelated to treatment or location, other than a dip in methane emission at 12 pm in the recycle tree row location.

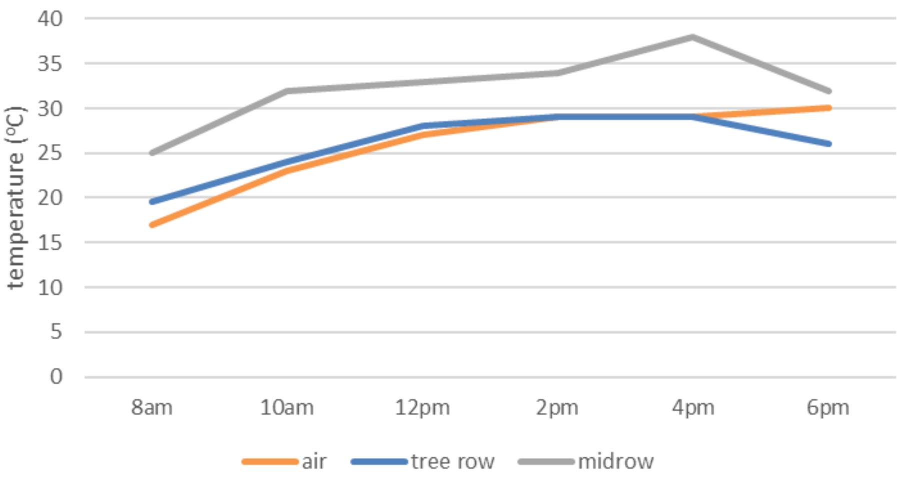

Figure 36. Air and, mid and tree row soil temperatures during temporal sampling of recycle treatment in October 2024.

There was no apparent spike in soil or air temperature associated with the sudden change in gas emission around 12 pm (Figure 36). Due to these inconsistent results, the sampling exercise was repeated in March 2025. Between the two sampling dates, midrow sampling units were damaged by cultivation and not replaced due to the impending harvest. Because of this; and that the midrow results were consistent, the six sampling locations chosen in March were six tree row sites instead of three tree row and three midrow sites. This allowed two replicates of the three treatments.

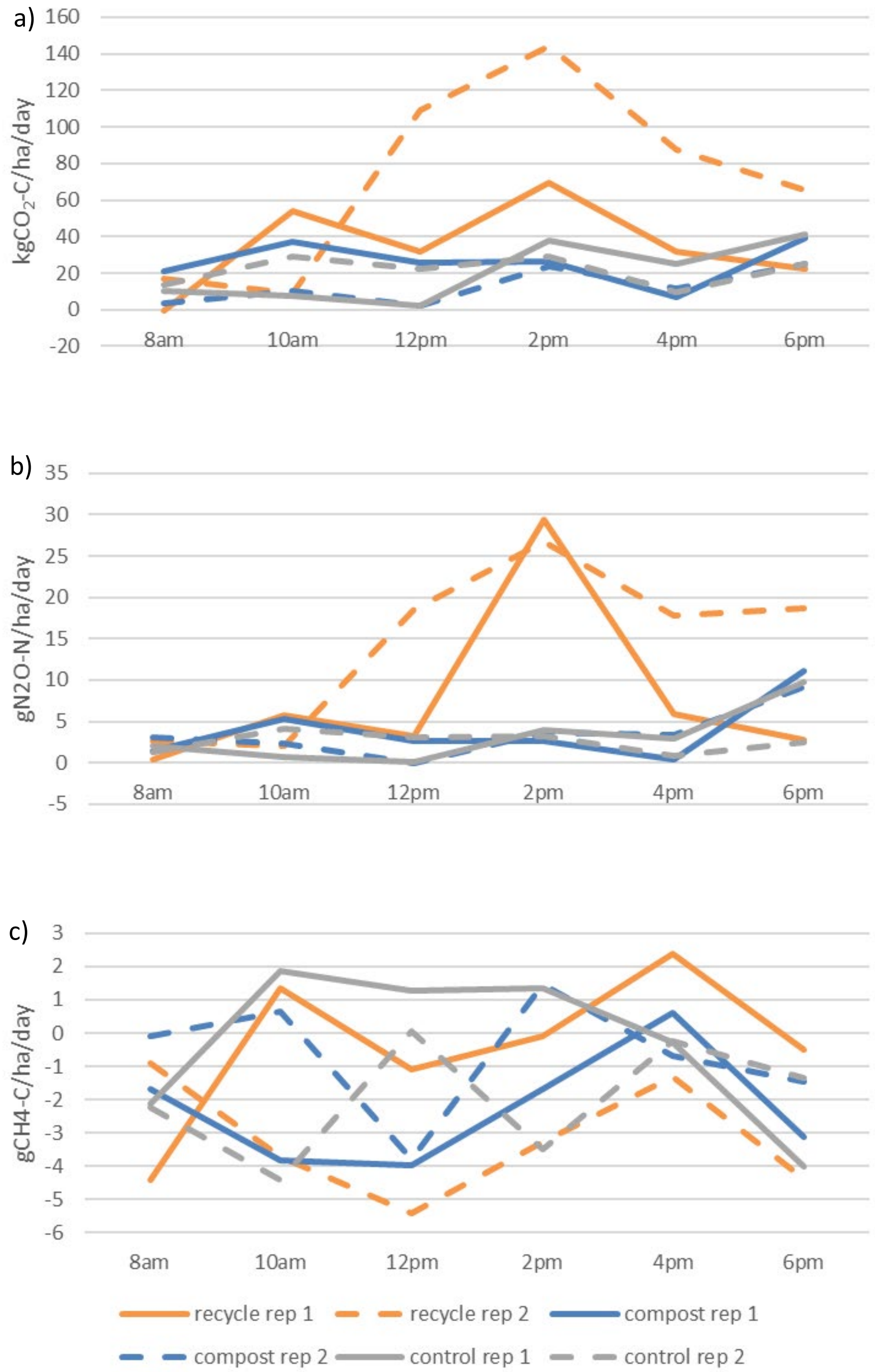

Figure 37. Temporal measures of carbon dioxide, methane, and nitrous oxide emissions in March 2025. Solid lines indicate tree row locations and dashed lines indicate midrow locations. a) CO_2 flux, b) N_2O flux and c) CH_4 flux.

Carbon dioxide and nitrous oxide emission from recycle plots was elevated with a peak around 2 pm consistent with the October sampling (Figure 37). Methane emissions were unrelated to treatment or sampling time. Air and surface soil temperatures were also slightly elevated around 2 pm (Figure 38).

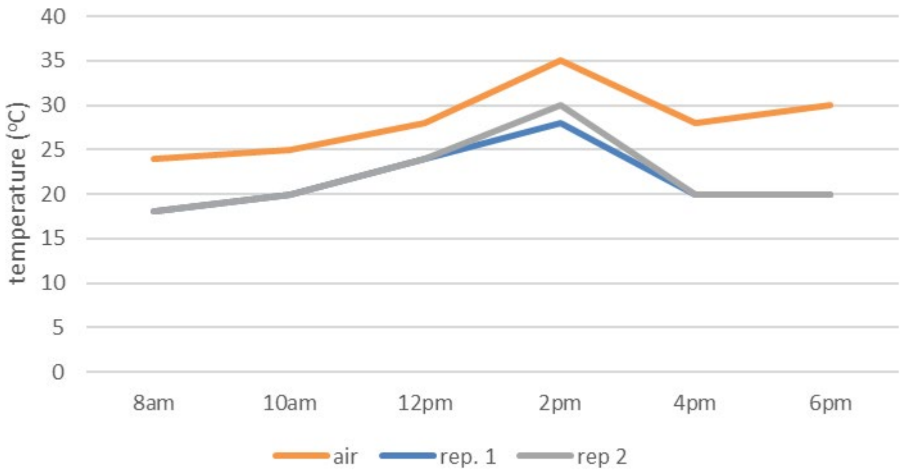

Figure 38. Air and soil temperatures during sampling of recycle treatment in March 2025.

The slight elevation of air and surface soil temperatures around 2 pm aligned with the sudden change in carbon dioxide and nitrous oxide emissions. Previous work on diurnal variation in soil respiration (carbon dioxide emission) has found an exponential relationship between respiration and soil temperature (Makita *et al.* 2019, Liu *et al.* 2016). This may explain the elevated GHG emissions at 2 pm. Higher soil temperature could have driven increased GHG emissions where sufficient microbial substrate (amendment) and soil moisture were present.

Greenhouse gas emissions from the recycle tree row locations varied during the day for both the October and March temporal sampling exercises. This may also explain some of the variability between sampling dates (as shown in Figure 32) and will need to be taken into account when developing future GHG sampling strategies. While the effects of these variations were minimised between treatments by measuring each replicate separately, a more accurate estimate of greenhouse gas emissions would be obtained by use of a continuous flow logging gas analyser at each site. This was beyond the scope of the current project.

