Hort Innovation

Final Report

Advanced production systems for temperate nut crops

Project leader:

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Delivery partner:

South Australian Research and Development Institute (SARDI)

Project code:

ST16003

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The program involved four inter-related research projects managed by industry representative body and three state research agencies:

ST16000 – Almond Board of Australia (ABA)
ST16001 – Agriculture Research Victoria (AVR)
ST16002 – New South Wales Department of Primary Industries (NSW-DPI)
ST16003 – South Australian Research & Development Institute (SARDI)

Research reported herein was managed by SARDI.

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Thankyou.

Project Summary

Australian temperate nut industries recognise that new production systems need to be developed and adopted to maintain and improve profitability and sustainability. There are a number of perceived challenges (and opportunities) associated with these systems spanning genetics and tree training systems, alternate harvest technologies and orchard floor practices as well as resource use efficiencies and tolerance of non-biological stresses. In 2015, Hort Innovation commissioned a research program (ST15003) of four inter-related research projects that was designed to contribute to the development of advanced production systems for Australia's temperate nut industries. The program integrated levy funds from the Almond Board of Australia (ABA) and the Australian Walnut Industry Association with support from the South Australian, Victorian and New South Wales governments into a package that was matched by the Australian Government's Rural Research and Development for Profit (Rural R & D for Profit) program. The South Australian component of this work was contracted through Hort Innovation project ST16003 to the South Australian Research and Development Institute (SARDI), the research division of the state's Department of Primary Industries and Regions.

The principal objective of SARDI's ST16003 project was to assist the ABA in the development of the Australian Almond Centre of Excellence (ACE), north of Loxton South Australia. The ACE site was established as a cooperative venture between the ABA and the South Australian government, with SARDI providing experimental and orchard design input not only to complement the initial four-year research program, but also the longer-term requirements of the ABA and research community. The ACE site was designed to facilitate experimental and demonstration activities to progress the development of more efficient almond production systems. At the same time, SARDI recognised that the vast majority of current plantings, including large areas established in the last 5 years, continued to be based on traditional low planting density systems and that research outcomes needed to also support these traditional orchards. Further to ACE orchard establishment and research activities, SARDI conducted a number of offsite investigations during the project period. SARDI's ST16003 research activities addressed concerns that were raised following interactions with the ABA and Agriculture Research Victoria (AVR) in 2015 and included:

- Designing large-scale experimental orchards, as long-term research platforms, to host future investigations by industry, commercial partners and various non-profit research providers.
- Establishing trial plantings and commencing investigations into the interactions between planting materials (rootstock and variety) and density
- Establishing trial plantings and commencing investigations into the benefits of various soil amendment strategies
- Testing the compatibility of traditional and new planting materials and their suitability for alternate production systems
- Describing ACE climatic conditions and exploring adaptation management options
- Monitoring and modelling resource use efficiencies associated with various field treatments
- Developing molecular technologies for rapidly quantifying root density/distribution
- Testing the tolerance of rootstocks to salt stress
- Industry communication and extension activities

Some of the results from these investigations represent incomplete datasets given the age of the orchards they were collected from. However, there is real opportunity to capitalise upon this foundation data and continue to collaborate with project partners (ABA and AVR) to demonstrate alternate production concepts to existing and potential nut crop producers, industry development officers, agronomists and consultants. The demonstration orchard at Loxton supports the "seeing is believing" component of industry adoption of the project's outputs. The project generates real world performance data to enable existing producers and future investors to make evidence-based economically rational investment decisions.

Project outputs and recommendations

Establishment of the Almond Centre of Excellence (ACE) in Loxton SA.

OUTPUT	More than 40 ha of large-scale experimental orchards suited to long-term field investigations and industry demonstration activities. SA government (PIRSA/SARDI) was instrumental in securing and establishing the site.
RECOMMENDATION	Maintain existing treatments and continue monitoring performance.

Commercial scale yields pointing to early treatment effects

OUTPUT	2021 saw the first commercial scale harvest operations in four of SARDI's five field trials. Harvest operations covered 600 trial plots and more than 3000 individual experimental trees.
RECOMMENDATION	SARDI to further develop and share experimental harvest strategies with ABA and AVR to ensure future datasets at ACE and the AVR SmartFarm orchards are accomplished safely, efficiently and accurately.

A DNA based root quantification assay developed for *prunus* rootstocks

OUTPUT	DNA based almond root quantification assay able to differentiate more than 17 unique *prunus* rootstock genotypes. Initially developed as a quantitative, descriptive research tool it could also be further adapted into an indicator of tree health, soil health and root activity. Useful as a guide to fertiliser and irrigation applications.
RECOMMENDATION	Incorporate assay in future soil-based investigations and further interrogate/validate the relationship between traditional and molecular based root assessments Develop the integration of root detection with quantitative assay for pathogenic nematodes as a tool to de-risk replanting decisions

Climate risk and adaptation options assessed

OUTPUT	ACE climatic conditions were considered against future risks, and an adaptation strategy tested
RECOMMENDATION	Practical climate adaptation options warrant further investment

Optimised density trials highlight opportunities for production efficiencies

OUTPUT	Two density optimisation trials established across 6.5 ha testing tree spacings ranging from 308 to 1481 trees/ha. Early yield and canopy development data reported.
RECOMMENDATION	Continue monitoring density response through to orchard maturity

Assessing the value of soil amendment treatments

OUTPUT	7 ha field experiment testing soil amendment application rates/methods
RECOMMENDATION	Continue monitoring yield response. Repeat soil condition assessments.

Rootstock compatibility screens

OUTPUT	Two genotype compatibility screens testing the production characteristics of more than 140 graft combinations planted at medium and high density
RECOMMENDATION	Continue monitoring yield metrics, canopy size and architecture and pathology/compatibility disorders through to maturity

Salt tolerance traits for commercially relevant *prunus* rootstocks investigated

OUTPUT	Six prunus rootstock genotypes assessed for their tolerance to salt stress. Cornerstone, Garnem and Barrier-1 show promise for saline conditions.
RECOMMENDATION	Assess rootstocks under saline field conditions. North Adelaide Plains (recycled wastewater) or Riverland (brackish groundwater)

Calibrated and validated numerical models suited to testing response to hypothetical production scenarios

OUTPUT	Numerical models developed to predict the response of planting density and irrigation system on water and nutrient movement as influenced by likely climate and hypothetical irrigation scenarios
RECOMMENDATION	Strengthen model outputs by incorporating additional seasons of measured field data from ACE. Extend models' range by incorporating measured data from other regions, e.g., AVR SmartFarm trials Install PIRSA Lysimeter units in new ACE plantings and use measured water and nutrient use efficiency data to further refine predictive models

Strengthened collaboration between industry and research partners

OUTPUT	ST15003 facilitated greater interaction between interstate research providers and provided a platform to develop collegiate (rather than competitive) interactions.
RECOMMENDATION	Continue to nurture cross-agency collaborations and, in turn, more robust outputs for industry

Industry communication and extension activities

OUTPUT	Various extension activities listed in APPENDIX A; including field days, online workshops and multiple conference presentations
RECOMMENDATION	Publish abridged, factsheet style, versions of the chapters reported herein as online resources for grower audience Publish outputs from ST16003 activities in peer reviewed journals: - Development of prunus root quantification assay (together with SARDI Molecular Diagnostics and CSIRO Agriculture & Food) - Salt tolerance of prunus rootstocks (together with AVR Irymple) - Modelling soil water and nutrient dynamics in almonds

SARDI – ST16003

Advanced production systems for temperate nut crops

Final report to Hort Innovation, 15 October 2021

Government of South Australia
Department of Primary Industries and Regions

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

SECTION 1. PIRSA/SARDI contributions to the establishment of ACE

Key points

- The Department of Primary Industries and Regions South Australia (PIRSA) played a significant role in establishing the Almond Centre of Excellence (ACE). Early contributions included the identification of suitable land and facilitation of purchase to enable the Almond Board of Australia access through a lease arrangement with the South Australian Government.
- SARDI contributed to a whole of property soil survey and worked closely with the Almond Board to determine the mix of plantings and their design layout to maximise value for future research.
- Separate to SARDI's targeted research plantings, two general purpose Resource Blocks were established to host third party, smaller scale, investigations. The Resource blocks were planted at low density with traditional varieties and medium density with newer varieties.
- Three external companies have already used the Resource Blocks for four trials testing a range of commercial foliar and soil-based treatments for almonds.
- The Resource blocks are approaching their fifth leaf and, to date, have been assessed for tree growth and phenology (SARDI) and yield (ABA).

1.1 Orchard purchase and establishment

Search for a suitable site

Work to identify suitable properties to host the ACE experimental orchards commenced in late 2014, with PIRSA officers conducting preliminary investigations in consultation with the ABA.

A total of 52 potentially suitable properties were identified through a property search conducted by Renewal SA. PIRSA applied due diligence to these properties and provided a short list of 10 properties to the ABA for consideration. The ABA added another four properties to this short list as a result of their own investigations.

After investigating each potential site for their suitability as experimental orchards, the current site of the Almond Centre of Excellence was selected based on a number of criteria including its location and soils, suitable scale to allow for the potential future expansion of trials, and proximity to the ABA office at the Loxton Research Centre.

In 2015, the South Australian Minister for Agriculture, Food and Fisheries executed a Deed of Agreement with the ABA for the establishment of the Inaugural Centre of Excellence for the Australian Almond Industry. Land was purchased and is currently leased to the ABA for the ACE experimental orchard.

Pumping station location and establishment

In 2017 the then Minister for Regional Development granted the Almond Board of Australia funding to construct an off-farm water delivery system from the River Murray to the external boundary of the experimental orchard property. This included all work related to the laying of the pipeline (including under the road), pumps and pump shed.

Water supply and power easements were secured on the adjoining, privately owned, land as part of the land purchase. Permissions to lay the pipeline along the road boundary and to lay pipeline under the road were obtained by the ABA as part of the deed arrangements. Due to the location of the power transformer, a licence to access crown land was also secured by SA Power Networks to allow for the installation of an on-ground power transformer and by the then Minister for Agriculture to lay electrical cable from the transformer to the pump shed.

Soil survey activities

A reconnaissance soil survey was undertaken at the ACE site in 1996, by the Irrigated Crop Management Service. This survey was reviewed as part of the site selection process described above in Section 1.1.

An Electromagnetic (EM) survey was then carried out at ACE on January 28th, 2017, by Peter Treloar, Minlaton. The results of the previous reconnaissance survey and the EM survey were used to guide the selection of soil pit locations for a detailed soil survey carried out by Total Eden, Renmark, to identify textural and structural changes within the soil profile at numerous sites across the property.

Field activities associated with the soil survey took place between April 6 and 13, 2017. Total Eden conducted the soil pit descriptions and collected loose soil samples from each layer of each pit for laboratory analysis. SARDI staff collected undisturbed soil cores from every layer in a selection of 24 soil pits, to determine bulk density and soil water release characteristics across the site.

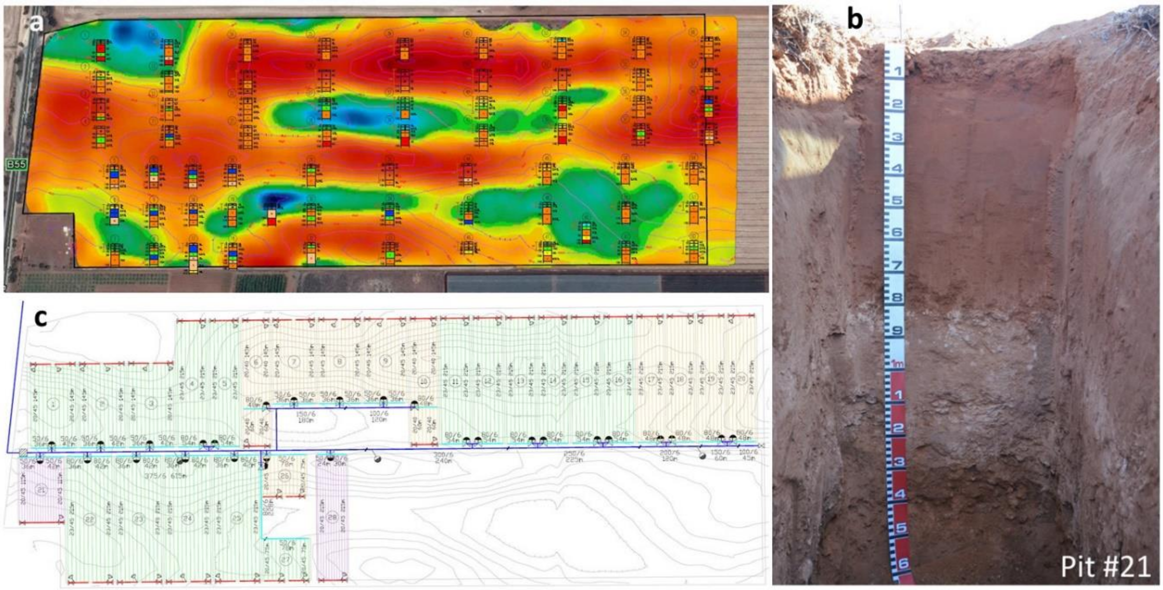


Figure 1-1. ACE soil profile description map overlaid onto EM38 survey (a), example of a soil profile (0-160 cm depth) at the ACE experimental orchard (b) and irrigation design showing valve units associated with experimental trial and commercial plantings (c)

Maps of soil properties were generated by Total Eden to aid in locating and laying out research plantings. The soil survey maps were used to determine the best areas to position experimental plantings and resource blocks. They were also used to design the irrigation system, with certain areas left unplanted due to potential drainage issues identified by the soil survey. Figure 1-1 displays an overlay of the detailed soil survey and the EM survey, as well as a photo of a soil pit at the ACE site and the irrigation system design.

Weather station installation

The South Australian Natural Resources Management Boards, now known as Landscape South Australia, developed and manages a regional automated weather station (AWS) network comprising over 80 automated weather stations. The stations collect climatic and calculated data parameters every fifteen minutes, with that data transmitted and displayed upon the AWS website (https://www.awsnetwork.com.au/) each hour.

An additional station was installed at the Almond Centre of Excellence site, with the installation funded by PIRSA, and ongoing maintenance committed to by Landscape SA. The weather station provides very localised weather data to assist in interpretation of observations at the ACE property, including tree development, water use and climatic events (frost, heat waves etc.).

Determination of planting material

Extensive discussions took place between ABA and SARDI to negotiate the most appropriate allocation of the available land to different resource and trial plantings. A formal meeting was held on 12th January 2017 at the Plant Research Centre, Waite Campus, and attended by six representatives from SARDI (Jim Cox, Darren Graetz, Mark Skewes, Tim Pitt, Dane Thomas and Nigel Fleming), and six representatives from the ABA (Ross Skinner, Brendan Sidhu, Andrew Downes, Brett Rosenzweig, Ben Brown, Michael Ward).

Multiple smaller meetings and informal interactions continued after the initial meeting, particularly involving Andrew Downes and Brett Rosenzweig from ABA and Mark Skewes and Darren Graetz from SARDI. Discussions centred on the most appropriate row and tree spacings for the resource plantings (Horizon 1 & 2) and the most promising scions and rootstocks to be included in these plantings.

Discussions also focused on the requirements for research plantings, including the size and layout of plantings which would facilitate appropriate design of trials (application of treatments, replication, buffering etc.), and the collection of statistically robust data. These discussions resulted in clear guidelines for the development of research plantings at the site, to promote good scientific outcomes and thus the generation of robust recommendations for the almond industry.

1.2 Designing/monitoring general-purpose Resource Blocks

There are two Resource Block orchards planted at the Almond Centre of Excellence, designed specifically to host field trials in the areas of agronomy, nutrition, irrigation etc. These orchards represent traditional almond growing (Horizon 1), and current advanced almond growing (Horizon 2), as defined by the Almond Strategic Investment Plan 2017-21 (HortInnovation, 2017) .

The Horizon 1 Resource Block is a traditional planting density and genotype mix comprising 50% Nonpareil with alternating pollinator varieties Monterey and Carmel, all grafted to Nemaguard rootstock. This orchard mirrors the current industry standard planting layout, with Nonpareil as the major variety and two pollinators alternating between Nonpareil rows to ensure good cross pollination.

Learnings from this resource block will have direct relevance to the majority of almond producers who continue to produce almonds under this traditional growing system.

The Horizon 2 Resource Block is representative of the next phase of industry development towards higher density tree plantings and incorporating Nonpareil and 3 new varieties (Carina, Maxima and Vela) all grafted to Nemaguard rootstock. Some of these new varieties are self-fertile. Rows of each variety have been distributed to not only meet their pollination requirements but also to sufficiently buffer uniform size plots to allow statistical assessment of each of the four varieties. Assessments will focus on the yield potential of these new varieties under commercial growing conditions with the results being applicable to growers using the more advanced Horizon 2 growing system.

A range of third-party commercial trials have already been conducted on these blocks or are currently in place, as summarised below.

H1 Resource Block design

The H1 Resource Block was planted in 2017, and comprises three varieties (Nonpareil, Monterey and Carmel) budded to Nemaguard rootstock (Table 1-1). The planting was laid out with Nonpareil in every second row, with Monterey and Carmel alternating between rows of Nonpareil (Figure 1-2).

Due to a patch of shallow soil in the north-west corner of the property being deemed unsuitable for almond trees. The northern end of the first three valve units (36 rows) was consequently left unplanted.

Figure 1-2. Planting layout of Horizon 1 Resource Block, showing rows of Nonpareil (red), Monterey (green) and Carmel (white) trees.

Table 1-1. Summary of Horizon 1 planting

Rootstock	Scions	# Trees	Valves	Rows	Spacing	Density (trees/ha)	Area
Nemaguard	Nonpareil Carmel Monterey	986 NP 493 Ca 493 Mo **1969 Total**	1 – 5	1 – 52	7.0 x 4.5 m	317	6.20 Ha 52 rows

H2 Resource Block design

SARDI's H2 Resource Block, planted in 2017, is the only planting of purely Horizon 2 density on the property and is laid out at a spacing of 6.5 m x 3 m. This planting contains four varieties (Nonpareil, Vela, Carina and Maxima) all grafted to Nemaguard rootstock (Table 1-2). SARDI density investigations span traditional low density (H1) through to ultra-high density (H3) and are detailed further in SECTION 7 and SECTION 8.

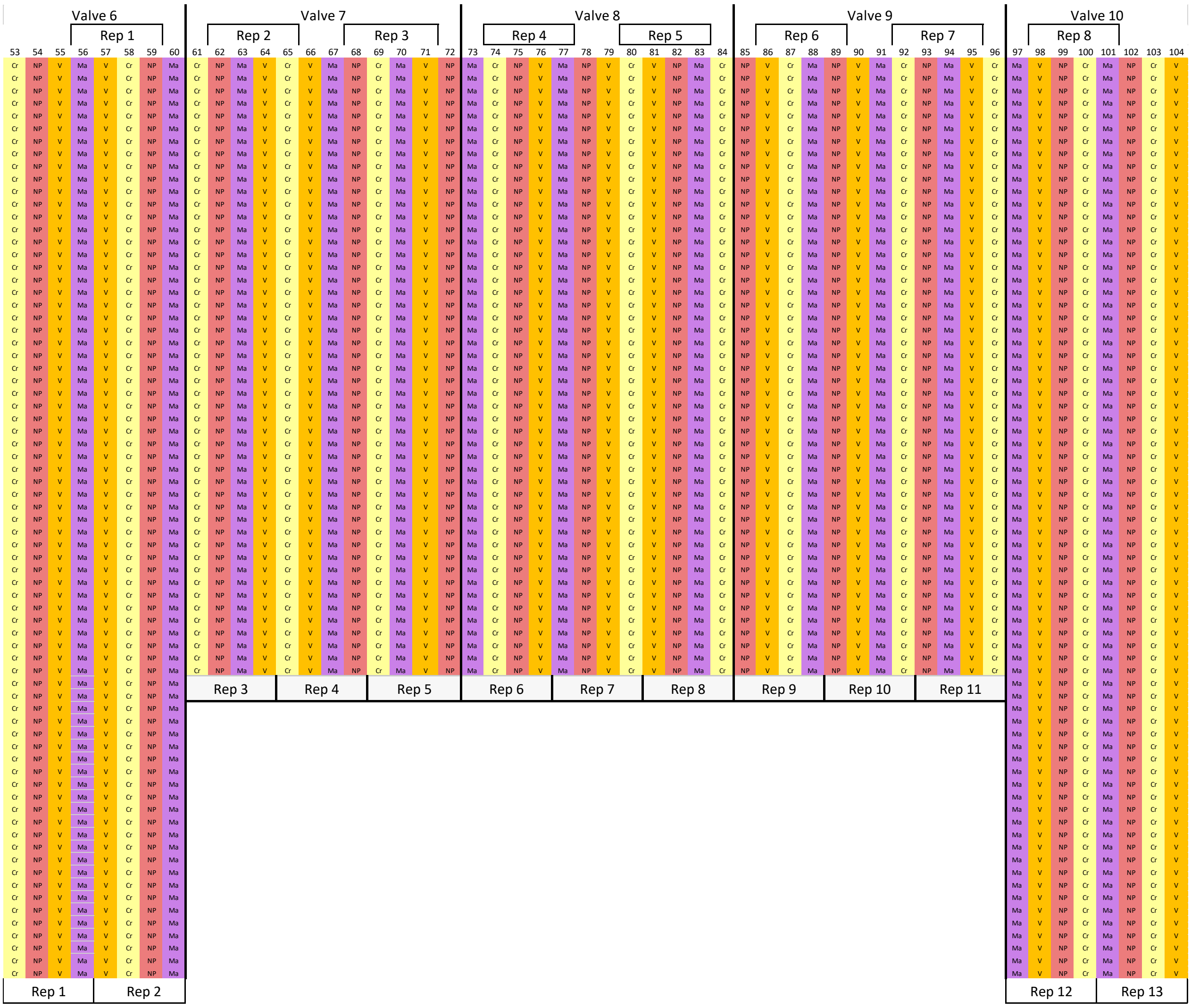


Figure 1-3. Planting layout of Horizon 2 Resource Block, showing rows of Nonpareil (red), Vela (orange), Carina (yellow) and Maxima (purple) trees. Potential for applying replicated treatments across all varieties, with buffer rows (top) and without buffer rows (bottom) are also shown.

Table 1-2. Summary of Horizon 2 planting

Rootstock	Scions	# Trees	Valves	Rows	Spacing (m)	Density (trees/ha)	Area
Nemaguard	Nonpareil Carina Maxima Vela	733 NP 733 Cr 733 Ma 733 Vel **2932 Total**	6 – 10	53 – 104	6.5 x 3.0	513	5.72 Ha 52 rows

The four varieties in the H2 Resource Block are laid out in a randomised order, such that individual plots of four rows containing all four varieties can be selected as treatment plots (Figure 1-3). The design allows for four row plots with buffer rows (8 replicates as shown at the top of Figure 1-3), or four row plots without buffer rows (13 replicates as shown at the bottom of Figure 1-3).

Establishment

The Resource Blocks were planted in early spring 2017. However, the installation of irrigation infrastructure was delayed, and as a result the trees were initially watered using a tractor towed spray cart that manually distributed water into basins around each tree. This manual watering operation continued for more than six weeks, until the automated irrigation system came into operation in October 2017.

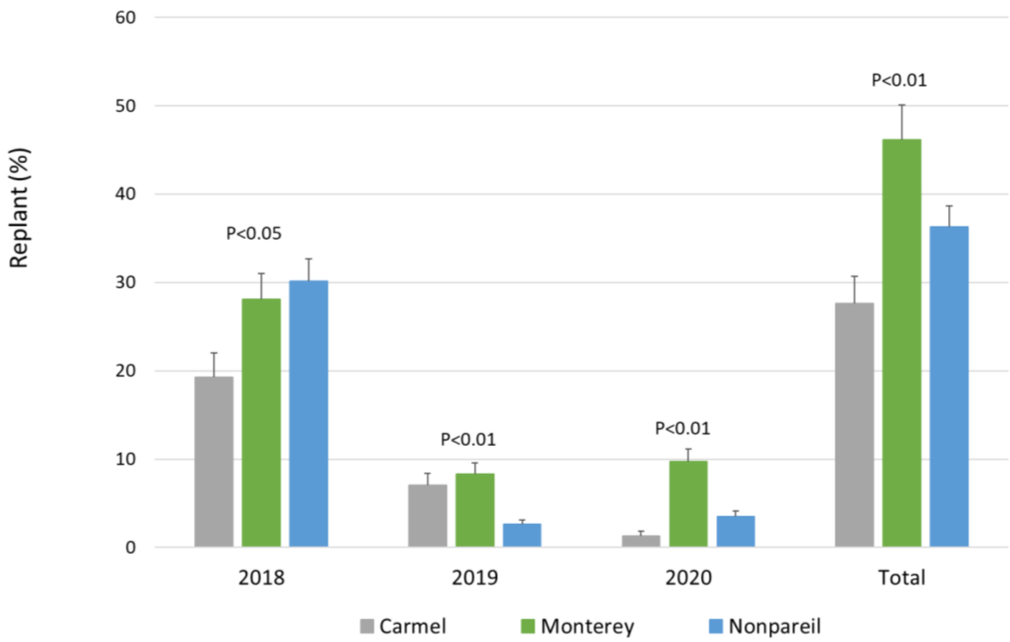


Figure 1-4. Summary of replanted trees in H1 Resource Block by variety over the first three years. Error bars are standard error of the mean.

There were a significant number of tree deaths during the first season, largely due to the initial challenges associated with delayed irrigation availability. In addition, high winds during spring of 2018 and 2019 caused damage in some 2nd and 3rd leaf plantings. Orchard operations resulting from this wind damage ranged from trimming and re-staking through to complete removal and replanting of damaged trees. Further discussion of climatic conditions, including wind, is provided in SECTION 2.

Figure 1-4 and Figure 1-5 display the number of replanted trees of each variety, in H1 and H2 Resource Blocks respectively, through the first three years of the life of these plantings.

Tree size data for the Horizon 1 Resource Block are shown in Figure 1-6. Whilst the relative height of different varieties has changed over time, the slope of the graph suggests that all trees are still growing vigorously.

Canopy growth measures for the H2 Resource Block (Figure 1-7) again show variable genotype effects across time (tree height on the left (a), and tree width on the right (b)). However, the shape of the tree width graph (b) in particular suggests that the growth of trees in the H2 Resource Block is slowing over time, likely due to competition between adjacent trees at this closer spacing (6.5 x 3.0 m, as opposed to 7.0 x 4.5 m in H1).

The 2019/20 season saw the first nuts harvested from the ACE experimental orchard. Mechanical harvesting was carried out in H1 & H2 Resource Blocks (planted in 2017), on third leaf (2020) and fourth leaf (2021) trees. Each resource block was harvested as a single production unit by the ABA, which precluded statistical analysis of the data.

Yield data for third (blue bars) and fourth leaf (orange bars) trees are displayed in Figure 1-8, as weight of kernel per hectare. There are clear varietal differences in yield at this early point in the life of these plantings, with Carmel, Maxima, Carina and Vela clearly out-yielding Nonpareil in the same year at the same tree density.

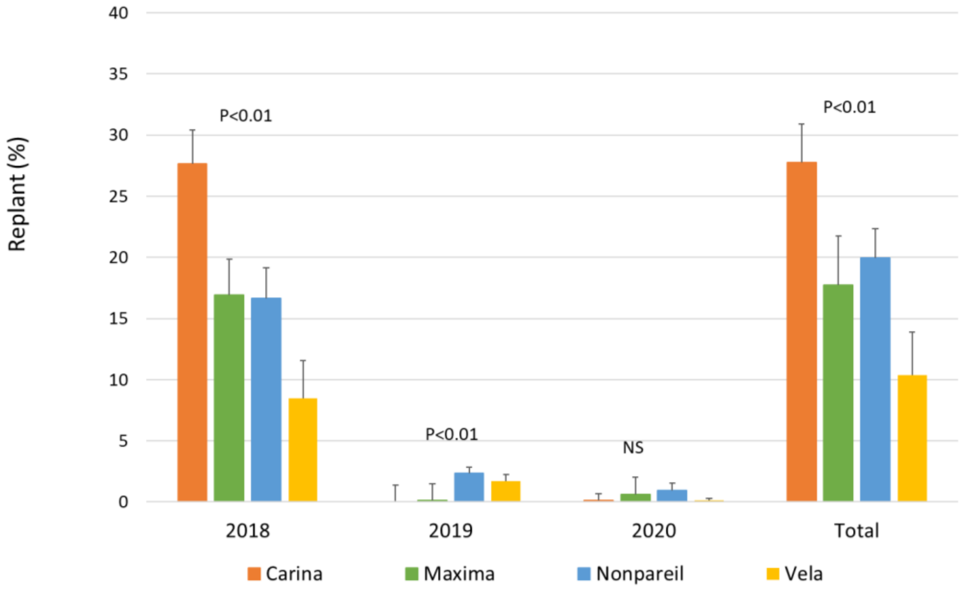


Figure 1-5. Summary of replanted trees in H2 Resource Block by variety over the first three years. Error bars are standard error of the mean.

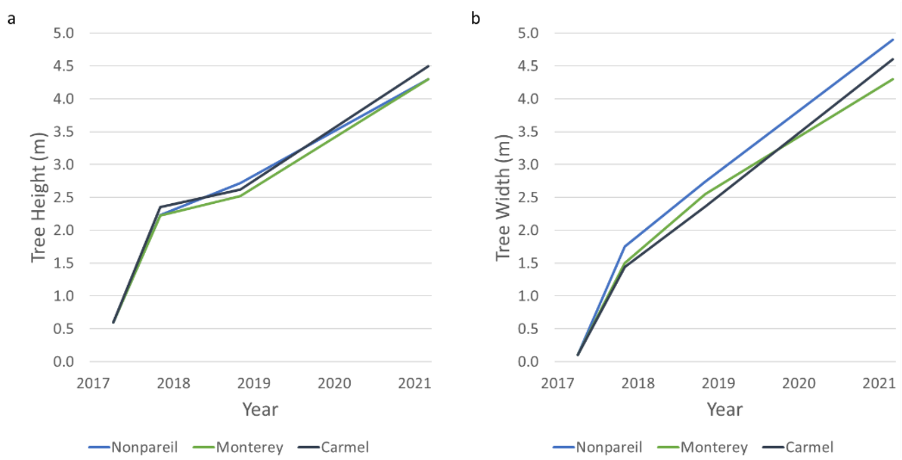


Figure 1-6. Horizon 1 Resource Block average annual tree height (a) and tree width (b) measurements

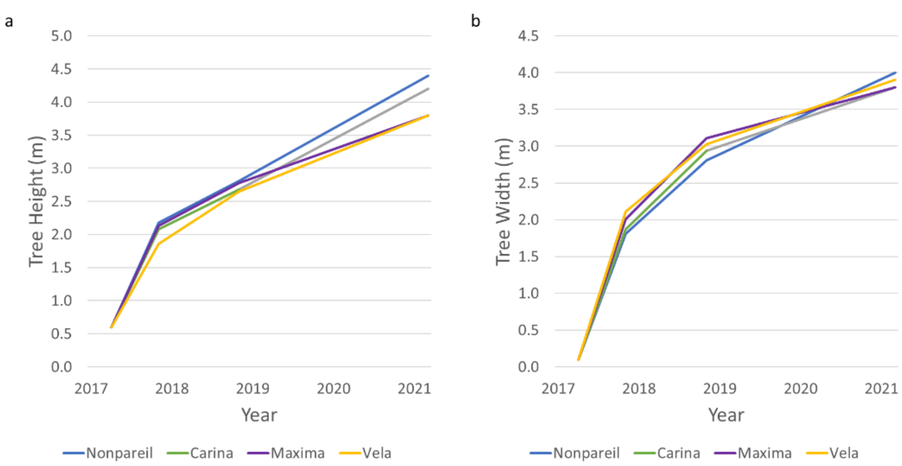


Figure 1-7. Horizon 2 Resource Block average annual tree height (a) and tree width (b) measurements

The yield relationship across the first two harvestable years differed between the H1 and H2 densities. Yield at H1 density increased by between 2.5 and 6 times from 3rd leaf (2020 harvest) to 4th leaf trees (2021 harvest). The early yields (2020) in the H2 block were more than double those in H1 and they remained higher in 2021. H2 yield increased by 1.5 and 2 times across the first two seasons. It is expected that the rate of yield increase will slow for H2 trees as canopy's fill their space and competition from the neighbouring trees takes effect.