Harvest

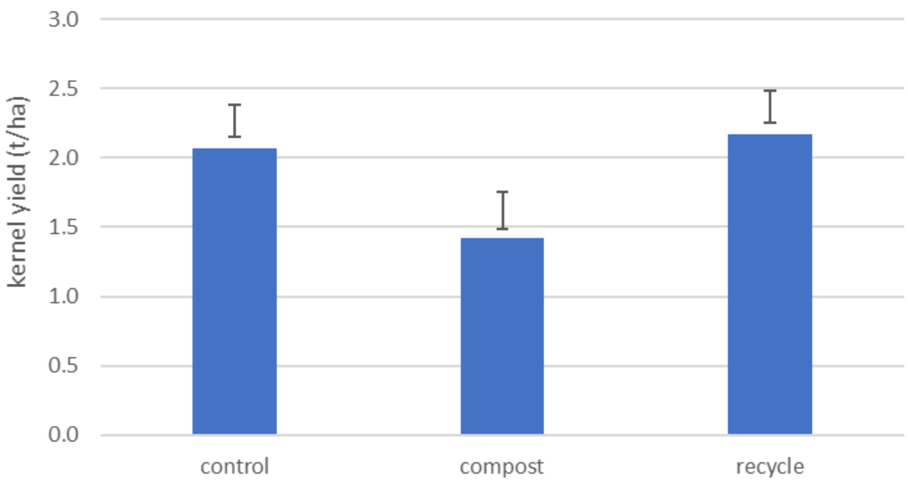

Figure 39. Yield of Nonpareil kernel harvested in February 2025 (first crop). Error bars indicate one standard error.

All trees were shaken and harvested with conventional equipment. Nonpareil trees were shaken on 8 February 2025 and nuts harvested on 11 February. There was no significant effect of treatment on nut yield of these 3rd leaf almond trees.

This is consistent with Californian results where a yield response to WOR was not achieved until at least the 7th leaf harvest (Holtz *et al.* 2018, Culumber *et al.* 2025).

Conclusions

Young almond trees established well under the whole orchard recycling treatment at the Merbein site. Tree growth rates were temporarily restricted in the first year but after that there was no penalty in tree height, light interception or harvest yield in the WOR treatment.

Soil organic carbon levels were significantly elevated and maintained in the WOR treatment, but improvements in other soil quality parameters have not been observed.

There was no evidence of disease carryover from the previous orchard, with the proviso that initial disease levels were quite low.

Some evidence of nitrogen scavenging and reduced nitrate leaching under WOR was found.

There did not appear to be major soil emissions of carbon dioxide, nitrous oxide or methane under WOR.

These findings are all consistent with those of work associated with the development of WOR in North America.

Outputs

Table 3. Output summary

Output	Description	Detail
The monitoring and evaluation (M&E) plan.	Prepared for Hort Innovation and delivered in Milestone 102.	A program logic and monitoring and evaluation plan.
Stakeholder engagement plan	Prepared for Hort Innovation and delivered in Milestone 102.	Table of relevant stakeholders and their roles within the project.
Article	External awareness of whole orchard recycling project	Northwest Farmer profile articles March 2024 (attached).
Article	External awareness of whole orchard recycling project	Australian nut grower article Autumn 2024 (attached).
Article	External awareness of whole orchard recycling project	Hort Innovation Impact Update – Sustainability Edition November 2023 (attached).
Article	Promotional industry article	Almond Bytes: 'Almond orchard recycling trial a sustainability first' (attached)
Article	Promotional industry article	South Australian Farmer, Autumn 2022. Almond orchard recycling trial a sustainability first (attached)
Conference presentation	Australian Almond Conference	Amanda Schapel presented as part of a discussion panel on Whole Orchard Recycling at the 2023 Australian Almond Conference.
Factsheet	Industry factsheet (ABA)	Fact sheet: Reducing our impact, August 2023. Almond Board of Australia (attached)
Podcast	Promotional industry episode	Victorian almond trees experience 'Whole Orchard Recycling'/ Orchard Tech, March 2022. (attached)
Podcast	ABC Radio	Victorian Country Hour (2022) Whole orchard recycling Victorian Country Hour - ABC listen
Podcast	Promotional industry episode	Tapping into Circular Economies. Innovation Ag Episode 9, May 2023 (podcast) Episode 9: Tapping into Circular Economies – Victoria Drought Resilience Adoption and Innovation Hub
Podcast	Promotional industry episode	The healthy handful: Sustainability practices in an Australian almond orchard. August 2024. The Healthy Handful
Video	Promotional industry video	Whole orchard recycling, 2022. Australian almonds (video) Sustainable almonds - Australian Almonds
Orchard walk	Women On The Land site visit	Women in almonds bus tour, 30 January 2025. Almond Board of Australia). Women in Almonds Bus Tour - Australian Almonds

Outcomes

All outcomes aim to support sustainable orchard systems, to drive productivity and profitability and align with the Almond Industry Strategic Investment Plan (2022-2026) as per below:

Outcome 1: The Australian almond industry has increased profitability, efficiency and sustainability through innovative R&D focusing on an integrated approach to plant improvement, orchard productivity, soil health, water-use efficiency, pollination, IPDM and emerging technologies.

Strategy 3: Identify options to improve water efficiency and supply, and promote healthy soils though covered cropping/mixed cropping, inter-row plantings, organic amendments, and waste stream management.

KPI: Increased water-use efficiency t/ML

Strategy 8: Enhance the understanding of the impacts of climate change on almond production system, including defining the almond industry greenhouse gas emissions footprint, and evaluating industry options for offsetting greenhouse gas impacts

KPI: Development of options for managing almond industry greenhouse gas mitigation

Table 4. Outcome summary

Outcome	**Alignment to fund outcome, strategy and KPI**	**Description**	**Evidence**
<u>Intermediate outcome</u> Increased awareness amongst almond growers of orchard recycling as a potential tool for orchard redevelopment.	Almond Industry Strategic Investment Plan (2022-2026) as above.	Strong engagement with the Almond Board of Australia has supported the widespread promotion of this project to industry. With the large area of almond trees that are due for redevelopment over the next 5-10 years awareness of Whole Orchard Recycling as a management option is the first step towards adopting this management practice.	Refer to Table 3: Output summary of extension activities associated with this project(above) A small number of commercial growers are undertaking whole orchard recycling.
<u>Intermediate Outcome</u> An initial understanding of the impact of orchard recycling for carbon farming, changes in soil health, irrigation use efficiency during orchard establishment.	Almond Industry Strategic Investment Plan (2022-2026) as above.	Whole orchard recycling was successfully implemented during orchard establishment. The trees receiving this treatment are performing at a similar level to the control trees. Elevated levels of soil carbon (as an indicator of soil heath and the potential for carbon farming) continue to be recorded under the whole orchard recycling treatment.	This report describes the impact of whole orchard recycling on soil carbon, soil health and water use during orchard establishment.
<u>End of Project Outcome</u> Initial recommendations on the use of whole orchard recycling for orchard establishment	Almond Industry Strategic Investment Plan (2022-2026) as above.	Whole orchard recycling was successfully implemented during orchard establishment under Australian conditions. The trees receiving this treatment are	This report describes these results in detail.

under Australian conditions.		performing at a similar level to the control trees. This builds on experience in the USA and supports the conclusion that following three years' experience whole orchard recycling is a technically viable management practice in Australia. Increases in yield/productivity are yet to be recorded, however overseas experience suggests it will be a number of harvests before this occurs.	

Monitoring and evaluation

Table 5. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Do almond industry levy payers regard the project investment as worthwhile and are they willing to invest in its continuation beyond orchard establishment, into the production phase?	The project has demonstrated the successful implementation of whole orchard recycling in Australia. A small number of growers are starting to experiment with whole orchard recycling on a limited scale, however access to appropriate equipment can be challenging. Significant improvements in soil organic carbon have been recorded that are likely to support carbon farming and demonstrate improvements in soil health. No improvements in yield have been observed and these aren't expected for another 3-4 seasons.	Based on experience in the USA it will likely be another 3-4 seasons before yield increases are see in the whole orchard recycling treatment. Maintaining industry commitment until this time will need a strong focus on other benefits such as carbon farming and improvements in soil health. Understanding of the cost-benefit of whole orchard recycling will support grower adoption – care must be takes to collect sufficient information so these metrics can be calculated when appropriate (likely once yield improvements are observed). Engagement with contractors that can offer a whole orchard recycling service to demonstrate a need and better establish benchmark costs. The ability to inset carbon emission is potentially an additional benefit to whole orchard recycling. The collection of information to support the development of Australian Carbon Credit Unit (ACCU) Scheme methods will increase the relevance of this project.
To what extent has the project resulted in greater awareness and interest in whole orchard recycling?	The series of communication activities (see Table 3) has maintained a high level of awareness of whole orchard recycling within the industry. A small number of growers are starting to experiment with whole orchard recycling on a limited scale.	Much of the initial communications focused on the project establishment and a visit by Brent Holtz from California in the following season. A focus on soil benefits (carbon farming and soil health) will be needed to maintain industry engagement until productivity gains are observed.
Has the project maintained an active linkage with the industry communication project?	The linkage between the Whole Orchard Recycling project and the industry communication project (as managed by the ABA) has remained very strong. Many of the publications and events completed as project outcomes have been instigated by	The whole orchard recycling trial site at Merbein is a focus point for the Australian industry. Permanent signage would allow the site to be supported by a wider range of stakeholders.

	the ABA (see Table 3 above).	