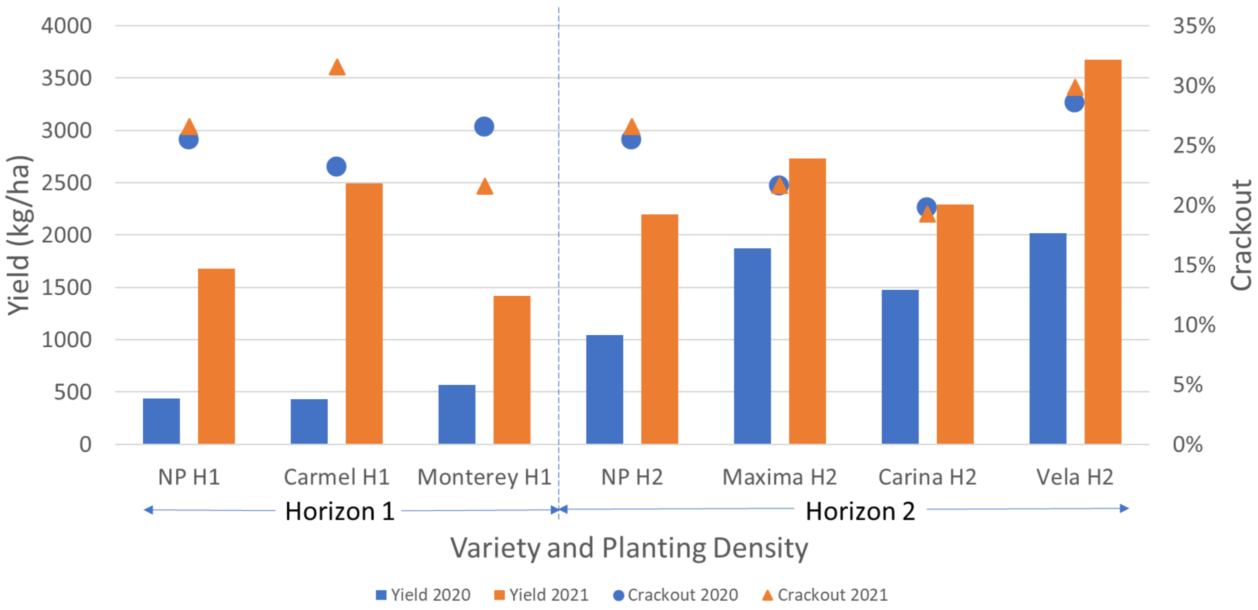


Figure 1-8. Yield (kg/ha) from varieties in H1 & H2 Resource Blocks in 2020 (3rd leaf) and 2021 (4th leaf).

Figure 1-8 also shows percentage crack-out for 2020 (blue circles) and 2021 (orange triangles). Varietal differences are apparent, in particular the low crack-out for Carina nuts. Crack-out was consistent between seasons for Nonpareil, Maxima and Carina and Vela, but much more variable for Carmel and Monterey.

Trial work conducted on H1 and H2 Resource Blocks

A number of external companies are already utilising the H1 and H2 Resource Blocks to conduct research and demonstration trials.

Stoller Australia Pty Ltd – *Maximise pollination, nut setting and size in almonds* (H1 Resource Block). Testing a new product called Bio-HOLD, which aims to boost yields which would otherwise be limited by poor weather conditions during flowering, and potentially reduce biennial bearing.

Campbells Fertilisers Australasia – *Foliar treatments of the biostimulant Megafol* (H1 Resource Block). Trialling Megafol, a plant based biostimulant that defends against abiotic stresses such as frost, wind, extreme heat and water scarcity. Megafol seeks to improve nut set when used during flowering, as well as increasing canopy development and nut retention when applied during the season.

Omnia Specialities Australia Pty Ltd – *Biostimulants in Almonds* (H2 Resource Block). Products being trialled include Rhizovator PC; Bacstim 100; Mega Kelp 7; and two developmental foliar products.

Omnia Specialities Australia Pty Ltd – *Pruning wound protection for Eutypa and Botryosphaeria* (H2 Resource Block). Seeking to support label extensions to almonds for Greenseal and Sprayseal, which are registered against Eutypa & Botryosphaeria infections in grapes, pome and stone fruits. SARDI Plant Health and Biosecurity are collaborators in this project, being responsible for applying treatments and assessing results.

SARDI flowering assessments in Resource Blocks

Timing of flowering is a critical factor in obtaining high yields under current almond production systems, especially for those sites growing Nonpareil as their preferred variety (Connell et al., 2018). In spring 2020, measurements commenced with aerial RGB imagery being collected twice weekly across Trials 3, 5, 6 and the H2 Resource Block. This rapid method maximised the opportunity to characterise the timing and density of flowering across the breadth of varieties that feature in SARDI's suite of ACE experimental orchards.

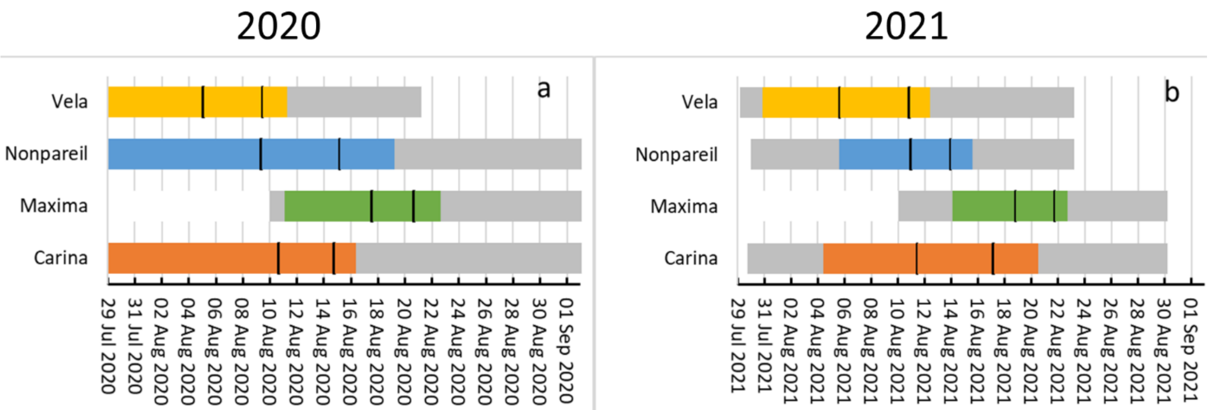


Figure 1-9. Flowering period for Vela, Nonpareil, Maxima and Carina at the Almond Centre of Excellence, Loxton SA, in 2020 and 2021

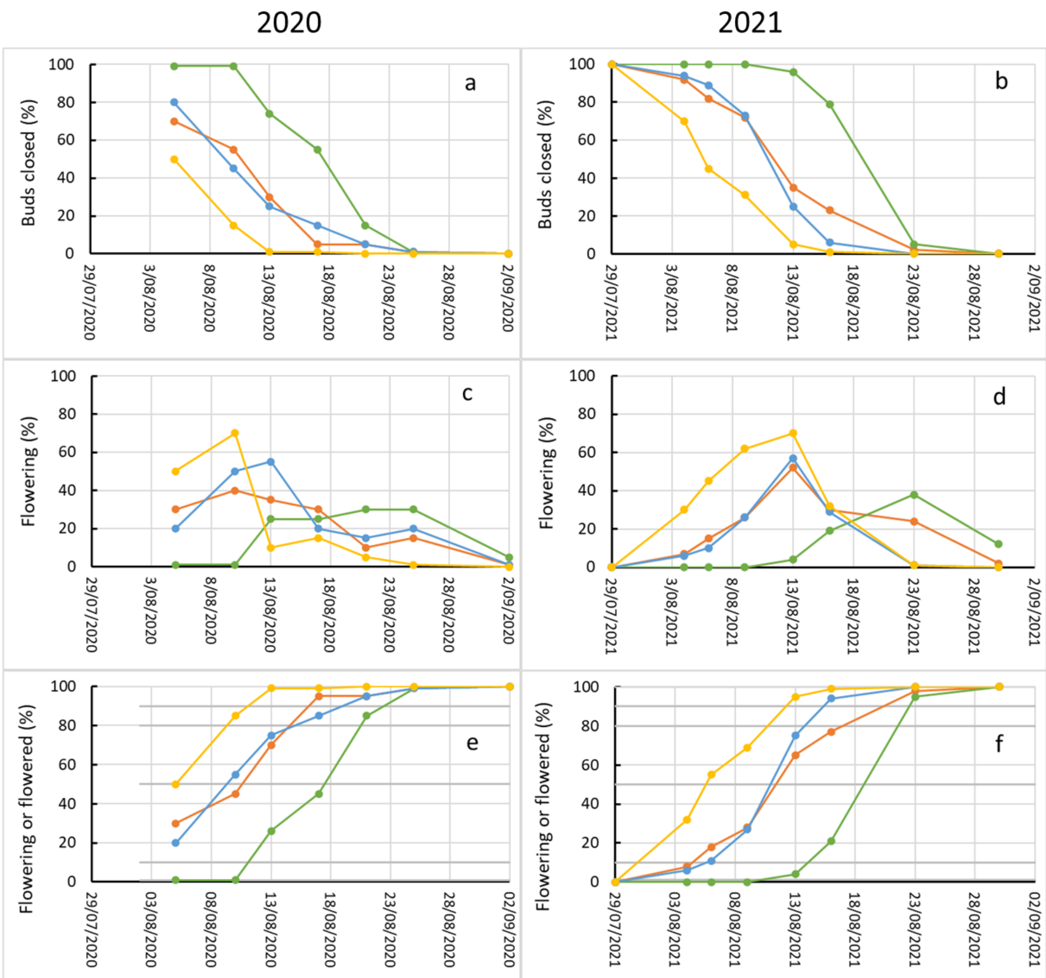


Figure 1-10. Timing of flowering phenology for four varieties at the Almond Centre of Excellence, Loxton SA, in 2020 and 2021. Vela (yellow), Nonpareil (blue), Maxima (green) and Carina (orange).

Aerial imagery was supported by more detailed ground-based assessments of flowering in four varieties: Vela, Nonpareil, Maxima and Carina (Figure 1-9 & Figure 1-10). Flowering assessments were repeated in 2021. In both years floral bud development stages were assessed as Buds Closed (stages from swollen buds to visible but not fully emerged corolla), Flowering (the rapid stage of stamens visible and the more prolonged stage of open flowers) and Petal Fall (data not shown) were recorded, according to the method of Thomas and Connell (2018).

Flowering assessments occurred in both 2020 and 2021. The period of peak floral receptivity (measured as the combined stages of Stamens visible and Open flowers, Figure 1-10 c & d) and the cumulative measure of Flowering or flowered (measuring the accumulation of flowers that had reached or proceeded beyond the 'open flowers' stage, Figure 1-9 a & b and Figure 1-10 e & f) show flowering occurred earliest in Vela and latest in Maxima in both years, with only minor differences between the years. Differences between the two years included a slightly earlier commencement of flowering in Maxima in 2020, and a more prolonged peak in Vela in 2021.

Phenological stages of Nonpareil and Carina occurred between those of the early Vela and the late Maxima. It is not possible to state when budburst and flowering of Nonpareil and Carina began in 2020 (due to late commencement of assessments) but it appears to have been earlier in 2020 than the compressed flowering period of 2021. In both years the overlap of floral receptivity between Vela and Maxima was short. There was a longer cross-over period of high floral receptivity between Maxima and both Nonpareil and Carina: and between Vela and both Nonpareil and Carina.

Whole of Property Investigations

Fertiliser slug tests were conducted across the ACE fertigation system in mid-November 2020 to support resource use assessments and complement the automated collection of irrigation and soil moisture condition data. The slug tests confirmed timing and extent of nutrient availability, not only validating the assumption of even nutrient distribution across the valves, but also adding rigour to SARDI's numerical modelling exercises.

Figure 1-11 describes day 1 of a series of slug tests completed in mid-November 2020. The solid lines ("First") indicate the concentration of fertiliser at the dripper nearest the valve and demonstrate the delay in arrival of fertiliser at each valve as a result of the distance of travel along the mainline to each valve. Valve 22 (Trial 5/6) is quite close to the start of the mainline, and valve 38 (Trial 4) is at the far end of the mainline.

The broken lines ("Last") indicate the concentration at the dripper furthest from the valve. The difference between the solid and broken lines of the same colour indicates the time taken for fertiliser to make its way along the submains and laterals of the valve unit, to reach the last dripper.

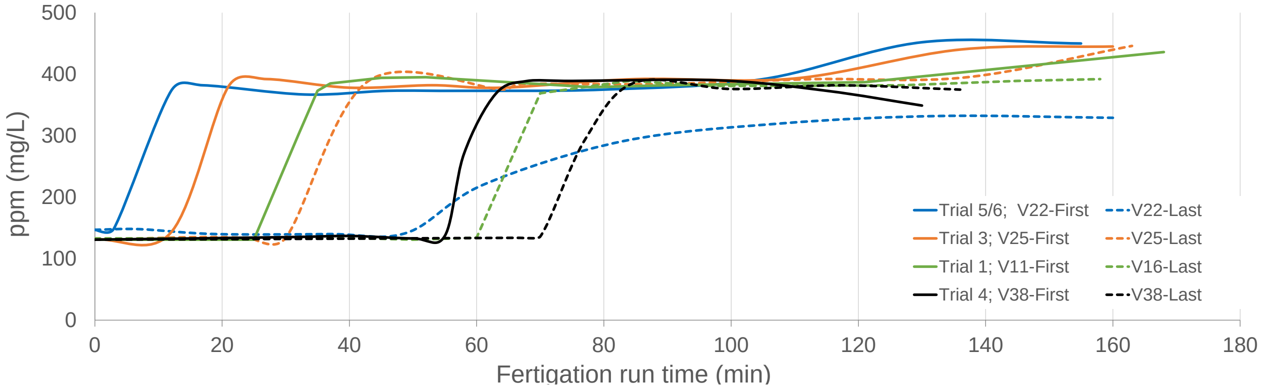


Figure 1-11. Concentration of fertiliser at the first and last dripper in 4 valve units across the Almond Centre of Excellence following commencement of fertiliser injection into the mainline (Nov 2020).

SECTION 2. Review of climate and weather at ACE including extreme events

Key points

- Temperature, rainfall and evapotranspiration from 2015/16 through to 2020/21 were examined at ACE in relation to a base period from 1986 to 2005
- Wind events were examined in relation to observed tree damage
- Temperatures were mostly warmer, despite including a negative IOD year and a La Niña year
- Rainfall was low in all except one season
- There is a worrying trend of warmer seasons becoming more common, occurring during wetter seasons and when climate drivers are usually associated with cooler seasons
- Risk events for almond production include heatwaves, rain at harvest, late frost and strong wind
- Heatwaves are increasing; rainy and moist conditions at harvest have been low in recent years although it is unclear if this is a long-term trend; frost and strong wind are variable

2.1 Abstract

The weather and climate of each growing season differs from others in unique ways. Understanding how they differ and if these differences are similar to the median conditions or if they are towards the extremes of the natural variation is best done using deciles (or another separation according to percentiles e.g., terciles, quintiles). We examined temperature, rainfall and evapotranspiration indices in each of the last six seasons (2015/16 to 2020/21) and placed them according to a 20-year base period from 1986 to 2005. We also examined the wind associated with a major tree damage event in 2019.