Recommendations

This project has established a platform to better understand and promote the opportunity from whole orchard recycling in Australia over the long-term. On this basis we recommend:

- The trial site be maintained with regular assessments to support carbon farming, soil pathology, greenhouse gas emissions, soil moisture, soil water nutrients, tree size and yield. This will allow the ongoing impact of whole orchard recycling on orchard sustainability and productivity to be quantified.
- Additional measurements of soil health be considered to improve our understanding of the impact of whole orchard recycling on soil microbial communities and potential effects on orchard performance.
- Additional measurements of root location and density be considered to improve our understanding of the impact of whole orchard recycling on rooting patterns and tree access to resources such as water and nutrients.
- The collation of results to support the development of a proponent lead Australian Carbon Credit Unit (ACCU) method for whole orchard recycling.

References

Brown, P.H., Saa, S., Muhammad, S., Khalsa, S.D. (2020) Nitrogen Best Management Practices. Almond Board of California, Ed. Sebastian Saa, Gabriele Ludwig, Jenny Nicolau, Ashley Knoblauch.

Culumber, C.M., Gao, S., Thao, T., Poret-Peterson, A., Zuber, C., Camarena-Onofre, D., Perez, J., Hendratna, A. and Holtz, B.A. (2025) Impact of whole orchard recycling on greenhouse gas emissions, soil carbon storage, and almond productivity in a replanted orchard. Agriculture, Ecosystems and Environment 389 (2025) 109664

Fleming, N., Fang, K., Shanmugam, K., Pitt, T. and Petrie, P.R. (2024). Assessing large-scale almond field experiments using a Mobile Orchard Phenotyping Platform. *Acta hort.* ISHS-article/1395.31

Holtz, B., Browne, G.T., Doll, D., Culumber, M. Yaghmour, M.A., Jahanzad, E., Lampinen, B. and Gaudin, A. (2018) Whole almond orchard recycling and the effect on second generation tree growth, yield, light interception, and soil fertility. Acta Hortic. 1219. ISHS 2018. DOI 10.17660/ActaHortic.2018.1219.41. Proc. VII International Symposium on Almonds and Pistachios. Ed.: M.G. Wirthensohn

Holtz, B., Culumber, C.M., Zuber, C., Browne, G.T., Yaghmour, M., Gao, S., Poret-Peterson, A., and Gordon, P. (2020). Early nitrogen fertilization is important on first-year second generation almond trees following whole orchard recycling. West Coast Nut, November, 2020, 20-26

Jahanzad, E., Holtz, B.A., Zuber, C.A., Doll, D., Brewer, K.M., Hogan, S. and Gaudin, A.C.M. (2020) Orchard recycling improves climate change adaptation and mitigation potential of almond production systems. PLoS ONE 15(3): e0229588. https://doi.org/10.1371/journal.pone.0229588

Klute A. and C. Dirksen (1986). Hydraulic Conductivity and Diffusivity: Laboratory Methods. Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods - Agronomy Monograph no. 9 (2nd Edition). Madison, WI 53711, USA, American Society of Agronomy-Soil Science Society of America.

Liua, X., Zhang, W., Zhang, B., Yang, Q., Chang, J. and Houd, K. (2016) Diurnal variation in soil respiration under different land uses on Taihang Mountain, North China. Atmospheric Environment 125 (2016) 283–292

Longbottom, M. (2014) of Australian Wine Research Institute. Greenhouse gas abatement in viticulture. NSW,SA,Vic, 2011-14 [Action on the Ground]. datalibrarian.171.7 (http://www.N_2O.net.au/knb/metacat/datalibrarian.171.7/html).

Makita, N., Kosugi, Y., Sakabe, A., Kanazawa, A., Ohkubo, S., Tani, M. (2018) Seasonal and diurnal patterns of soil respiration in an evergreen coniferous forest: Evidence from six years of observation with automatic chambers. PLoS ONE 13(2): e0192622. https://doi.org/10.1371/journal. pone.0192622

Soares, M.F., Timm, L.C., Siqueira, T.M., Vasconcelos dos Santos, R.C. and Reichardt, K. (2023) Assessing the spatial variability of saturated soil hydraulic conductivity at the watershed scale using the sequential Gaussian co-simulation method. Catena Volume 221, Part A, February 2023, 106756 https://doi.org/10.1016/j.catena.2022.106756

Intellectual property

No project IP or commercialisation to report

Acknowledgements

The authors would like to thank Neale and Debbie Bennett for hosting the project on their property, the Almond Board of Australia, especially Deirdre Jansch, for assistance and promotion, Select Harvests (Upul Gunawardena) for collaborative advice and the supply of compost. Amanda Schapel for assistance with project development and Koch Contracting, Ogyris Pty Ltd (Ian Sluter and Geoffrey Allen) for provision of technical services.

Appendices 1: Detailed Methodology

Location

The Whole Orchard Recycling (WOR) field trial was located at Merbein, Victoria (34° 10.063'S, 142° 3.596' E, elevation 53 m). Merbein is in the Sunraysia region of Australia and has a Mediterranean climate - average high/low temperatures range from 16°/4° C in July to 33°/17° C in January. Average annual rainfall of 287 mm is relatively evenly distributed throughout the year.

Removal of previous orchard and preparation of material

The previous orchard had been planted in 1992, and was removed in February 2022. Trees were extracted with an excavator and then chipped with firstly a Tana Shark Waste Shredder, then a Morbark 3400X Wood Hog Horizontal Shredder, resulting in a size which passed through a 75 mm screen. Material (wood chips or compost) was broadcast onto trial plots at a rate of around 60 t/ha with a Penta V5440 Manure Spreader. Once material was broadcast onto the soil surface, tree mounds were drawn up, transferring topsoil and associated chip or compost material into the tree row. Organic amendment was broadcast at the same rate as the removed orchard – a nominal rate of around 60 t/ha. The process of drawing soil and amendment material from tree rows 7.25 m apart into mounds 2.5 m wide, however, resulted in a local application rate of around 180 t/ha to the tree row.

The new orchard was laid out with rows of Non-pareil trees alternating with Shasta and Pyrenees pollinators. Six replicates of three treatments were applied to nine Nonpareil rows at half a row per plot. The three treatments were recycled wood chips (recycle), almond-based compost (compost) and control treatment with mounded tree rows but no amendment (control). Recycle and compost treatments had around 60 t/ha of either wood chips (recycle) or almond-based compost (Select Harvests, Wemen, Victoria) applied to soil. The eighteen plots were allocated to nine tree rows and consisted of half a tree row each. The full trial area consisted of 24 rows of 31 trees, with rows aligned east/west. There were 15 trees to each plot, with one buffer tree at the end of each row and one buffer tree in the center. Row spacing was 7.25 m and tree spacing within each row was 4.5 m. Twelve rows were planted to Nonpareil variety (even-numbered rows). This included nine treatment rows plus one buffer row to the north and two buffer rows to the south. Odd-numbered rows were planted to either Shasta or Pyrenees variety, such that the row order from north to south was Shasta, Nonpareil, Pyrenees, Nonpareil, in a repeating pattern. Treatments were applied, and measurements taken, from Nonpareil rows only.

Irrigation and soil moisture monitoring

Trees were planted with a single line of irrigation dripline (Netafim CNL 20012, 1.6 L/h at 0.40 m spacing) in August 2022. A second dripline was installed in November 2022. A nest of soil water extractors was installed at 30 cm, 60 cm and 90 cm depths in the tree row at each of nine monitoring sites in November 2022. The soil water extractors were constructed from a ceramic cup approximately 20 mm in diameter and were supplied by Kovac Engineering (Mildura, Victoria, Australia). Water samples were stored frozen in 50ml containers prior to analysis for nitrate using a continuous flow analyser at Eurofins APAL Agricultural Laboratory (Hindmarsh, Australia). An Enviropro 1.2 m capacitance soil moisture probe (Entelechy, Golden Grove, Australia) was also installed at each site, as well as a pressure sensor in the dripline (PBT pressure sensor 0-10 bar range, SICK Pty Ltd, Heidelberg West, Australia) to record irrigation run times. Soil water samplers and capacitance probes were located adjacent to the dripline 1 m from a healthy tree. Soil water samples were frozen immediately to accumulate batches for analysis and then analysed by Eurofins APAL Agricultural Laboratory (Hindmarsh, Australia) for nitrate-nitrogen content.

Sampling collars for greenhouse gas measurement were installed in February 2023 and remained permanently in tree rows and for as long as possible in midrows (up until harvest). Collars consisted of 100 m lengths of 225 mm diameter pvc DWV pipe, inserted flush with the soil surface. Collars were located either under dripline 1 m from the nearest tree, or in the centre of the midrow, in line with the tree row locations. Collars had short lengths of stainless steel 6 mm chain attached, which were used to fasten sampling receptacles during GHG sampling. Sampling collars remained in place permanently during the trial. At each sampling time, a gas sampling chamber was placed onto the sampling collar and GHG samples extracted. The chamber consisted of a 300 mm length of 225 mm diameter DWV pipe with a screw end cap on one end and a slip coupling (Storm Plastics, Edwardstown, Australia) on the other. The chamber was placed over the sampling collar and clamped onto it to provide an airtight seal. An over-center latch on each side of the chamber clamped the chamber onto the collar via the short stainless steel chains. A fixed port in the top of the chamber led to a 5 cm length of flexible pvc tubing which terminated in a tap with a Luer screw fitting.