The years since 2015/16 to 2020/21 were usually warmer with greater heat accumulation, and higher evapotranspiration than any during the base period. The warm temperatures in 2016/17, a negative IOD year and 2020/21, a La Niña year were not expected considering these conditions are usually associated with cooler and wetter conditions. Rainfall was high in 2016/17 but low in all other seasons. The fact that warm seasons are becoming more common, and that they can occur during wetter seasons and when climate driver conditions are typically associated with cooler seasons is a worrying trend for the region.

Weather conditions for extreme events such as heatwaves, high evaporative demand days, frosts and rainfall during the harvest operations are daily weather events that describe risk to almond production. The largest number of high temperature days occurred in the seasons and months that are much warmer than usual. Minimum night temperatures close to or below 2°C occurred as late as mid-October in 2017 and 2020 but 2 to 4 weeks earlier in other years. Evapotranspiration has been increasing in recent decades and there are numerous days in most seasons and months having evapotranspiration higher than the 90th percentile for the time of year.

Wind damage to the orchard was observed in November 2019 and thought to be associated with wind conditions several days earlier. Although wind gusts were high at that time, gusts on earlier

days did not cause damage. Wind gusts on these occasions corresponded to the 90th to 95th percentile for the last 10 Novembers at nearby Bureau of Meteorology stations. That is, the winds were higher than typically experienced and similar to a 1 in 10 to 1 in 20-year condition. This suggests wind gusts of the speeds that caused damage will be reasonably frequent, but as tree damage is not experienced on all these occasions that the combination of high wind and the large canopy of vigorously growing trees (there was a scion effect) contributed to an unfortunate combination of circumstances resulting in tree damage.

2.2 Background and aims

Agricultural and horticultural production are influenced by the weather and climate during a season. Placing the growth, yield or water use of a single season into the context of other seasons and thus helping to understand and learn from management decisions is assisted by an understanding of how the weather and climate compares to these other seasons. This analysis reviews the weather and climate from the last six seasons (note the first plantings at ACE occurred in the winter of 2017) and compares them to the variation observed during the 20-year period from 1986 to 2005.

A range of climate indices are compared. These include indices of mean temperature and the associated heat accumulation which progresses plant development through its stages from budburst to harvest; rainfall received at the site and evapotranspiration which measures water loss which between them can assist in the understanding of irrigation demand; and weather events such as heatwaves and frost, excessive rainfall and moist conditions which hinder harvest operations. These weather conditions may constitute extreme events. Another extreme event is wind. Wind can be a destructive force to orchards and unfortunately compared to rainfall and temperature there is a poor observation history of wind in inland Australia. This causes difficulties when determining if the wind that results in tree damage is a rare 1 in 100-year event or one that could be expected every 5 or 10 years.

2.3 Materials and methods

Data sources

The Bureau of Meteorology is the primary source of climate data for the analysis used in this investigation. Analysis of climate and daily weather at ACE used the Meteorological station located at the Loxton Research Centre (station 24024). This station commenced operation in 1984 when the previous station (24023) also located at the Loxton Research Centre closed (open from 1965 to 1985). These two stations provide a combined record of over 50 years of daily observations for Loxton, and the Almond Centre of Excellence (ACE) research site which is located approximately 5 km to the North. Despite the longevity and high quality of data collected by The Bureau of Meteorology, there will always be some missing data when observations of a particular weather element or particular days are not recorded. To overcome this difficulty, we obtained Patched Point Datasets (PPD) for Australian locations from the SILO database (https://www.longpaddock.qld.gov.au/silo/). SILO derives Patched Point Datasets (PPD) which both spatially and temporally complete datasets from observational records provided by the Bureau of Meteorology which may contain missing values (Jeffery *et al.,* 2001). As such, the PPD contains 'Observed' data of historical weather records from the particular Meteorological station that are the actual measured data and 'Patched' data where no data exists. Use of Patched Point data is standard practice in climate risk analysis in Australia as the patched data is considered robust, although it is likely that patched data are less accurate when calculating rare or extreme weather events. It should also be noted that SILO data does not contain observations of wind and uses a standard of 2 m/s when calculating evapotranspiration.

Wind data was obtained from the Bureau of Meteorology stations of Loxton Research Centre (station 24024) located about 5 km south of the ACE property and Renmark Aero (station 24048) located about 20 km north of the ACE property. Wind data from June 2018 was also obtained from a weather station was installed on the property. This station is part of the NRM weather network (https://www.awsnetwork.com.au/) of over 80 weather stations across the SA Murray-Darling Basin NRM, South East NRM, and Alinytjara Wilurara NRM Regions and the Lower Murray Water, and Langhorne Creek Grape and Wine Irrigation districts. The Bureau of Meteorology's observations are measured at a height of 10 m above the surface with wind speed observations being 10-minute average wind speeds unless specifically labelled as gusts, in which case they are an almost instantaneous readings over 3 seconds. The SANRM readings are typically at 2 m above the surface and wind gust was deemed to be the maximum wind recorded in the 15-minute recording intervals. Wind at the SANRM stations would be expected to be about 75% lower than the Bureau of Meteorology's observations as wind speed is typically less close to the land surface.

Data analysis

Climate indices for a season in total and for the separate months have been calculated. The tables and figures for this analysis show an annual period from May to April (not January to December) as it better represents the yearly growth cycle of almonds and most fruit and tree crops in the Riverland.

The indices examined were temperature (maximum, minimum and mean), heat accumulation measured as GDD base10, reference evapotranspiration calculated as FAO56 (Allen et al., 1998) but assuming a wind speed of 2 m/s), rainfall accumulated each month and over the growing season from (1st September to 30th April), and the number of days in each week with a positive moisture balance. A day was calculated as being moisture balance positive if a reservoir of rainfall (set to a maximum of 10 mm to allow for runoff and drainage) was not removed through reference evapotranspiration on the same and subsequent days. This calculation is a simplified measure of wetness potentially useful to gauge susceptibility to diseases and of undesirable wet conditions during the harvest period.

These climate indices are widely accepted and easily recognised ways to summarise the seasons and climate of the particular location. We have compared the conditions in recent years according to the variability of the longer-term historic climate (in this case the period from 1986 to 2005 was used as a base period for calculating deciles). Daily weather is also shown for the seasons from 2017/18 to 2020/21.

The analysis of wind damage used wind speed, wind gust and wind run above 3 m at the Bureau of Meteorology's Loxton Research Centre and Renmark Aero (station 24048) and similar information at 2 m from the SANRM Loxton station located on the Loxton Research Centre and the SANRM Loxton Almond station located on the ACE property.

To determine if the wind conditions measured at the ACE property thought to be associated with tree damage were unusual it was necessary to understand how those conditions compared to a longer history of observations. This was done by comparing the relatively short history of observations at ACE (from June 2018) with conditions during the same period at the Loxton Research Centre, and then examining how these conditions compared to historical observations.

2.4 Results and Discussion

Review of seasons

Table 2-1 shows that compared to 20-year base period from 1986 to 2005, the years since 2015/16 to 2020/21 were usually warmer with greater heat accumulation, and higher evapotranspiration than any during the base period, although individual months may have been cooler and with less evapotranspiration. The 2015/16 was categorised as an El Niño and positive IOD year which are associated with warm and dry conditions, while the 2019/20 season was a positive IOD year and similarly associated with warm and dry conditions. However, the warmest seasons of 2017/18 and 2018/19 (both warmer than any during the 20-year base period) were neutral years. The warmer and drier conditions in the 2020/21 season were not expected considering the prevalence of La Niña conditions (The Bureau of meteorology declared a La Niña in September 2020) which typically result in cooler temperatures particularly in spring and wetter conditions from winter to spring. The warm temperatures in 2016/17 were unexpected considering the negative IOD conditions although the higher than average rainfall was expected considering the negative IOD conditions. Rainfall in all other seasons has been low. The fact that warm seasons are becoming more common, and that they can occur during wetter seasons and when climate driver conditions are typically associated with cooler seasons is a worrying trend for the region.

Weather conditions also provide information about risk. The daily weather for the past 4 seasons (2017/18 to 2020/21) are shown in Figure 2-1 to Figure 2-4. Heatwaves, high evaporative demand days, frosts and rainfall during the harvest operations are daily weather events that describe risk to almond production. Wind damage is another high-risk condition explored in greater detail below.

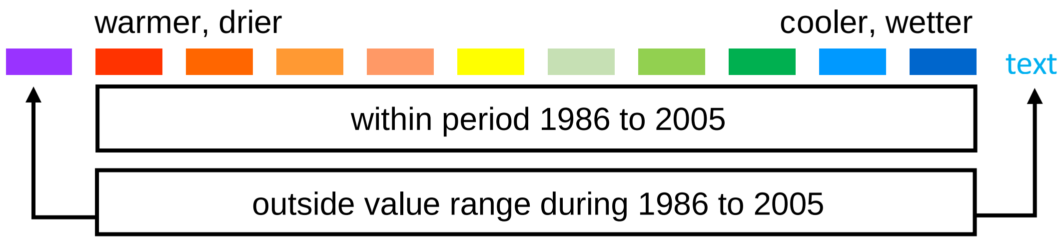
Rainfall during the harvest season (late January to March/April) is considered a major climatic risk to almond production. The risk is hard to quantify but is associated with wet conditions (rain and low evaporation). An index of moisture balance positive days has been used to gauge the risk of rain at harvest. The trees have been harvested in the last 2 seasons. These have both had low historic risk of Rainfall at harvest with 2019/20 being the higher risk year.

The index of Moisture balance positive days can also be used to gauge moist conditions throughout the year and may be related to conditions conducive to foliar disease. The number of moisture balance positive days has been low in recent years.

Heatwaves are considered a high risk. Days and nights warmer than the 90th percentile for the time of year are highlighted in red in Figure 2-1 to Figure 2-4. Not unsurprisingly the largest number of these occur in the seasons and months that are much warmer than usual. The cooler 2020/21 season differed from the four earlier seasons in having comparatively few hot days or nights. High evaporative demand days are frequently correlated to warmer days and are considered most damaging when associated with heatwaves. In fact, evaporative demand (evapotranspiration) is more closely related to high sunlight, long days (a seasonal effect), low humidity and high wind. Evapotranspiration has been increasing in recent decades and there are numerous days in most seasons and months having evapotranspiration higher than the 90th percentile for the time of year. The summers of 2019/20 and 2020/21 are exceptions in that there were few days with evapotranspiration higher than the 90th percentile.

Frosts are among the most damaging weather events. While low temperatures during dormancy are unlikely to be sufficiently low in Australia to cause damage, damage after bud swell may occur. The Bureau of Meteorology considers that 2 °C in the Stevenson screen is likely to result in 0°C at the ground surface. This is an approximation, which may not be suitable to an almond orchard considering the ground surface usually radiates heat providing some warming and protection from low air temperatures and the sensitive organs on the almond plant are some distance above the ground surface. Minimum temperatures close to or below 2 °C can occur as late as mid-October (e.g., 14th October 2017, 18th October 2020) with the last frost day typically being 1st October. Other recent seasons have had considerably earlier last days of frost (mid to late September).

Table 2-1. The general climatic temperature information at Loxton in the 20-year base period from 1986 to 2005 and in individual seasons. Colours of the values are shown below.



A. Mean growing season temperature (GST) calculated from 1st September to 30th April (°C), and monthly temperature (°C).

	Growing Season Temperature	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1986-2005	18.8	12.8	10.6	9.8	10.7	13.4	16.0	19.0	21.2	22.7	22.7	19.7	16.1
2015/16	21.0	13.5	10.6	9.7	11.2	13.3	20.5	20.8	24.4	24.7	23.6	22.7	17.5
2016/17	19.6	14.6	11.1	10.6	11.4	12.8	15.6	18.7	22.1	24.5	22.7	23.2	17.1
2017/18	20.8	12.3	9.3	10.7	10.8	14.7	18.0	21.8	22.0	25.4	24.6	20.8	18.9
2018/19	20.2	12.9	9.9	11.1	12.0	12.7	18.1	18.9	24.2	26.6	22.6	21.5	17.0
2019/20	19.6	13.6	10.2	11.5	10.7	14.0	17.6	19.0	24.4	23.3	22.4	19.8	16.1
2020/21	19.4	12.1	9.7	9.4	10.7	15.1	16.7	21.8	21.4	23.2	22.0	19.7	15.8

B. Mean growing degree days base of 10°C (GDD10) calculated from 1st September to 30th April) (°C days), monthly totals are shown for May through to August, and accumulation from 1st September to end of each month subsequent month.

	Growing Season GDD	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1986-2005	2144	94	39	*24*	*41*	*106*	293	562	908	1303	1661	1962	2144
2015/16	2666	111	39	27	45	100	426	750	1197	1653	2048	2443	2666
2016/17	2324	143	48	37	58	85	259	520	895	1346	1702	2111	2324
2017/18	2604	78	11	46	42	142	390	744	1117	1593	2002	2337	2604
2018/19	2472	93	30	63	69	82	332	600	1039	1553	1906	2263	2472
2019/20	2334	111	36	52	38	121	357	627	1074	1486	1846	2150	2334
2020/21	2288	70	24	13	44	153	360	715	1068	1477	1812	2112	2288

C. Mean growing season evapotranspiration calculated from 1st September to 30th April (mm), and monthly evapotranspiration (mm).

	Growing Season Evapotranspiration	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1986-2005	1159	56	38	*43*	*62*	*90*	133	160	185	195	164	140	92
2015/16	1299	60	41	47	58	97	175	175	223	200	179	150	100
2016/17	1186	63	39	44	68	80	135	167	192	205	160	156	92
2017/18	1266	56	42	55	63	108	147	169	189	218	171	149	115
2018/19	1258	61	42	58	74	102	148	157	198	229	170	151	104
2019/20	1211	61	44	47	68	101	155	168	223	197	151	136	81
2020/21	1191	57	41	48	62	100	122	187	189	202	159	135	98

D. Mean May to April rainfall (mm), and monthly rainfall (mm).

	May to April Rain	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
1986-2005	268	23	28	*28*	*30*	*28*	28	22	23	16	20	10	14
2015/16	200	13	8	20	25	27	5	41	2	46	0	9	4
2016/17	408	46	26	27	31	102	18	14	29	29	35	1	52
2017/18	172	15	2	11	31	6	19	56	19	4	3	5	2
2018/19	175	15	30	12	38	2	10	18	41	5	3	4	0
2019/20	224	21	29	14	7	18	3	24	0	15	22	9	61
2020/21	177	12	15	6	31	29	40	11	9	13	3	7	0