GHG sampling procedure

Sampling was based on the method of Longbottom (2014) and scheduled for the same time each day - between 10 am and 1 pm. Gas samples were extracted by attaching a 30 ml syringe to the Luer fitting on the sampling chamber, opening the tap and flushing the syringe three times to circulate air. Thirty millilitres of sample was then extracted, and the tap closed. The syringe was unscrewed, a hypodermic needle attached, and 10 ml of sample expelled to minimise mixture of sample with the atmosphere. The remaining 20 ml of sample was injected into an evacuated 12 ml exetainer to slightly overpressure the container. Samples were collected at 0, 30 and 60 minutes after placement of the chamber. There were nine monitoring sites, and each site contained a tree row and a midrow location. Six collection chambers were used and could sample one replicate of three treatments simultaneously. Replicate 1 was sampled from 10 am to 11 am, replicate 2 from 11 am to 12 pm and replicate 3 from 12 pm to 1 pm at each sampling. Surface soil temperature at each location was measured by placing a thermometer inside the sampling collar and recording start and finish temperature of each samping. Soil moisture was measured by inserting a theta probe (Delta Devices, Cambridge, England) into the soil surface immediately before attaching the collection chamber. Ambient temperature at the start and finish of each sampling day was obtained from the Bureau of Meteorology web site by searching for “Merbein temperature”. Blank samples of ambient gas concentration were collected just before 10 am and after 1 pm. GHG samples were sent to Central Analytical Resarch Facility, Queensland University of Technology, for analysis of carbon dioxide, nitrous oxide and methane.

Soil sampling procedure

Annual soil cores were taken before and during the trial for assessment of soil carbon levels, nitrogen levels and bulk density. Samples were collected at 0-30 cm depth using a hydraulic soil sampling rig with a 40 mm diameter collection tube (Christies Engineering, Horsley Park, Australia). Samples were dried at 40°C then analysed by Eurofins APAL Agricultural Laboratory (Hindmarsh, Australia) for Carbon Farming Initiative suite CFI Texture TOP (soil texture, bulk density, nitrate, ammonium, organic carbon, gravel). Soil cores were also collected at 30-60 cm depth in January 2022 (pretrial), November 2022 (start of trial) and September 2024 (end of trial). Although these samples were collected at more than 30 cm depth, the mounds being sampled were approximately 45 cm high. Thus the 30-60 cm samples were actually around the original soil surface and contained some mound material as well as original topsoil.

Undisturbed soil cores were taken in November 2022 and September 2024 for measurement of bulk density, saturated hydraulic conductivity and soil moisture release curves. Duplicate cores were collected at 0-30 cm and 30-60 cm depths from tree rows in 2022 (all replicates) and tree rows and midrows (three replicates) in 2024. Cores were collected in steel rings 50 mm high and 74 mm diameter. Saturated hydraulic conductivity was measured by the constant head method according to Klute and Dirksen (1986). Gravimetric water content was measured at saturation and equilibrium water content after applying 3, 6 and 10 kPa suction by tension table and 60, 200 and 1500 kPa applied pressure (Soilmoisture Equipment Corp., Goleta, California). Oven-dry weights were measured after 24 hours at 105°C and soil moisture release curves were calculated.

Annual soil samples were taken to determine the rate of breakdown of wood chips in soil. The amount of wood chips in soil was assessed by the weight of material which was larger than 2 mm (measured during sample analysis) from samples collected by the hydraulic soil rig in November 2022 and August 2023, due to the absence of gravel in soil. In August 2023 and September 2024 the amount of wood chips was also measured directly as material which did not pass through a 6 mm sieve, following the method used during development of WOR (Holtz, pers. comm.). Around 20 kg of field moist soil was collected from 0-30 cm depth of 9 plots (3 replicates). Soil was air dried and passed through a 6 mm sieve. Retained wood chips and subsamples of soil were dried at 105°C for 24 hours and wood chip content reported as percentage by weight of dry sample.

Regular soil sampling (2-3 monthly) was undertaken for analysis of soil organic carbon, nitrate and ammonium. A single hand auger sample 50 mm diameter and 30 cm deep was taken adjacent to the dripline 1 m from a tree in each plot. At the next sampling another sample was taken adjacent to the dripine, 150 mm from the previous location. At each sampling time the location moved 150 mm (away from the tree). This was repeated until the new sampling location was 1 m from the next tree, at which time sampling proceeded in the return direction on the other side of the dripline. All samples were dried at 40°C and analysed by Eurofins APAL Agricultural Laboratory (Hindmarsh, Australia) for soil organic carbon, nitrate and ammonium.

DNA analyses of soil for soil borne pathogens were carried out before and during the trial to assess the risk of disease carry-over from the previous orchard. Hand auger samples were collected at 0-15 cm depth next to 6 trees in January 2022 (previous orchard) and September 2024 (WOR trial). Samples were analysed for the Hort Veg panel of soil tests (specified in Table 2) as well as almond (*Prunus dulcis*) root DNA.

Table 6. Species screened by Hort Veg Test Panel, SARDI Molecular Diagnostics

Common name	Target species
Aphanomyces root rot	*Aphanomyces euteiches*
Blackleg	*Leptosphaeria maculans*
Black dot	*Colletotrichum coccodes*
Black root rot	*Thielaviopsis basicola*
Cavity spot of carrot	*Pythium sulcatum*
	Pythium violae
Charcoal rot	*Macrophomina phaseolina*
Common scab	*Streptomyces scabies*
	(test targets the Streptomyces txtA gene)
Clubroot	*Plasmodiophora brassicae*
Fusarium basal rot of onion	*Fusarium oxysporum, F. sp. cepae*
Onion white rot	*Sclerotium cepivorum*
Pink root	*Setophoma terrestris*
Pythium	*Pythium Clade F*
	Pythium Clade I
Rhizoctonia	*Rhizoctonia solani AG2.1*
	Rhizoctonia solani AG2.2
	Rhizoctonia solani AG3
	Rhizoctonia solani AG4
	Rhizoctonia solani AG8
Root knot nematodes	*Meloidogyne arenaria, M. incognita, M. javanica*
	(test cannot distinguish between the 3 species)
	Meloidogyne fallax
	Meloidogyne hapla
Root lesion nematodes	*Pratylenchus crenatus*
	Pratylenchus neglectus
	Pratylenchus penetrans
	Pratylenchus thornei
	Pratylenchus zeae
Sclerotinia rot	*Sclerotinia sclerotiorum, S.minor*
	(test cannot distinguish between the 2 species)
Stem nematode	*Ditylenchus dipsaci*
Verticillium wilt	*Verticillium dahliae*
Almond	*Prunus dulcis*

Tree size and light interception

Tree size was measured manually while trees were small, with measuring rod (height) and callipers (trunk diameter). Once trees had grown larger, tree height and trunk diameter was measured by lidar with a Mobile Orchard Phenotyping Platform (MOPP). Light interception was measured by light sensors (MOPP) once trees were large enough to cast sufficient shadow. The MOPP is an instrument which uses GPS and geolocation of trees to create geofences and assign recorded data of tree height, size or light interception to individual trees. The MOPP has been described in Fleming *et al.*(2024).

Table 7 details the methods used to take size measurements taken at Merbein

Table 7. Tree measurements at Merbein

operation	dates	method
tree height, canopy width, trunk diameter	January 2023, August 2023	manual
tree height	August 2024, January 2025	MOPP
trunk diameter	July 2024, February 2025	MOPP
light interception	February 2024, January 2025	MOPP

Harvest

Harvest was carried out at the 3rd leaf stage in early 2025 with conventional harvesting equipment. Gross plot yield was measured by weighing the harvest bin before and after harvesting each plot. This was done by driving the harvest bin across two caravan wheel load scales (Mister Hitches Portable Wheel Load Scales 1500Kg – Towsafe V2 Model) and recording the axle weights, as well as the towball downforce and calculating total gross weight. Plot yield was calculated as the weight difference before and after harvesting each plot.

Nonpareil trees were shaken on 8 February and nuts harvested on 11 February. A subsample of nuts (1.5-2 kg) was collected from each plot during the harvest operation. The wet field weight of each sample was recorded before the samples were dried in ovens at 40°C until constant weight. The dry sample weight was then recorded, and the samples passed through a Jesse Mini-Huller to separate the kernels from the hulls and shells. All kernel weights were normalised to 5% moisture content.

Kernel weights from each subsample were used to determine crack-out percentage relative to the wet sample weight, and this percentage was applied to the wet field weight to estimate kernel yield from each plot. Kernel yield per plot was divided by the area of each block to determine kernel yield per hectare.