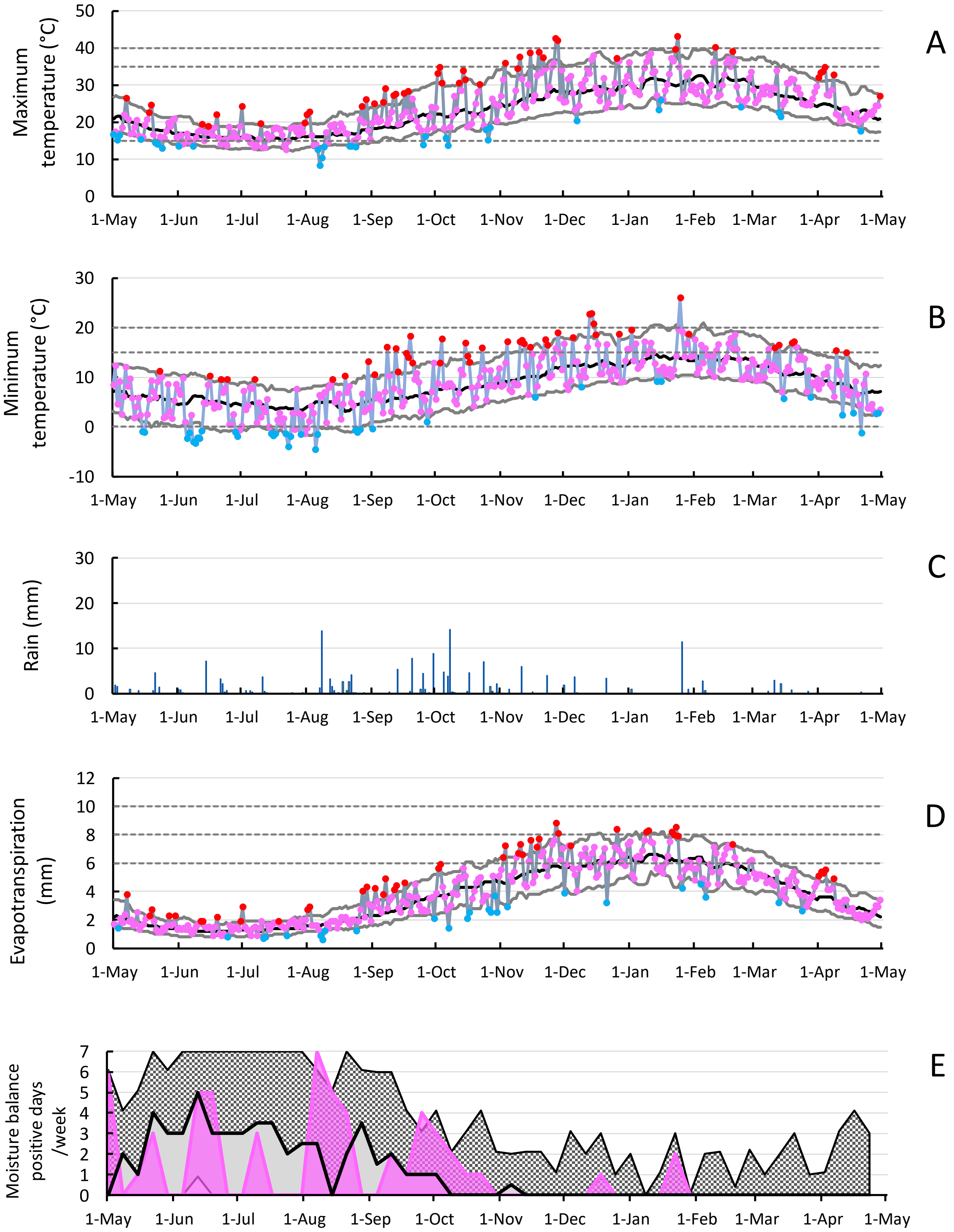


Figure 2-1. Weather in 2020/2021 season. A. Daily maximum temperature, B. minimum temperature, C. rainfall, D. reference evapotranspiration, E. the number of days in each week with a positive moisture balance. Red symbols are daily values greater than the 90th percentile, blue symbols for those less than the 10th percentile. The median (black line), 10th and 90th percentile (grey lines) of the 7 days centred on each day for the years 1986 to 2005 are shown. In the moisture balance graph (E) the grey area defined by the black line is the median, the hashed area defines the 90th percentile, and the pink lines the values in this season.

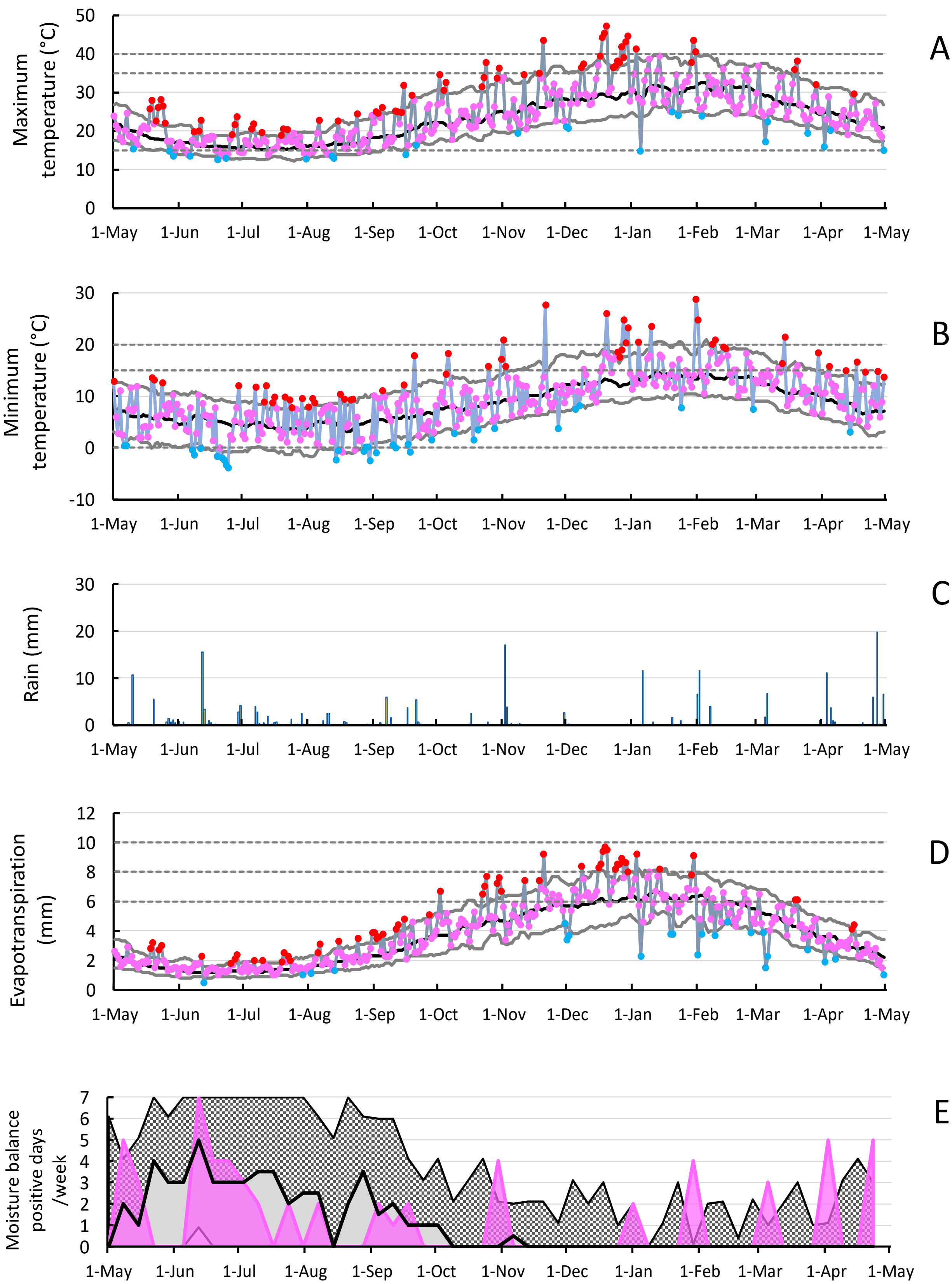


Figure 2-2. Weather in 2019/2020 season. A. Daily maximum temperature, B. minimum temperature, C. rainfall, D. reference evapotranspiration, E. the number of days in each week with a positive moisture balance. Other details as for Figure 2-1.

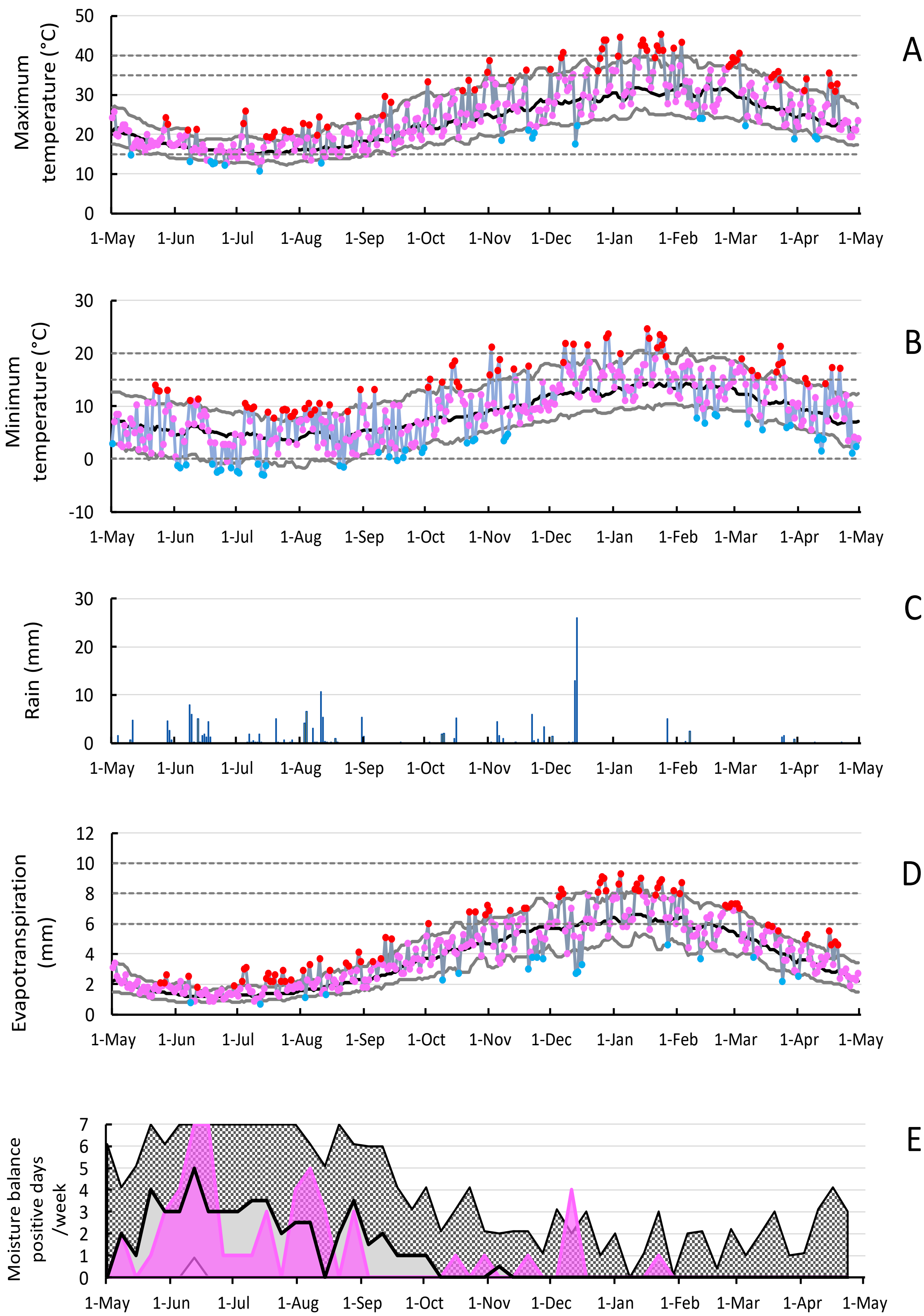


Figure 2-3. Weather in 2018/2019 season. A. Daily maximum temperature, B. minimum temperature, C. rainfall, D. reference evapotranspiration, E. the number of days in each week with a positive moisture balance. Other details as for Figure 2-1.

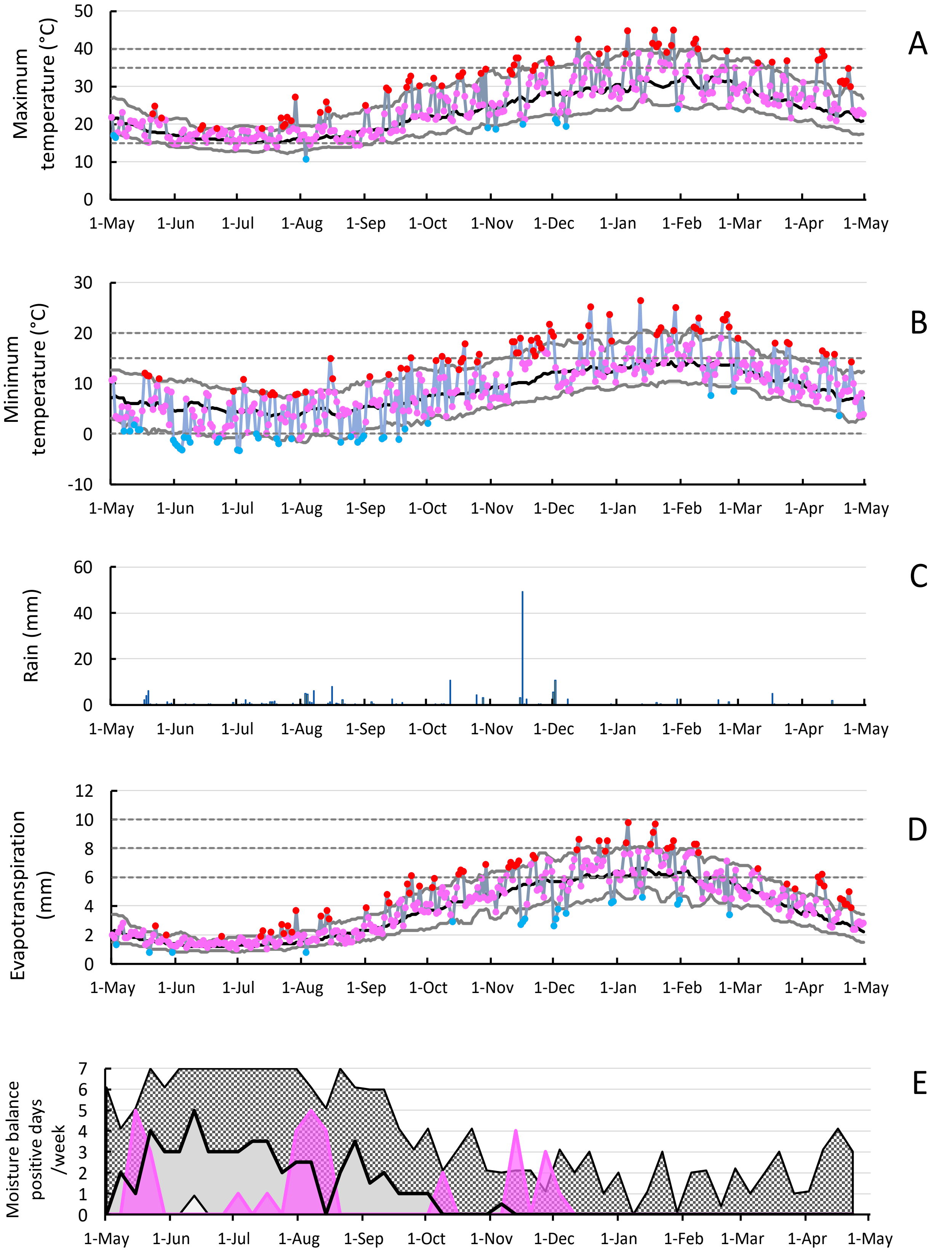


Figure 2-4. Weather in 2017/2018 season. A. Daily maximum temperature, B. minimum temperature, C. rainfall, D. reference evapotranspiration, E. the number of days in each week with a positive moisture balance. Other details as for Figure 2-1.

Wind and wind damage to the orchard

Wind in November 2019 caused damage to the orchard with trunks or major limbs snapped on many trees, Figure 2-5. Details of damage to individual trials can be found in the relevant sections (Section 2: Optimised planting density; Low (Horizon 1) to Medium (Horizon 2) and Section 5: Soil amendment trial for damage in 2019; and Section 1.8 Trial work conducted on H1 and H2 Resource Blocks for damage to the two Resource blocks in the preceding years. A summary of tree replanting, which was predominantly due to replacement of wind damaged trees in the second and third year after planting shows most damage occurred in younger trees, and it appears some varieties are most susceptible than others, Table 2-2. The older low density (H1) Resource block suffered more damage in the 2018/19 season (second year after planting) than the higher density (H2) Resource block and both these blocks experienced comparatively minor damage in 2019/20 season compared to the comparatively younger trees in the Soil amendment trial and Optimised planting density trail. The pattern of wind damage in the Optimised planting density trial showed that for Nonpareil, which suffered the most damage, indicated that lower density plantings received more wind damage.

Table 2-2. The % of trees requiring replanting summarised by the scion variety in each trial. The % of trees that required replanting in 2020 in the two Resource blocks are shown in parenthesis. Individual trials did not contain all varieties.

	Resource block 1 (H1 density)	Resource block 2 (H2 density)	Trial 1 Soil amendment	Trial 3 Density optimisation
Trial Planted	2017	2017	2018	2018
Replanting year	*2019 (2020)*	*2019 (2020)*	*2020*	*2020*
Carina	-	0 (0)	3	0
Carmel	7 (1)	-	47	-
Maxima	-	0 (1)	-	-
Monterey	8 (10)	-	-	-
Nonpareil	3 (4)	2 (1)	28	23
Shasta	-	-	-	1
Vela	-	2 (0)	18	4

An analysis of the wind conditions at the time of the initial damaging wind events in the 2019/20 season do not allow a threshold of wind to cause damage to be calculated. Figure 2-6 shows greater temporal detail of wind during October to December 2019 at the SANRM weather stations (readings each 15 minute) and the Bureau of Meteorology's Loxton Research Centres (station 24024) (readings each 10 minute). The periods of high wind gust occurred from 18th October to 25th October (neither causing damage), 1st November (9 PM), 6th November, 25th November, 20th December, 30th December. A similar situation was observed at the SANRM Loxton station (data until 14th November as many missing values after this date). The initial damage to the trees was observed on Monday 4th November and it is likely that the high wind on evening of Friday 1st November caused the damage to the orchard. Of note is that similar high wind earlier in the week (25th October) was not associated with damage. Further damage to already injured trees over the next 1 to 2 months would most likely have been due to the repeated higher wind gusts. It should be noted that both the SANRM weather station and the Bureau of Meteorology stations indicate the winds during October 2019 were not unusual, suggesting the combination of high wind, large canopy of vigorously growing trees contributed to an unfortunate combination of circumstances resulting in tree damage.

Placing the wind conditions experienced in 2019/20 in context of a longer period will further our understanding of the risks from wind and to determine if the high wind was an unusual weather event. Historical wind observations exist for about 10 years at two nearby Bureau of meteorological stations. From this history it can be seen that wind varies seasonally and while generally similar there are distinct differences between nearby observation stations of Loxton Research Centre (station 24024) and Renmark Aero (station 24048), Figure 2-7. A point from this Figure is that although the wind conditions generally follow a season pattern of calmer conditions during autumn and windier in spring, there are differences between two nearby locations in daily wind speed and maximum wind gust above 3 m. This is most easily seen in the more extreme conditions (yellow, orange and red lines). Observations in 2019 when a major wind damage event occurred show that year was unremarkable with monthly median (black line) wind speed and wind gust being similar to the longer-term conditions, Figure 2-8.

Figure 2-5. Wind damaged trees (November 2019). Crack in soil from tree movement (a); Snapped trunk (b); Snapping of secondary limbs resulting lop-sided canopy and injured primary stem (c); Splitting of main stem near crotch of major secondary branch junction (d).

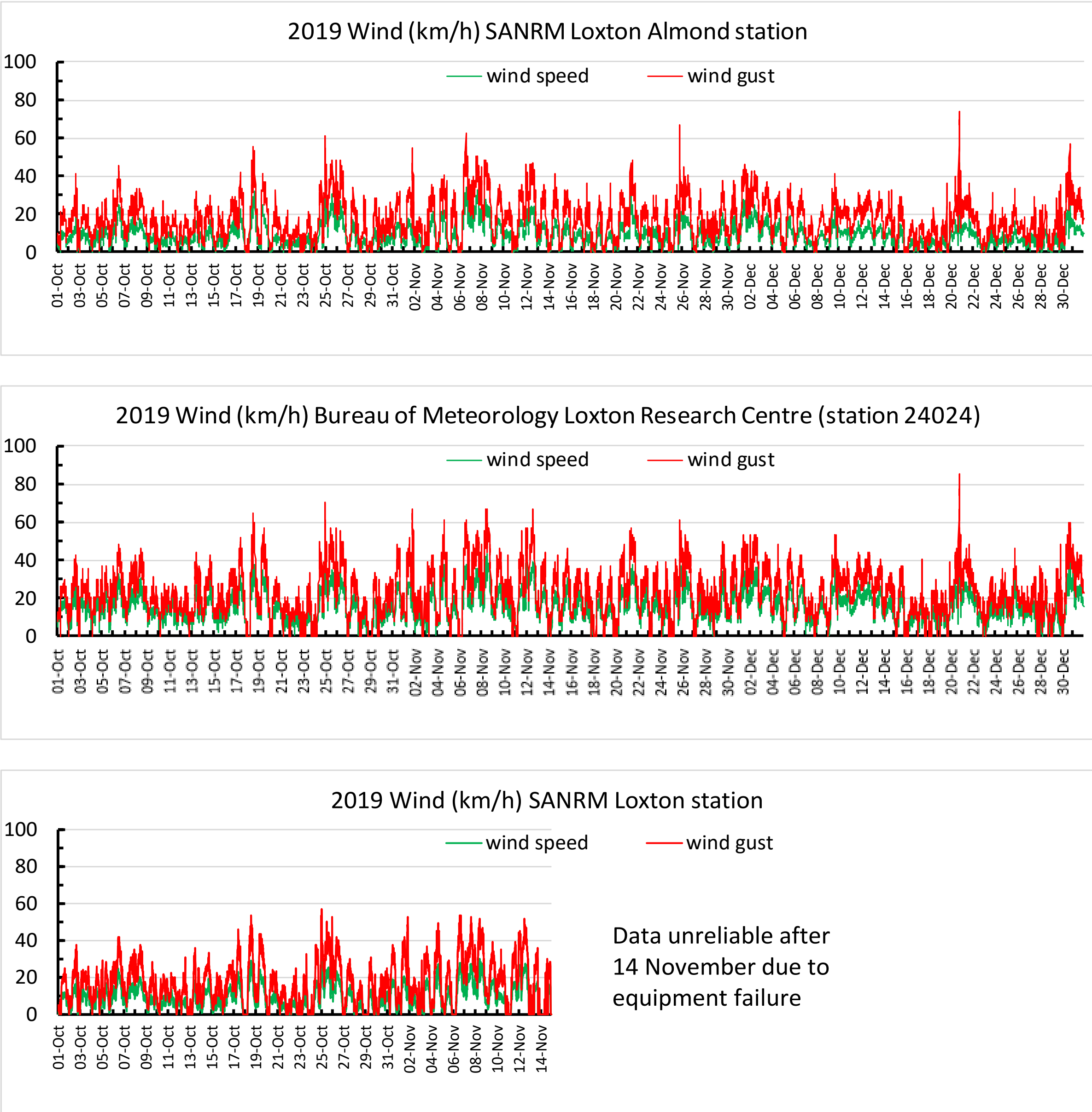


Figure 2-6. Average wind speed (15 minute average for SANRM stations and 10 minute for Bureau of Meteorology station) and wind gust during October to December 2019.

The SANRM Loxton Almond weather station at the ACE property with an observation history since July 2019 shows the seasonal pattern of wind speed and wind gusts are similar (lower in autumn and higher in spring) to those recorded at the nearby Bureau of Meteorology stations, while the absolute values differ, Figure 2-9. This could be related to the influence of localised influences on wind or because the wind was measured at a lower height of 2 m compared to 3 m at the Bureau of meteorology stations. The lower measurement height of 2m above ground surface of SANRM measurements would suggest an approximate 75% lower wind which was generally observed for wind gusts although Figure 2-10 10 shows closer to a 60% reduction in average daily wind speed at both the SANRM Loxton and SANRM Loxton Almond stations compared to the Bureau of Meteorology's Loxton Research Centre station. Differences in location, even relatively short distances do affect wind as seen earlier where wind at nearby Bureau of Meteorology stations differ; and also because the SANRM station is located within an orchard where existing trees would act as a barrier to wind movement and create turbulence as the wind passes through and over the canopy.

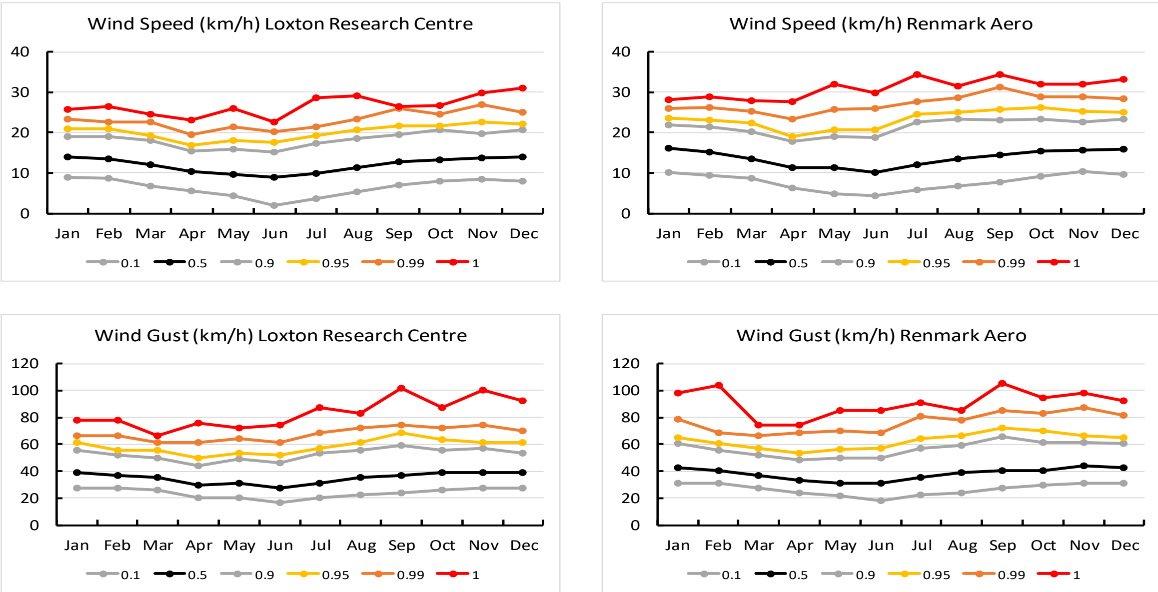


Figure 2-7. Wind speed (km/h) and wind gust (km/h) at the Bureau of Meteorology's Loxton Research Centre (station 24024) and Renmark Aero (station 24048) showing monthly median and percentiles calculated from daily values from 2010 to March 2020.
The lines are the percentiles of daily observations in each month with the median shown as the black line; 80% of the daily observations are within the two grey lines (10th and 90th percentiles) while the yellow (95th percentile), orange (99th percentile) and red (maximum) lines show the extreme higher winds.

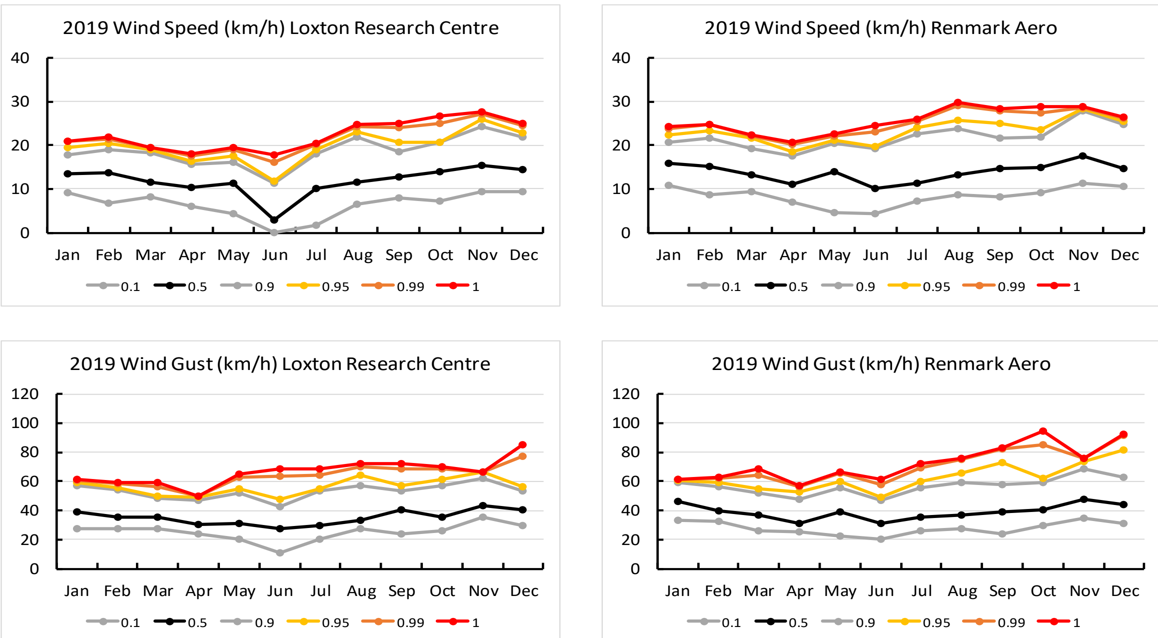


Figure 2-8. Wind speed (km/h) and wind gust (km/h) in 2019 at the Bureau of Meteorology's Loxton Research Centre (station 24024) and Renmark Aero (station 24048) showing monthly median and percentiles calculated from daily values.

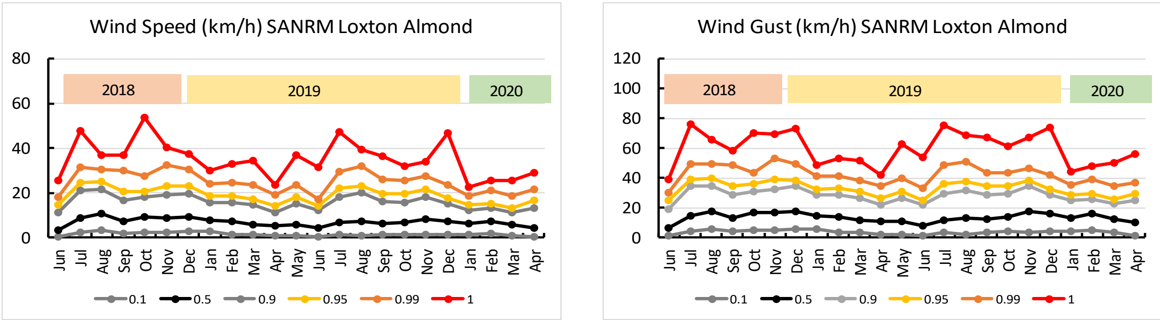


Figure 2-9. Monthly wind speed (km/h) and wind gust (km/h) from its installation in June 2018 to April 2020 at the SANRM Loxton Almond station. Monthly median and percentiles calculated from daily values are shown. NB. Wind gust was deemed to be the highest mean wind speed each 15 minute recording period, which differs from wind gust recorded by Bureau of Meteorology stations.