Appendices 2: Soil physical measures – midrow locations (2024)

The effect of treatment on soil moisture release curve is shown in Figure 40

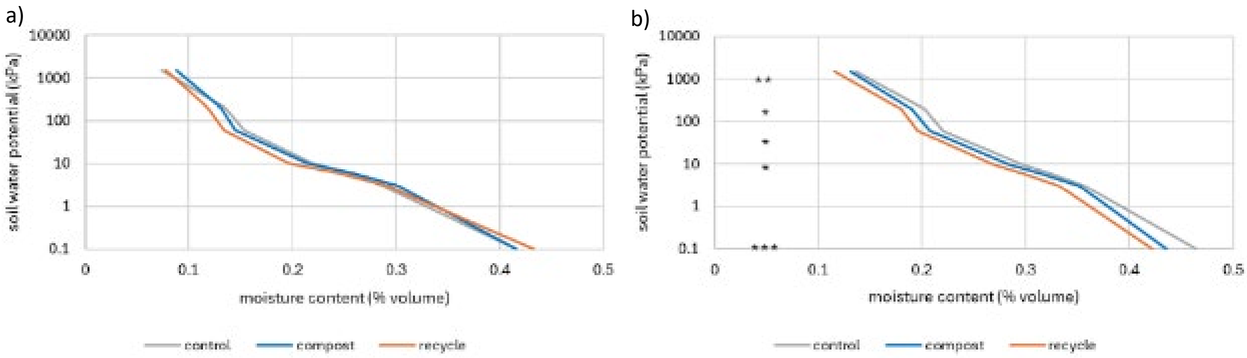

Figure 40. Soil moisture release curves of 0-30 cm and 30-60 cm samples from midrow location in 2024. a) 0-30 cm and b) 30-60 cm Significant differences between treatments are indicated at p<0.05 (*) p<0.01 (**) and p<0.001 (***).

There was no significant effect of treatment in 0-30 cm samples, but a consistently lower soil moisture in the recycle treatment of 30-60 cm samples. Thistrend was also found with the tree row locations and is likely to be due to soil type differences such as depth of topsoil. The effect of treatment on changes in soil moisture is shown in Figure 41.

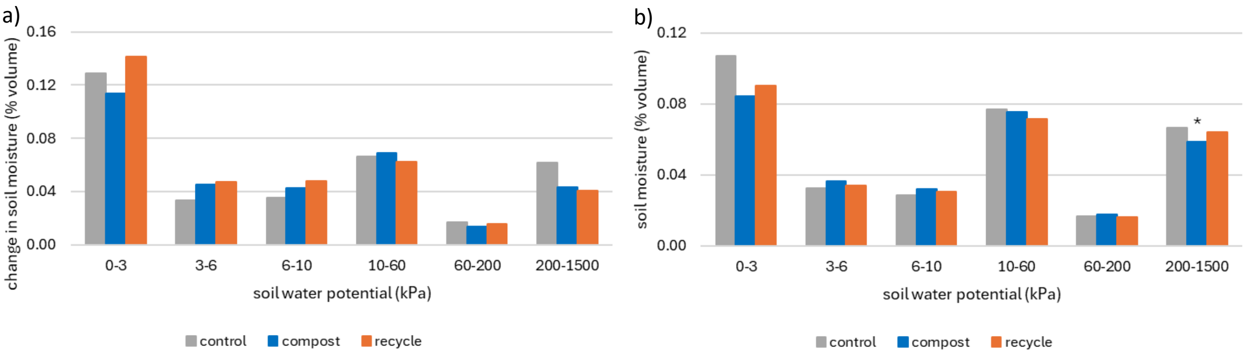

Figure 41. Changes in soil moisture of 0-30 cm and 30-60 cm samples from midrow location in 2024. a) 0-30 cm and b) 30-60 cm

There were no significant effects of treatment on changes in soil moisture at either 0-30 cm or 30-60 cm depths.

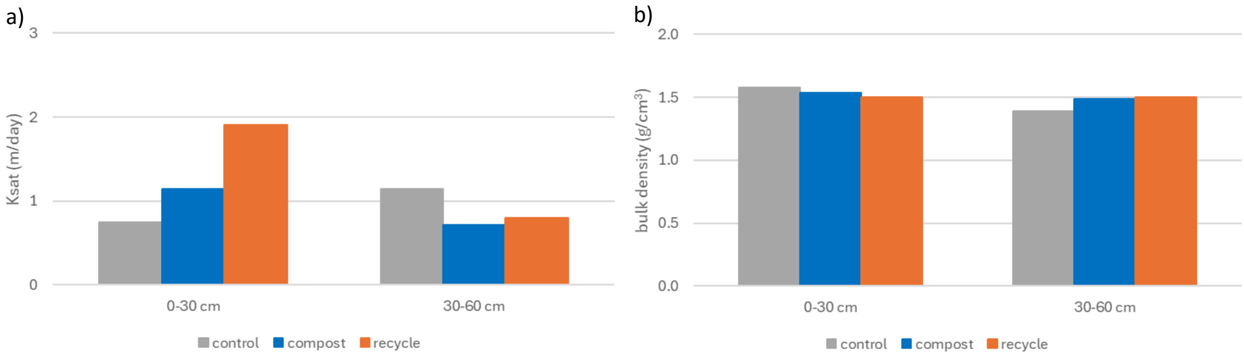

Figure 42. Saturated hydraulic conductivity (a) and bulk density (b) at 0-30 cm and 30-60 cm depths in midrow location in 2024.

There were no statistically significant effects of treatment on saturated hydraulic conductivity at either 0-30 cm or 30-60 cm depths.

Appendices 3: Old trees make way for new in recycling trial

Almond Board of Australia
Almond Bytes - February 2022
All the latest in almond industry news

Thu 10:15 AM

Old trees make way for new in recycling trial

There were mixed emotions earlier this month when the over 30-year-old trees were bulldozed at Neale Bennett's Merbein property.

These trees will be mulched using an industrial shredder and incorporated back into the orchard floor, with the orchard to be replanted in June as part of a three-year trial to quantify the impact of orchard recycling on soil carbon stores, soil greenhouse gas emissions and other soil health measures.

Another important aspect of the project is working with contractors to refine the process to get the best result, while also making it a more affordable option for growers and encouraging adoption of the practice more broadly across the industry.

Neale has been keen to trial orchard recycling after seeing the benefits achieved in California in terms of improved soil health, irrigation efficiency and productivity improvements.

The ABA has been working with Neale and SARDI on this Hort Innovation funded project.

Appendices 4: Victorian almond trees experience 'Whole Orchard Recycling'

HOME ABOUT NEWS & INFORMATION LOCATIONS INDUSTRY JOB OFFER CC

VICTORIAN ALMOND TREES EXPERIENCE 'WHOLE ORCHARD RECYCLING' 2022-03-28

VICTORIAN ALMOND TREES EXPERIENCE 'WHOLE ORCHARD RECYCLING'

Article by: Hari Yellina

To help prepare the area for fresh plants, a Victorian almond producer is burying entire 30-year-old trees. In a method known as entire orchard recycling, which has been embraced in the United States, the chipped-up lumber will be absorbed back into the soil. Neale Bennett, a long-time almond grower, said he had been watching the method blossom in California and was eager to put it to the test. "There is no doubt that we have a commitment to grow as sustainably as possible," he added, adding that "there is always an opportunity for improvement." "We all want to build long-term business models, and if that involves doing things differently, I believe our industry has a strong track record of accepting change and innovation."

Mr Bennett's farm is near Merebin, Victoria, and it has mulched roughly three hectares of 30-year-old trees. The productivity of the orchard begins to drop at this age, signalling to the producer that it needs to be renovated. The ability to use carbon and physical material to offer a perfect platform for new trees is one of the ideas' appeals. It takes the place of the old method of burning the trees once they've been removed from the orchard. Hort Innovation is carrying out the work, which is being led by the South Australian Research and Development Institute (SARDI), the Department of Primary Industries and Regions' research arm (PIRSA).

While full orchard recycling is employed in the United States, the goal of the research is to investigate if similar environmental benefits can be achieved in Australia. Almond tree trunks, branches, and roots gather considerable amounts of carbon over their lifecycle, according to SARDI lead scientist Paul Petrie, and his team will be searching for ways to harness that carbon through this study. "We want to assess the impact of entire orchard recycling on an Australian almond orchard's carbon footprint, including carbon storage and turnover in the soil, soil greenhouse gas emissions, and any effects on newly planted trees," he said.

Researchers will also evaluate potential co-benefits from orchard recycling, such as faster orchard tree development, increased irrigation efficiency, and enhanced soil health, according to Dr. Petrie. Tim Jackson, chief executive officer of the Almond Board of Australia (ABA), said the research will bring scientific rigour to the benefits of entire orchard recycling in Australian circumstances. It will help with orchard redevelopment initiatives, as well as quantifying expectations surrounding carbon farming, soil health changes, irrigation efficiency improvements, and productivity gains, he said. "The recycling outcomes on Californian soils have been warmly embraced," he said, "and are adding to the industry's long-term aspirations to become at least carbon neutral."