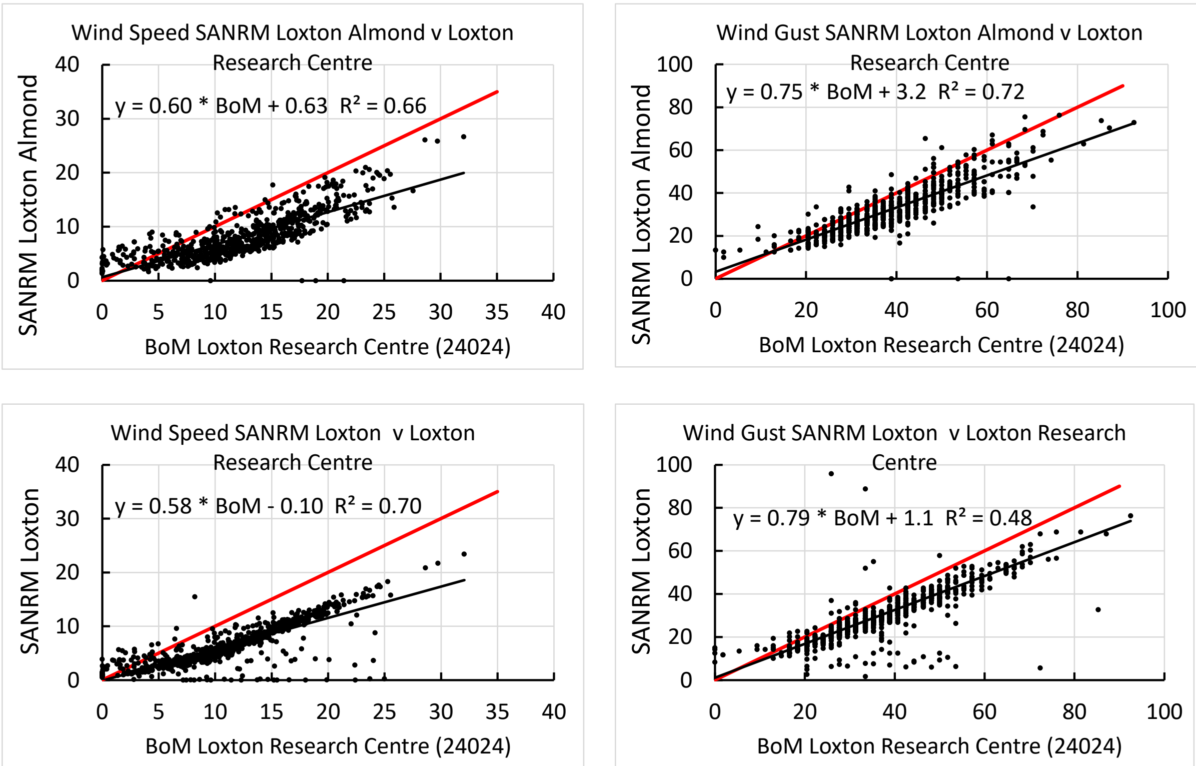


Figure 2-10. Relationship between daily average wind speed (km/h) and daily maximum wind gust (km/h) at the two SANRM stations of Loxton Almond (22/6/2018 to 5/5/2020) and Loxton (1/1/2017 to 3/4/2020) with the Bureau of Meteorology's Loxton Research Centre (station 24024). The linear regression line (black) and equation are shown. The red line shows the 1:1 relationship. NB. Wind gust was deemed to be the highest mean wind speed each 15 minute recording period, which differs from wind gust recorded by Bureau of Meteorology stations.

SECTION 3. Adaptation to climate and weather risks; assessment of sprinkler irrigation to cool orchards

Key points

- Temperature, rainfall and evapotranspiration from 2015/16 through to 2020/21 were examined at ACE in relation to a base period from 1986 to 2005
- Sprinkler irrigation is a potential adaptation to evaporatively cool orchards in a warming climate
- Sprinkler irrigation after 8 a.m. gave larger immediate reductions in temperature
- Sprinkler irrigation before 8 a.m. gave smaller reductions in temperature, but these lasted longer and gave a greater overall effect
- The largest temperature reductions were on dry, warm, sunny days
- The poor relationship between wind and temperature reduction was possibly due to loss of moist air from small measurement plots
- Detrimental effects of sprinkler irrigation may include increased disease pressure and water use

3.1 Abstract

Almond producers, like many agricultural and horticultural producers face risks from climate and weather. Managing these risks requires an assessment of the risks in the current and in projected future climate(s). Knowledge gaps are an important aspect of managing risks. Management options to alleviate or avoid the risks include those that can happen today, those that may be economic to implement at a later date or gaps in our knowledge that require further research and development. The use of sprinkler irrigation to evaporatively cool orchards was explored as an adaptation to a warmer climate. While it is known that evaporation can reduce temperature, the effectiveness of a sprinkler irrigation system designed to supply irrigation water to the plants to also cool the orchard was unknown in Australian almond orchards.

Sprinkler irrigation did create cooler conditions both during the period when the sprinklers were ON and for a number of hours after irrigation had finished. There was however a difference in the cooling pattern over time when irrigation was commenced earlier in the day (before 8 AM) and when it was commenced later in the day (after 8 AM). Commencing sprinkler irrigation after 8 AM resulted in large declines in temperature which lessened each hour after the sprinklers had been turned off. In comparison commencing irrigation before 8 AM resulted in initially smaller cooling effects which increased and remained relatively stable for about 5 hours before declining. This meant that compared to the later commencement of sprinkler irrigation the decrease in temperature was greater from 3 to 10 hours after sprinklers had been turned OFF.

The reduction in temperature compared to areas not receiving sprinkler irrigation was largest when the air was drier (low %RH or high dew point depression); when it was warmer; or when solar radiation was higher. These are also the conditions that enhance evapotranspiration. The

relationship between the decline in temperature and wind was poorer but generally less wind resulted in a greater cooling. This is possibly related to the wind moving the cool moist air out of the sprinkler plots.

It should be noted that while sprinkler irrigation may be beneficial to keeping a cooler canopy and overcoming detrimental effects of high temperatures there may be undesirable consequences of the moister conditions on disease pressure. Furthermore approximately 40% more irrigation was applied in the sprinkler irrigated plots compared to the Drip irrigated plots. Procuring this additional water will likely place strains on the economic viability and social and environmental licence of almond production.

3.2 Background and aims

Almond producers, like many agricultural and horticultural producers face risks from climate and weather. Recent studies (Thomas and Hayman, 2019a, Thomas and Hayman, 2019b) examined the climate and weather risks to almond production and related them to climate indices. Relating risks to indices of climate or weather allows quantitative measures including assessing if there is a trend in how the risks is changing over time; the year-to-year variation and the role of climate drivers during the historic climate. If the climate driver increases or decreases the chance of adverse or of favourable conditions in the coming season, then seasonal forecasts of these climate drivers can be a useful management tool. Managing climate risk of an orchard also requires an assessment of the risks in projected future climate(s). The expectations from climate change science on how the weather and climate risks may change in what is likely to be a future warmer and drier climate can provide a guide to longer term planning. An important component of this information are some possible adaptation options that the industry could use to respond to and manage the adverse conditions presented by the weather and climate risks. Table 3-1 summarises these findings. These risks remain relevant to Australian almond producers. Of note is that many experiments being conducted by SARDI at ACE could be deemed to include the secondary focus of climate adaptation: Higher density plantings are expected to produce more yield per ML of applied water; Modelling of water and solute movement is expected to elucidate irrigation efficiency; Improving soil properties is expected to improve resilience to heatwaves.

This section focuses on a further adaptation to mitigate warmer conditions: the role of sprinkler irrigation to create a cooler environment through evaporative cooling of the environment.

Heatwaves were rated as the second most important climate and weather concern to almond producers behind the risk of Rainy and wet conditions disrupting harvest operation. The importance of heatwaves affecting almond production would be expected to increase as the evidence from climate science is that warmer conditions and increased number and severity of heatwaves are expected with high confidence in coming decades.

Table 3-1. Summary of climate and weather risk, trends, variations and expectations from climate science and possible industry responses. Table based on Thomas and Hayman, 2019a, 2019b.

Rain at harvest Considerable year-to-year variation in amount of rain, number of rain days and moisture positive days during the harvest season (February to April) but with a weak relationship of El Niño decreasing and La Niña increasing this risk. The trend in recent decades of increasingly higher evapotranspiration may mitigate the risk although the natural strong seasonal pattern of declining evapotranspiration and drying potential in the autumn months will remain. The industry continues to explore ways of mitigating this risk through irrigation scheduling, weather forecasts to assist with harvest scheduling, shake and catch harvesting, and improved drying of fruit in stockpiles either through altered covers or actively venting air through stockpiles.
Heatwaves and Warmer spring and summer temperatures A direct cost is extra water as warming leads to an increased demand for water requirements. There is a strong trend of warmer conditions and more and longer heatwaves throughout the year but with considerable year-to-year variation. Warmer conditions and more heatwaves in spring and early summer in El Niño years and positive IOD years. There is high confidence in further warming and of increased heatwaves. There is an acceptance that almonds can cope with heat but there is uncertainty on the threshold temperatures that cause damage to almond crops. Management may also have to plan for the expected higher evapotranspiration due to the warming climate. There is a need to continue exploring ways to manage heatwaves and cool canopies through increased use of weather forecasts to ensuring adequate and timely irrigation, evaporative cooling or other means such as leaf surface covers that reflect light, or growth regulators that impart heat protection to the crop. Improving soil structure and water holding capacity may increase resilience to heatwaves, and also to generally warmer growth conditions.
Quantity and quality of irrigation water and Inadequate winter rain to fill profile and leach salts Supply of irrigation water is affected by storage and inflows into the main rivers which are expected to decline at 2-3 times the decline in rainfall. There is a general relationship that the Murray-Darling basin receives less rainfall in El Niño years and positive IOD years. Projections of rainfall in the short term are less clear than changes to temperature. However, it would be prudent to expect a water constrained future and fluctuations in the quantity and possibly quality of irrigation water. The increase in evapotranspiration may place greater strain on the availability and cost of water. The response to irrigation continues to require attention in the current and future climates when drivers for water loss by plants will change. Altered management practices such as plant spacing, density, pruning or training may affect kernel yield per ML of water applied. Increased understanding of the salt sensitivity of each almond growth stage would indicate if more sensitive stages need to be managed with greater care.
Temperature too cold for pollination Pollination efficiency is considered to be at risk if temperatures are below about 15 °C and if rain occurs. A warming trend should increase the conditions deemed suitable for pollination as flowering occurs in a cool time of the year.
Insufficient chill accumulation to satisfy flowering and Non-synchronized flowering Chill accumulation prior to August in most almond growing regions of more than 40 chill portions is in excess of the 23 chill portions required to complete dormancy in Nonpareil almonds. However, a 2 °C warmer climate may reduce chill portions to levels approaching those considered insufficient for current main varieties to satisfy dormancy, and considerably below that to optimise yield (thought to be 35 chill portions). It is possible chill accumulation may be promoted using surface covers that reflect sunlight and reduce heating, or sprinklers that enhance evaporative cooling. Rest breaking agents that assist in overcoming dormancy are available for use in some industries. Traditional almond varieties are self-incompatible thus orchards consist of several varieties to ensure synchronicity of flowering. The time of flowering occurs due to a complex interaction of chill accumulation and heat accumulation which will change independently in a warmer climate and may affect synchronicity of flowering in traditional varieties. Self-fertile varieties should reduce the risk of non-synchronized flowering between different varieties.
Frost The date of last frost and the number of frosts after July are highly variable on a year-to-year basis and there are no strong indications that the risk of frosts has changed in recent decades. In the long-term frost frequency and severity is expected to decrease although spring frosts may increase in coming decades. Frost can be managed by careful site selection, improving air movement (e.g., fans or similar), sprinkler irrigation, soil moisture, or ground cover.
Rain and Humidity leading to disease The number of rainy days and of moisture balance positive days from August to April is highly variable on a year-to-year basis but with more rainy days and of moisture balance positive days in spring and early summer in La Niña years and negative IOD years. There is high confidence of warmer conditions in the future but less certainty about relative humidity. Many horticultural pests and diseases are sensitive to rainfall, temperature and humidity, so the suite of problem species may change in a warmer and drier climate. Managing these is likely to require constant vigilance.

3.3 Materials and methods

Evaporative cooling using sprinkler irrigation

The evaporative cooling experiment was conducted in the Soil amelioration research trial at ACE. Further detail of this trail can be found in Section 5 – Soil amendment trial. Briefly the trial was planted in 2018 as 6 replicated blocks of 12 treatments with each experimental plot consisting of four rows of 7 trees planted at 4.5 m within row tree spacing and rows 7 m apart. Each row is of a different variety (Nonpareil, Carina, Vela and Shasta) on Garnem rootstock. The treatments consisted of a range of soil organic matter amendments covering amount applied and method of application including growing inter-row crops for generating biomass in-situ. Additionally, this trial included a comparison of irrigation methods. These different irrigation systems were used as the treatments in the evaporative cooling trial. These irrigation treatments included drip irrigation only (industry standard; Drip which was used as the control treatment); those receiving drip irrigation supplemented with sprinkler irrigation (Drip + Sprinkler); and those receiving sprinkler only irrigation (Sprinkler). Irrigation by drip in the Drip and the Drip + Sprinkler treatments occurred at the same time with same irrigation applied by the drip system. Irrigation by sprinkler in the Drip + Sprinkler treatment was managed to irrigate the inter-row between sowing in May to approximately September for production of a ryegrass cover-crop in order to produce in-situ soil carbon. Irrigation by sprinkler in the Sprinkler treatment was of the row and inter-row and managed for irrigation of the trees.

In the 2019/20 season evaporative cooling was examined after 11th November 2019 as prior to this date the temporal resolution of measured irrigation ON / OFF times was too low and in the order of hourly or four hourly values with both reporting systems (Talgil – the irrigation scheduling system used at ACE and SWAN Systems – an irrigation and nutrient management system being evaluated at ACE). The Phytech plant health indicator (essentially a series of automatic dendrometers) installed in November 2019 allowed a 10-minute resolution of irrigation ON times.

In the 2020/21 season the treatments examined in the evaporative cooling experiment included drip irrigation only (industry standard of drip irrigation in the tree line; Drip); this was the control treatment; and sprinkler irrigation only (Sprinkler). Irrigation by sprinkler in the Sprinkler treatment was of the row and inter-row and managed for irrigation of the trees. Unlike the previous season the treatment receiving drip irrigation supplemented with sprinkler irrigation (Drip + Sprinkler) was not examined. This was to increase the sample size of the respective treatments.

All decisions over irrigation scheduling were taken by orchard management according to the requirements of the plants or to meet orchard operation requirements. Irrigation frequency decreased from weekly or less frequent during June to mid-August, approximately every 3 to 5 days until early September, then almost every day and usually twice per day, and occasionally three times per day until March or April and reducing to weekly of less in May. Sprinkler irrigation was applied less frequently and during November to March was typically applied every second or third day and reduced to every fourth day from April. Sprinkler irrigation prior to late January 2021 typically commenced from mid-morning (8 AM or after), while from late January to mid-April sprinkler irrigation typically commenced at 7 AM or earlier. These early morning commencements of sprinkler irrigation were to maintain a dry orchard inter-row to facilitate harvest operations.

From August 2019 to May 2020 6.7 ML/ha was applied to the Drip treatment compared to 11.0 ML /ha by the Sprinkler treatment to account for lower irrigation efficiency to the almond trees, Figure 3-1. The Drip + Sprinkler treatment received an additional 0.5 ML /ha from June to September 2019 when it was stopped. The Sprinkler treatment received similar amounts (11.3 ML /ha) the following season from August 2020 to May 2021, while the Drip treatment received 8.6 ML/ha. Further details on irrigation can be found in Section 5 – Soil amendment trial.

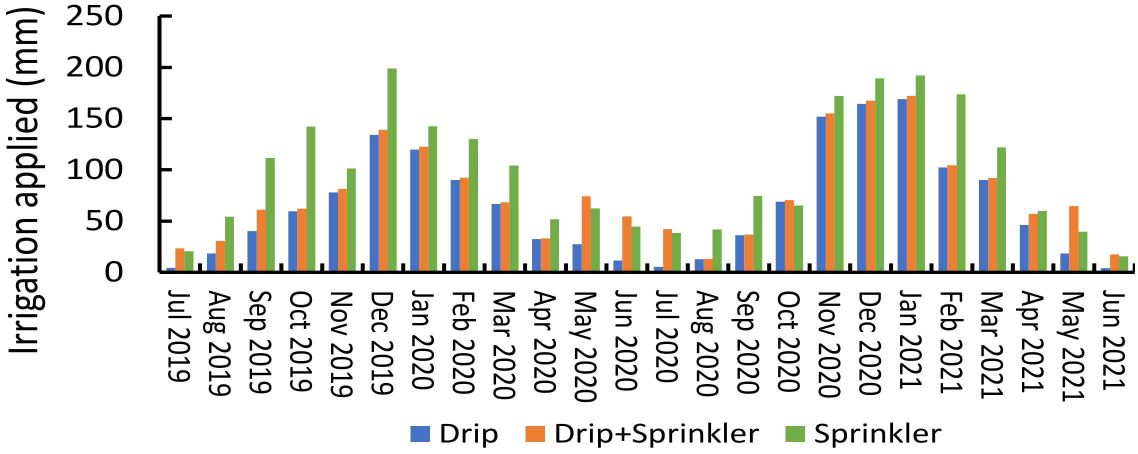


Figure 3-1. Monthly irrigation (mm) applied in the Drip, Drip+ Sprinkler and Sprinkler treatments.