Victorian Almond Trees Experience 'Whole Orchard Recycling' - Orchard Tech

Appendices 5: SA Farmer profile article Autumn 2022

SA Farmer

Share ✉ f X

3 min read

NUTS

Almond orchard recycling trial a sustainability first

SA Farmer

Feb 14 2022

A SUSTAINABILITY trial in a neighbouring region focused on making use of old trees could change the way almonds are grown in the Riverland and around Australia.

Former Almond Board of Australia (ABA) chairman Neale Bennett has partnered with the ABA and South Australian Research and Development Institute (SARDI) to undertake an orchard recycling project on his Merbein property.

The traditional method of orchard upgrades in Australia has involved removing old trees, burning them and ripping the ground in preparation for planting new trees.

The environmental impact of such practices has been brought into question in more recent times, with almond growers in California and Australia exploring more environmentally beneficial methods to achieve the same results.

Mr Bennett, who has been in the almond industry for more than 30 years, has been watching Californian growers undergo whole-orchard recycling projects for several years.

He was one of the early adopters to growing almonds in the Sunraysia and has a reputation for embracing new technology.

Mr Bennett said the trial was an exciting new chapter for his orchard.

"There is no doubt that we have an obligation to grow as sustainably as possible and the whole-of-orchard recycling trial is an important part of that," he said.

> "The way we manage our orchards has changed enormously since I planted those first trees 30 years ago. I think some might underestimate our sustainability credentials."

Ironically, Mr Bennett's first patch of almonds, just under 3ha, will be the focus of the first orchard recycling trial conducted in Australia.

It will involve bulldozing the trees, mulching them and then returning the organic matter to the freshly ripped orchard floor before replanting.

ABA CEO Tim Jackson said the trial would support growers to integrate whole-orchard recycling into their redevelopment programs, with clear expectations around carbon farming, changes in soil health, irrigation-use efficiency and productivity improvements.

He said the recycling results on Californian soils have been widely embraced and are contributing to longer-term aspirations for the industry to become at least carbon neutral.

"Almond growers are all about embracing the most sustainable practices available and this trial is yet another example of that commitment," he said.

The trial is based on the fact that almond trees accumulate significant amounts of carbon during their lifecycle.

When an orchard reaches the end of its commercial life, this resource is traditionally managed through burning as part of the orchard redevelopment.

While burning is a quick and effective means to clear debris from the site and can reduce pathogen load, it also releases a significant amount of carbon that could potentially be sequestered or at least incorporated to improve soil organic matter, fertility and help with the establishment and productivity of the new orchard.

The trial at the Bennett orchard aims to quantify the impact of whole-orchard recycling on the carbon footprint of an almond orchard, including the impact on carbon storage and turnover in the soil, soil greenhouse gas emissions and the carbon accumulation by the newly planted trees.

It will also assess any co-benefits such as improved irrigation-use efficiency and soil health, and potential negative impacts such as increased pressure from soil pathogens and potential for nitrogen drawdown.

Data collected will be used to inform the Australian Life Cycle Assessment and as data input into approved carbon market methodology.

Mr Jackson said the trial would complement the industry's soon-to-be-launched sustainability framework that has been developed to equip industry members with the tools and knowledge to meet the expectations of today's consumers.

Appendices 6: Industry factsheet (Almond Board of Australia)

Australian almond growers are committed to reducing their negative impact on the environment. This includes reducing waste and carbon emissions, striving for more efficient irrigation, increasing biodiversity, supporting pollinator health, and improving pest management and biosecurity. As an industry, it's important for us to strive for continuous improvement and seek to be the best we can.

Biodiversity

Biodiversity benefits almond growers by promoting soil health, contributing to natural pest control, and supporting native pollinators. Many of our growers plant native vegetation to support biodiversity, not just so they can reap the benefits but as a means of giving back to their local environment.

Whole Orchard Recycling

Whole Orchard Recycling is a process where almond trees at the end of their lifecycle are mulched and returned to the orchard floor. Research conducted in Californian almond orchards has identified significant advantages of Whole Orchard Recycling, including increased soil matter and increased water holding capacity.

Neale Bennett hosts the first Whole Orchard Recycling study of its type in Australia at his Merbein property.

australian almonds

www.australianalmonds.com.au

Appendices 7: Northwest Farmer profile articles March 2024

North West Farmer

THE MALLEE'S FARMING NEWSPAPER

FOLLOW US ON FACEBOOK AND AT NORTHWESTFARMER.COM.AU

MARCH 2024

MSF SIGNS A NEW STAR — Page 2

FARMING ADVOCATE HONOUR — Page 8

GOOD AMID WINE GLOOM — Page 12

Recycling revolution on almond farms

Merbein almond grower Neale Bennett's family represents more than 110 years of business on the same blocks, yet he has happily handed over three hectares so researchers can investigate the whole-orchard recycling phenomenon and whether it will be viable in the long-term for the industry in Sunraysia.

STORIES – PAGES 18-21

- On-farm pricing
- In-store pricing
- Shed clean-ups
- Price on results
- Consignment
- Forward pricing
- Re-classing service
- Prompt payment

Northern Wool is a locally owned wool buying business in Swan Hill & district providing growers with on-farm and in-store pricing, shed clean-ups, price on results, consignment and re-classing services

Northern Wool

Tony Keam Wool Buyer 0427 993 041

AH: (03) 5032 9547 F: (03) 5032 2032 E: tony-keam@bigpond.com

15 Shepherd Road, Swan Hill

A history of hard yakka

Just like his pioneering farming family, Merbein's Neale Bennett has no hesitation taking on daunting projects beyond his own property. ANDREW MOLE reports.

MERBEIN almond grower Neale Bennett's great-grandfather might struggle to find his bearings on the family farm today – what it's growing, how many farms there are, the houses, the roads, the flushing toilets and nary a bullock dray in sight.

When he and his brothers decided to take up a block in Sunraysia, it wasn't just something of a midlife crisis, it was a journey so convoluted and confronting it's incredible they even reached the Murray.

Melbourne-based plasterers by trade, the boys had missed the first allocation of land in the district.

In 1910, long before anyone thought of soldier settlement, when a second round was announced, they couldn't resist it.

However, Neale says getting the land was one thing, getting there proved a different challenge altogether.

"These were the days when the men were men and the womenfolk and children were left behind until land was cleared, some sort of home was built and crops could be planted," he says.

"But once my family had the land title, they needed the money to get to Merbein, to keep them going while the land was cleared and some infrastructure put in place, so instead of heading north to the Murray, they went west to Casterton, near the SA border in the depths of the state's western districts.

"They had got a contract there to do all the pavements in the town and that was going to be their cash for the trip to Merbein and whatever their future held."

From there, in true pioneer style, the dray was loaded and the walk north began – day after day.

But Neale says it was only after they arrived that the seriously hard work began.

He says their block came with every available native grass, bush and tree, and they all had to go. Water had to be secured, swags and tents replaced by homes with some air of permanence, and crops planted.

Try getting someone to tackle all that today – just to get a start.

"But once they had got that far, they were able to send for their families, who had been left in town all this time, and when they arrived, the focus was on infrastructure," Neale says.

"And they were still relying on off-farm work – at one point, that even included building a local church.

"The one thing of which there was no shortage around here was limestone and not only did that play a big role in construction, but because they were plasterers by trade, they soon set up a lime-burning operation, which had a double bonus."

When you burn limestone, which is basically calcium carbonate, you end up with quick lime (or calcium oxide).

When mixed with water, this produces slaked lime, calcium hydroxide. When slaked lime or quick lime was added to the land, it raised its pH and so improved its fertility. Slaked lime was also used as lime putty for building.

"Eventually, the homestead got finished and it is still standing there, with some of my cousins owning the land," Neale says.

"Then, as if one generation of pioneers wasn't enough, my grandfather decided he would strike out on his own so he, literally, went across the road and took up his own land.

"Which came with every available native grass, bush and tree, and they all had to go. And they did go, but we are still here."

Neale's grandfather cleared two 8.5-hectare blocks and that remains – by and large – the farm Neale runs today with his wife, Debbie.

He reckons he is on target to finish this year's harvest by Easter.

On the surface, that might not sound the world's biggest achievement, since 17ha is hardly daunting when you are equipped for mechanical harvesting.

But this is the point where Neale also concedes he is something of an impulse farmer, which he has regretted more than once.

In 1992, he was facing yet another series of challenges in the dried-fruits industry, in which he and his family had been engaged since circa 1910.

Pulling right out of the family history to do what he believed would be the best decision for his and his family's future, generated a fair bit of comment – and amusement – among neighbours and peers at the time.

"At times it was a bit like being in that old TV show *Greenacres*, where the city executive moves to the country and buys a farm and bumbles along from season to season," Neale says.

"This had been grape country for a long time, but things were getting challenging and things were happening which pushed us towards change.

"I was already thinking about diversifying. The dried-fruit market had been deregulated, labour costs were soaring and plenty of our plantings had

Merbein almond grower Neale Bennett. His family has been farming the same Merbein land for more than a century. Picture: Ben Gross

The modern face of the local almond industry when it comes to making the most of machinery.

RIGHT: This house was built by Neale's grandfather and is still home to his 85 year-old mother.

RIGHT: Hot dipping the sultanas in the old days at Merbein, which helps them dry quicker and gives them a nice golden colour. The dip was usually a mix of dipping oil, a vegetable-based oil and potash, heated in hot water. The grapes were dipped in the mix by hand after having been picked into dip tins (steel containers with holes that allowed the dip mixture to run out).

passed their use-by date.

"We could see the emergence of almonds as an opportunity, you could machine harvest, there was a lot of investment coming into the industry, it seemed a good decision to make."

A decision which today sees almost 4000 trees across the Bennett family's two blocks, and in a normal year that would deliver somewhere between 42 and 45 tonnes.

But there was no stopping Neale now – his impulse urges were going into overdrive.

He says there were a few small almond growers like him so they initially got together to help each other, and then came up with the bright idea of getting more machinery and going into contract harvesting.

As if he had nothing else to do.

"In 2014, we were approached by a corporate grower and on the back of a five-year contract, and in a rush of blood, said we would be in it," Neale added, shaking his head.

So when Neale says he hopes to have harvest finished by Easter, he means his 17-odd hectares plus another 970-plus hectares.

By Easter. That's two weeks away.

But as big a headache as it has been from time to time, Neale says they have been very lucky because they have been able to hang onto about 75 to 80 per cent of their original workforce.

"Labour is always the trick and to have this team stick together is great and does make things a lot easier to manage than my impulses may have initially allowed," he says.

He is also encouraged by the current harvest, a big step back to normality after the disaster of the previous season.

A normal year on the Bennett blocks yields about 42 to 45 tonnes of (mostly) nonpareil almonds but last year that was just 36 tonnes.

Neale believes Select Harvests copped a bit of harsh publicity when its $115 million loss was plastered all over the media and wider world.

He says it wasn't just almonds, right across horticulture it had been a very tough year.

"It was a year which had been way too wet, and too cold," Neale added.

"Like most irrigators, we do our fertigation through the drippers and they weren't running anywhere near normal levels because of all the rain so we were already underdone for nutrients.

"Then all that cooler weather hardly helped the nutrients that were delivered synthesise, so we ended up with a lot of flatter almonds.

"Even worse, the varroa mite incursion stopped movement of hives across the Victoria-NSW border and that further reduced productivity, so all of us, from Select Harvests to small production units such as ours, were hit hard by those conditions.

"But now things look a lot better, it's not wet, yields seem OK and there are fewer problems, so it's a matter of putting that bad harvest in the rearview mirror and focusing on rebuilding."

Neale says the previous harvest has also made sure everyone is going as fast as they can to get this one off the trees while weather conditions remain good.

The production target is to deliver processors – in his case Almondco in South Australia's Riverland – a crop with a 5 per cent moisture level in the kernel. That is the optimum level as the moisture impacts the quality of the final product and the 5 per cent gives you "the crunch" in your almond.

Neale's kernels are air-dried, with the process starting with shakers at the trees, windrowing and then the conditioner is used to constantly turn over the kernels, clean out the twigs and leaves, and prepare the crop for processing.

"We grow mostly Nonpareil, using Price and Carmel as our pollinators – but we have put in a trial patch of Shasta, a new self-fertile variety from California. It went in last year and we should start seeing some results in the next two or three years."

The pollinators are also used for value-adding in products such as the slivered, flake or almond meal market.

Speaking of the next two or three years, Neale is also one of the driving forces behind a whole-orchard recycling project being run on a few of his acres in partnership with the South Australian Research and Development Institute exploring ways to save water, boost productivity, and enhance carbon sequestration as a viable alternative to the traditional burning of trees past their use-by dates and being removed for replacement.

All good results that might help protect his business from the ongoing varroa management challenges, the market fluctuations and all the rest – and then everything will be fine.

Until the next problem emerges.

And it will, Neale concedes. Or it just wouldn't be farming.

Recycling's a meal

Pictured at Neale Bennett's Merbein whole-orchard recycling trial, which could revolutionise the industry, were Almond Board of Australia's Deidre Jaensch, SARDI's Paul Petrie and Nigel Fleming, University of California Cooperative Extension's Brent Holtz, grower Neale Bennett, and Hort Innovation's Nicole Byrnes.

I have been contacted by a number of constituents who share my outrage over the federal government's multi million dollar, taxpayer funded, Murray Darling Basin advertising campaign.

These ads, which have been airing on commercial TV networks for a number of weeks, falsely portray NSW farming families as environmental vandals and I am working towards having them taken off air.

The TV commercial blames NSW farming families for the state of the rivers, when water mismanagement by the federal government is responsible for the shocking state of our system.

I am calling on federal Water Minister, Tanya Plibersek, to take this dishonest government advertisement off-air immediately and to scrap the entire campaign.

We should never be portrayed as environmental vandals.

If you haven't seen the ad, below is the full transcript:

"The Murray-Darling rivers pump life through our nation. To our farms, communities and environment.

But water's being overused. And the next drought is only a matter of time.

We have to make sure there's enough water, otherwise the rivers may run dry.

If we don't act, it could threaten our iconic Aussie plants and animals, our food supply, and affect the drinking water of more than three million Australians.

Find out how the Australian government's plan will restore the Murray-Darling rivers.

Authorised by by the Australian Government, Canberra.

Helen Dalton
MP for Murray

Authorised by Helen Dalton MP, Funded using Parliamentary Entitlements.

GRIFFITH: 104 – 110 Banna Ave, Griffith NSW 2800 P: 02 6962 6644

DENILIQUIN: 228 Cressy St, Deniliquin NSW 2710 P: 03 5881 7034

BURONGA: Midway Centre, Midway Dr, Buronga NSW 2739 P: 0475 683 288

murray@parliament.nsw.gov.au

ticket for almonds

PROGRAM leader Professor Paul Petrie and his team are working hard to revolutionise the long-term management of Sunraysia's almond industry and from there, eventually, all of Australia's almond growers.

It's just that he is doing it in slow motion. Patience, Prof Petrie says, is a virtue in the almond industry and most perennial horticultural crops, as they take at least three years from planting to the first commercial harvest.

The concept he is exploring is whole-orchard recycling (WOR) – potentially a more environmentally friendly approach and a system which grew out of California's severe clean-air regulations, where they are unable to burn trees when the orchard reaches the end of its life.

"Almond orchards have a lifespan, after about 20 years the tree's productivity starts to drop off, so the growers need to redevelop, maybe planting new varieties and replacing infrastructure," Prof Petrie said.

"Unfortunately, when an orchard reaches the end of its commercial life, this resource is traditionally managed through burning as part of the orchard redevelopment.

"While burning is a quick and effective means to clear debris from the site and can reduce pathogen load, it also releases a significant amount of carbon that could potentially be sequestered or at least incorporated to improve soil organic matter, fertility and help with the establishment and productivity of the new orchard.

"Almond trees accumulate significant carbon during their lifecycle and the trial will explore the use of this resource as part of the orchard re-establishment.

"WOR looks at grinding the trees into chips and applying them as soil amelioration to the newly replanted almond orchard, with the long-term goals of less water, productivity benefits and an increased carbon sequestration.

"We are using about 3 hectares of Merbein producer Neale Bennett's land for the project, and he has just planted a mix of nonpareil with pollinators Pyrenees and Shasta, so at the moment we are monitoring tree establishment and growth, soil moisture, greenhouse-gas release and soil carbon levels."

The trial at the Bennett orchard aims to quantify the impact of whole-orchard recycling on the carbon footprint of an almond orchard, including the impact on carbon storage and turnover in the soil, soil greenhouse-gas emissions and the carbon accumulation by the newly planted trees.

It will also assess any co-benefits such as improved irrigation use efficiency and soil health, and potential negative impacts such as increased pressure from soil pathogens and potential for nitrogen loss.

"As the original organic matter from the ground trees breaks down, it draws nitrogen out of the soil – this can impact on tree growth and establishment, and needs to be managed carefully with judicious nitrogen applications," Prof Petrie said.

"The project is not quite two years' old yet, and it will be at least another two before we are able to harvest any nuts, so we will not have any tangible yield results until the end of next year."

Almond Board of Australia chief executive Tim Jackson said the Bennett WOR trial would "add significant rigour to the benefits of whole orchard recycling in Australian conditions.

Mr Jackson said it would help with orchard redevelopment programs and help quantify expectations around carbon farming, changes in soil health, irrigation use efficiency and productivity improvements.

He said the recycling results on Californian soils have been widely embraced and were contributing to longer-term aspirations for the industry to become at least carbon neutral.

"Almond growers are all about embracing the most sustainable practices available and this trial is yet another example of that commitment," Mr Jackson said.

"The global expectation around improving the sustainability of how you do business is not lost on our industry.

"A commitment to firstly measuring the achievements across the industry so far and tackling areas of improvement is gathering momentum farm by farm, processor by processor.

"The ABA has been consulting widely across the industry and beyond regarding sustainability in order to develop tools to support, educate and guide stakeholders of all sizes who are committed to being part of the Australian sustainable almonds program."

The whole-orchard recycling trial is managed by the South Australian Research and Development Institute, from its labs based in Loxton and Adelaide, and supported by Horticulture Innovation Australia.

"Unfortunately, when an orchard reaches the end of its commercial life, this resource is traditionally managed through burning"

Nitrogen boost for balance

GROWERS who do whole-orchard recycling may need to apply nitrogen as a fertiliser at greater rates than what is normally recommended for trees in their first leaf.

Returning 26 tonnes of wood chips to the soil per hectare provides 180kg of nitrogen, 348kg of calcium, 116kg of potassium – as well as almost 30,000kg of carbon.

These nutrients will not be immediately available to the next-generation orchard, but as the woody material decomposes and soil organic matter increases, the stored nutrients will be released gradually and naturally.

While the large amounts of organic material added to the soil by WOR have many benefits, they can create an imbalance in the ratio of carbon to nitrogen in the soil, which can lower the availability of nitrogen from fertilisers in the newly planted orchard.

Brent Holtz, the University of California Cooperative Extension county director and farm adviser – and architect of the WOR concept – recommends:

- Growers apply at least 170-225mg of actual nitrogen per tree 9-20kg per hectare in the first year of tree growth following whole orchard recycling. After the first year of tree growth, growers can return to typically recommended rates of fertiliser nitrogen application.
- Nitrogen should be applied early in the season.
- Nitrogen applications should be spread out so that no more than 28 grams of actual nitrogen is applied per tree per application in the first year of tree growth.

Appendices 8: Australian nut grower article Autumn 2024

Whole Orchard Recycling expert visits Australia

A Whole Orchard Recycling (WOR) trial that's underway in a Merbein almond orchard has drawn lavish praise from the Californian founder of the revolutionary process.

Brent Holtz giving a presentation on Whole Orchard Recycling to almond growers at the Merbein site.

Brent Holtz from the University of California Cooperative Research spent time at the 2.6 hectare trial site in mid January and said it was just as good as anything being done in California.

"I was excited in California when growers first started listening to me and started implementing Whole Orchard Recycling and it's been even more rewarding to see it actually being done now in Australia," he said.

The WOR process is enacted when orchards reach the end of their productive life: the trees are pulled out, chipped up and the woody material is incorporated into the soil prior to replanting.

Dr Holtz's oldest WOR trial is 23 years old and significant increases in soil carbon and soil organic matter are still being observed.

WOR has taken off in California, largely due to air quality concerns.

"The San Joaquin Air Pollution Control Board has given growers incentives not to burn their orchards but to recycle them, Dr Holtz said.

Funding is also available for companies to purchase the equipment required to recycle orchards.

Since the inception of the program alternative orchard and vineyard removal practices have been used on more than 162,00 acres of farmland.

Dr Holtz said as the timber breaks down, it helps the almond trees grow and improves the soil.

The Almond Board of California said this practice has many benefits:

- 19% increase in yield
- 58% increase in soil carbon
- 17% increase in soil nitrogen
- 42% increase in organic matter
- 19% increase in soil aggregation
- 32% increase in water holding capacity

The new almond trees at Merbein WOR site are only 18 months old, but researchers from the South Australian Research and Development Institute (SARDI) are keeping a close eye on the trial site to see if the Californian WOR results can be replicated in Australian conditions.

"We've seen in winter time a 42 per cent increase in our water holding capacity with whole orchard recycling in California and I think, in general, the soils in Australia are even sandier than those in California so I would expect you would see even a greater increase in Australia for whole orchard recycling," Dr Holtz said.

(From left to right) Deidre Jaensch, Almond Board of Australia, Paul Petrie, SARDI, Nigel Fleming, SARDI, Brent Holtz, University of California Cooperative Extension, Neale Bennett, almond grower and Nicole Byrnes, Hort Innovation

Since 2018, $185 million in grants has been allocated and it isn't just the almond industry that's benefitting.

Grape, walnut, citrus, plum, peach, cherry, nectarine, olive and apricot growers have obtained incentives through the San Joaquin Valley Air Pollution Control Board.

In Australia, 40 per cent of the almond orchards are 20 years of age or older, so many growers will need to consider whether they redevelop in the next five to 10 years, but no such subsidies exist.

WOR is more expensive than the conventional practice of setting fire to piles of old trees but the environmental benefits are hard to ignore.

More Australian growers could be enticed to use WOR if there were government incentives and this is something the Almond Board of Australia says it is eager to explore with state and federal agencies.

Appendices 9: Hort Innovation Impact Update – Sustainability Edition November 2023

ARTICLE

Sustainability quest propels almond R&D agenda

Publication date: 27 November 2023

For anyone wanting to know just how seriously Australian horticulture views the importance of sustainable production, they need look no further than the nation's almond industry.

The almond industry long ago recognised that sustainability was not just a hollow buzz word but in fact a guiding principle in its quest to cement a vibrant future for its growers.

Sustainability is very much at the core of the industry's research and development investment agenda, according to Hort Innovation head of sustainability research and development, Kathryn Young.

"It is an industry priority clearly set out in the Almond Strategic Investment Plan (SIP) 2022-26 which is a roadmap to guide Hort Innovation's investment of almond industry levies and Australian Government contributions," Ms Young said.

"Supporting sustainable orchard systems through an integrated approach focused on plant improvement, orchard productivity, soil health, water use efficiency, pollination, insect pest and disease management, and emerging technologies is the industry's highest priority, as detailed within the SIP.

"This industry priority is the catalyst for Hort Innovation continuing to invest – on behalf of growers – in a suite of R&D programs employing innovative technologies and approaches to equip growers with new knowledge and tools to bolster their sustainable farming practices and long-term viability."

Whole orchard recycling is the focus of one of the investments that sits under the 'pathway to carbon neutral' project theme umbrella.

The project is quantifying the impact of whole orchard recycling on the carbon footprint of an almond orchard, including the impact on carbon storage and turnover in the soil, soil greenhouse gas emissions and carbon accumulation by newly planted trees.

The information gathered through this project will support almond growers to integrate whole orchard recycling into their orchard redevelopment programs by demonstrating the potential of carbon farming, changes in soil health, irrigation use efficiency and productivity improvements.

Delivered by the South Australian Research and Development Institute (SARDI), the project is assessing any co-benefits from orchard recycling such as more rapid orchard establishment, as well as potential negative impacts such as increased pressure from soil pathogens and potential for nitrogen draw down.

Almond trees accumulate significant amounts of carbon through their trunks, branches and roots during their lifecycle. When an orchard reaches the end of its commercial life, this resource is traditionally managed through burning as part of the orchard redevelopment.

While burning rapidly clears debris from the site and can reduce pathogen load, it also releases a significant amount of carbon that could potentially be sequestered or at least incorporated to improve soil organic matter and fertility, and help with the establishment and productivity of the new orchard.

The alternative to burning prior to replanting is pulverisation of the perennial portion of the almond trees and incorporation into the soil prior to replanting (known as whole orchard recycling).

Victorian grower Neale Bennett first saw whole orchard recycling in action in California in the United States some years ago when attending a conference where the multiple benefits of incorporating mulched tree matter into the soil were reported.

"While a couple of growers here in Australia have been mulching one or two rows of old trees, until now there hasn't been any scientific measurement of the effects on water retention, soil structure, organic matter and carbon levels," said Mr Bennett, whose family-owned and operated orchard at Merbein is hosting trials for the whole orchard recycling project.

"We need to prove to industry and the wider community that this practice is a viable alternative to burning. We want to grow almonds in an environment where we're focusing on waste reduction, improving water usage and improving nutrient application and uptake – not just for the benefit of our production systems but also because that is what society is asking for.

"We are already doing that to a large extent – for instance, we've moved from 95 per cent sprinkler irrigation to 99 per cent targeted drip irrigation – but this research will hopefully enable us to magnify our sustainability efforts and the positive impact," Mr Bennett said.

Another 'pathway to carbon neutral' project being funded through Hort Innovation is focused on life cycle analysis in almond orchards.

Led by Edge Impact, this project is undertaking a life cycle assessment of the almond production at the industry level, with the intention of identifying sustainable practices in the industry and reducing the production of carbon emissions. This will be executed through:

- Developing future greenhouse gas emission reduction initiatives
- Raising awareness across the industry of its footprint
- Developing the capability of the industry to undertake future assessments
- Helping to position the industry for domestic and international opportunities that may arise from becoming carbon neutral and in the generation of carbon offsets.

Exploration of cover cropping as a management practice in Australian almond orchards is the subject of another Hort Innovation investment.

The cover crops for soil health and productivity project, led by the University of Adelaide, is assessing the efficacy and practicality of cover crops in specific almond-growing regions for more effective and sustainable orchard management.

The research is seeking to understand how cover crops influence every aspect of the production system and which crops are best to mitigate soil damage, minimise water use, encourage pollinators in the orchard and avoid the need for herbicide addition.

The newest project in the almond industry's repertoire, 'Enabling the pathway to best sustainable management practices', will assist and empower the industry in understanding sustainability risks and support the longevity of Australian almonds as a sustainable, profitable and well-respected industry.

This project utilises Growcom's purpose-built sustainability benchmarking platform, building modules as Almond Hort360. The project will provide the Australian almond industry with a foundation to approach sustainability in a targeted and industry-specific way.