In the 2019/20 season air temperature and %RH was measured each minute in four plots of the Drip, Drip+Sprinkler and Sprinkler treatments at 1.2 m height above ground level using Hobo S-THB-M002 temperature/RH sensor. Solar radiation at 2 m height was measured using Hobo S-LIB-M003 silicon pyranometer sensor at one location within the orchard. Wind speed was measured using Madge wind101A at 2 m height at three locations.

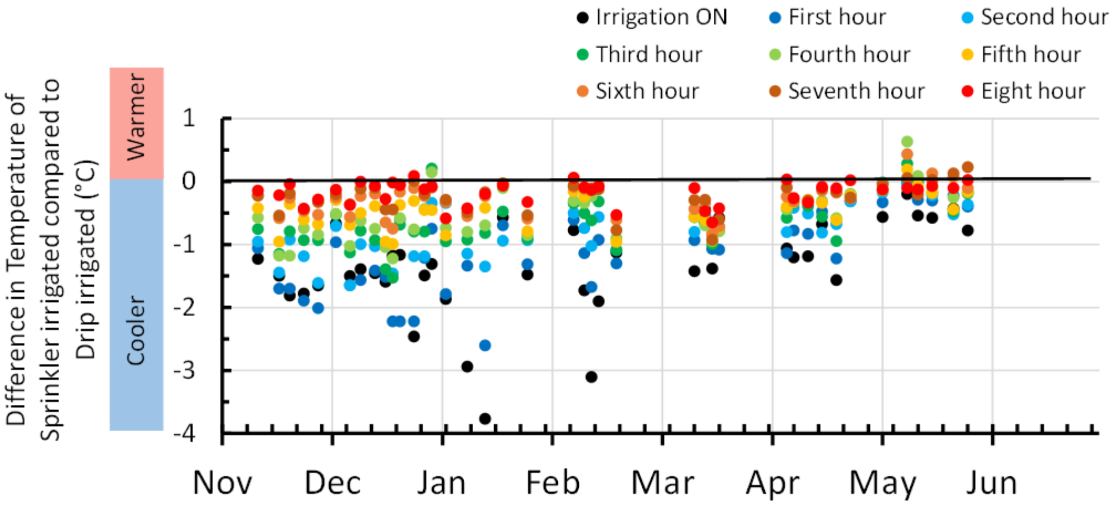
Owing to damage (animals) to many of the sensors during winter and early spring 2020 it was decided to install more robust TPG4505 loggers (Tinytag) for recording temperature and %RH and to reduce resolution to 5 minute intervals. This was completed on 28th October 2020. The wind speed equipment was also changed to Pro-D anemometers and LeWL dataloggers (LogicEnergy). Solar radiation at 2 m height was measured using Hobo S-LIB-M003 silicon pyranometer sensor at one location within the orchard.

The effectiveness of evaporative cooling was assessed by the difference in air temperature during and after sprinkler irrigation events in the Sprinkler treatment compared to the Drip treatment. It would be expected evaporative cooling would occur when Sprinkler was ON and decreases in air temperature largest when combined with Drip OFF. Similarly, it would be expected no evaporative cooling when Sprinkler was OFF with essentially the same air temperature between treatments when both Sprinkler and Drip were OFF. Differences were analysed at each recording time using T-test assuming equal variance.

3.4 Results and Discussion

Temperature was reduced by the sprinkler irrigation, Figure 3-2. In comparison air temperature decreased only marginally (mean of <0.2 °C) by drip irrigation compared to unirrigated sprinkler irrigated plots that had not received irrigation for at least 24 hours.

Figure 3-2 shows the average difference in temperature in the sprinkler treatment compared to the drip treatment when the irrigation was applied and for each hour after the sprinklers were turned off. Air temperature decreased when the sprinklers were ON compared to the drip irrigated plots by an average of 1.4 °C in the 2019/20 season and 0.9 °C in the 2020/21 season. Within these average declines in air temperature there was a range from almost nil (<0.2 °C) to 3.6 °C. While not a managed set of comparisons it was observed that there were generally larger decreases in air temperature when Sprinkler irrigation was ON during warmer parts of the day (10 AM to 3 PM) than earlier or later in the day. The data from the 2020/21 season shows there are two patterns of cooling corresponding to the time of day when the sprinkler irrigation was applied. Sprinkler irrigation prior to late January typically commenced from mid-morning (8 AM or after), while from late January to mid-April sprinkler irrigation typically commenced at 7 AM or earlier. These early morning commencements of sprinkler irrigation were to maintain a dry orchard inter-row to facilitate harvest operations. The cooling pattern seen in the period until late January 2021 shows the largest cooling when the sprinkler was ON and a reduction in cooling for each after the sprinkler was turned OFF is similar to the observations during the 2019/20 season.



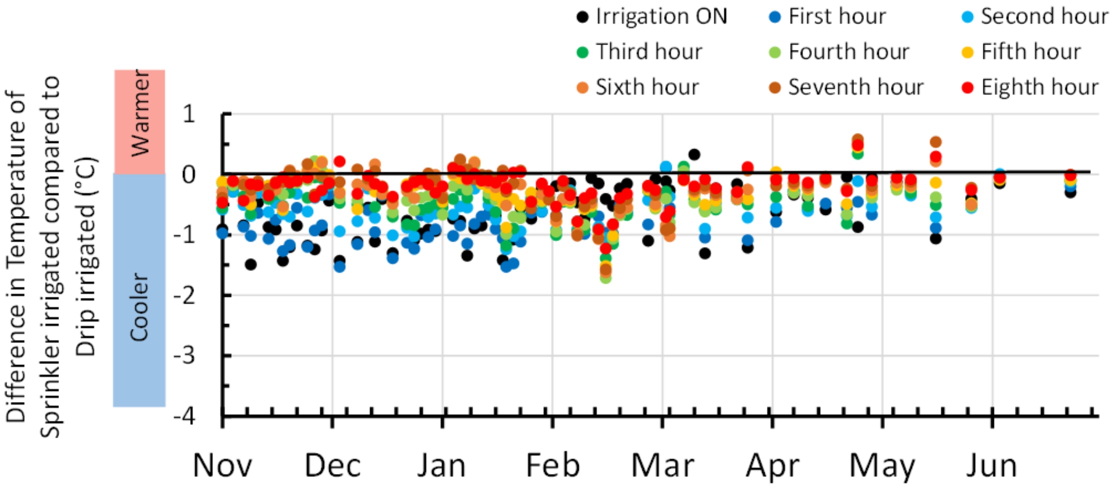


Figure 3-2. Decrease in air temperature when Sprinkler irrigation was ON and the average of each subsequent hour after it was turned OFF. 2019/20 season (upper) and 2020/21 season (lower).

The second cooling pattern which occurs on most occasions from late January to mid-April shows minimal cooling when the sprinklers are ON but a small and relatively stable cooling effect in the first 3 to 5 hours after the sprinklers were turned OFF which declines to minimal cooler thereafter. Figure 3-3 (lower) shows the average difference in temperature of the Sprinkler treatment compared to the Drip treatment when irrigation was commenced after 8 AM and when it was commenced before 8 AM. As in the 2019/20 season (Figure 3-3 upper), in the 2020/21 season when irrigation was commenced after 8 AM the decreases in air temperature were generally significant for the first 2 to 4 hours and rarely significant after 6 hours although on occasions significant, albeit small absolute declines in temperature occurred 10 or more hours after sprinkler irrigation.

These findings highlight the importance of weather conditions on the effectiveness of evaporative cooling. In the period from late January the minimal cooling when the sprinklers were ON probably reflects the higher relative humidity (mainly as consequence of cool night-time conditions) throughout the orchard at these times which would reduce effectiveness of latent heat transfer (evaporative cooling). In comparison when sprinklers were applied later in mid-morning corresponding to lower relative humidity the latent heat transfer and evaporative cooling was greater.

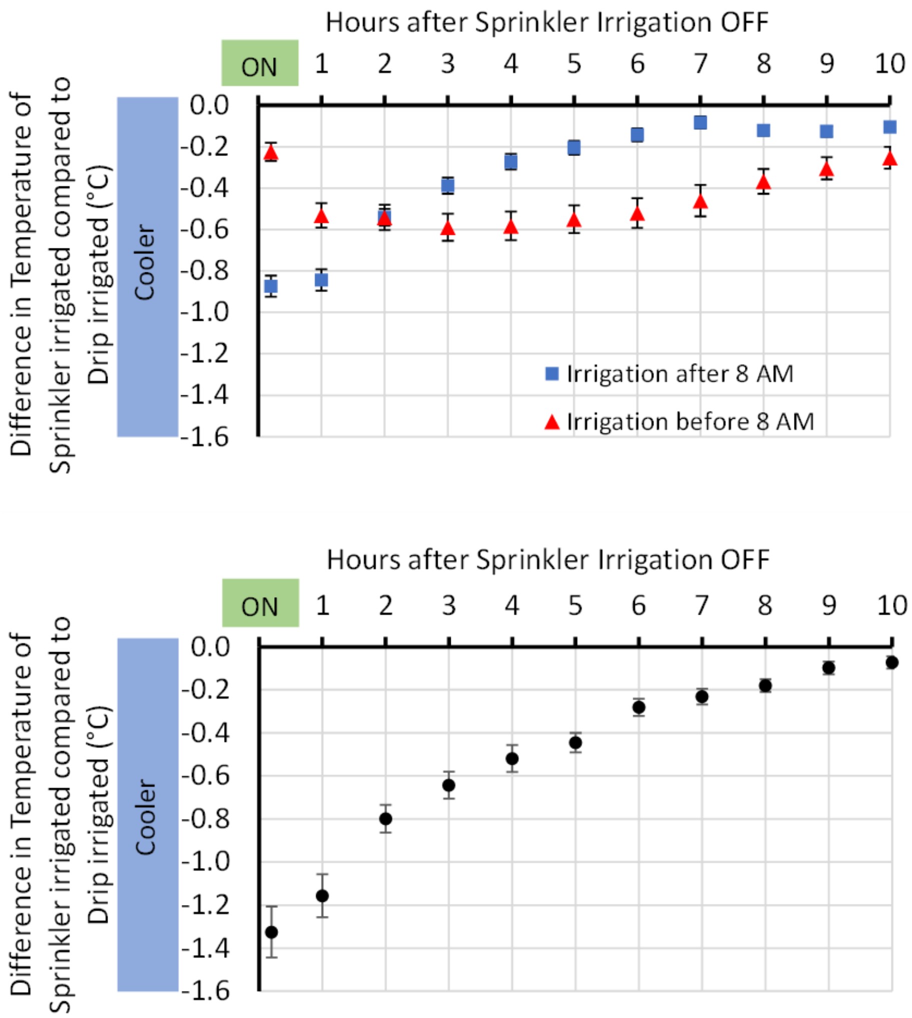


Figure 3-3. Decrease in air temperature when Sprinkler irrigation was ON and the average of each subsequent hour after it was turned OFF. The 2019/20 season (upper) shown as black circles. The 2020/21 season (lower) is separated according to irrigation commencing after 8 AM (blue squares) and before 8 AM (red triangles). SE shown as bars.

A series of correlations of the average temperature decline when the Sprinkler irrigation was ON with weather elements showed larger decreases in temperature in calmer conditions (less windy: expected as windier conditions would quickly transfer the cooler air away from the plots), sunnier, warmer and less humid conditions. Many of these weather elements would be auto correlated, and influenced by seasonal factors and management decisions of when irrigation was applied (*i.e.* which days and what time of day). Figure 3-4 shows the relationships of the effectiveness of evaporative cooling when the sprinklers were ON with some weather parameters for the 2019/20 season. Figure 3-5 shows the relationships of the effectiveness of evaporative cooling when the sprinklers were ON with some weather parameters for the 2020/21 season. The data for the 2020/21 season has been segregated according into occasions when sprinkler irrigation was commenced after 8 AM and when it commenced before 8 AM. For all weather elements, apart from that with wind speed, the relationship of the decline in temperature when the sprinklers were ON was not affected by the time of day when the sprinkler irrigation commenced. It should be noted that many of these weather elements will be auto correlated.

Cooling was greater when temperatures were higher. There was no relationship with absolute humidity or absolute dew point, but rather sprinkler irrigation was more effective in causing greater evaporative cooling when relative humidity was lower, or when dew point depression was higher. Higher sunlight (solar radiation) was also associated with greater evaporative cooling. These relationships (higher radiation, lower relative humidity, higher temperature) are the same as those that directly or indirectly increase evapotranspiration.

Wind speed had a less clear relationship with the decline in temperature. While higher wind increases evapotranspiration and could be expected to increase evaporative cooling and reduce the temperature in the sprinkler treatment, it would also move the moist air away from the sprinkler irrigated plots. As in the 2019/20 season, when sprinkler irrigation was applied after 8 AM a low wind speed resulted in larger declines in temperature. Wind had no or minimal influence on reducing temperature when sprinkler irrigation commenced before 8 AM.

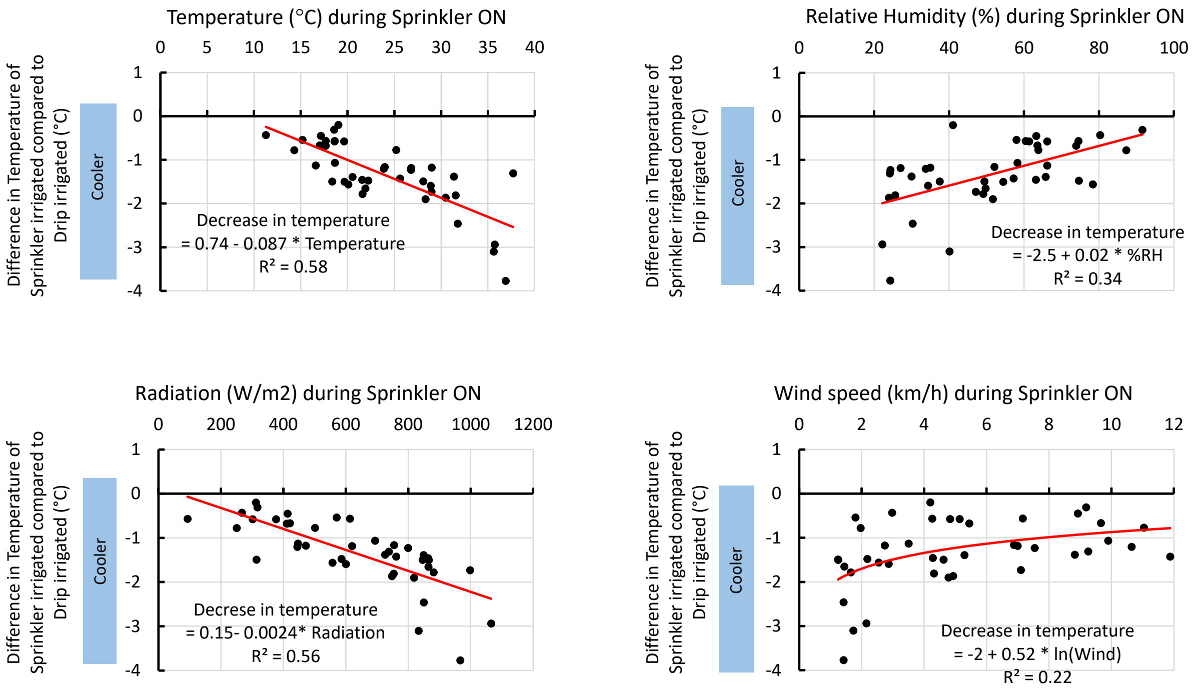


Figure 3-4. Relationship between the decrease in air temperature when Sprinkler irrigation was ON (restricted to when Drip irrigation was OFF) with the prevailing weather elements during those times in the 2019/20 season. Points show mean values for the period the sprinklers were ON. Regression line with equations are shown.

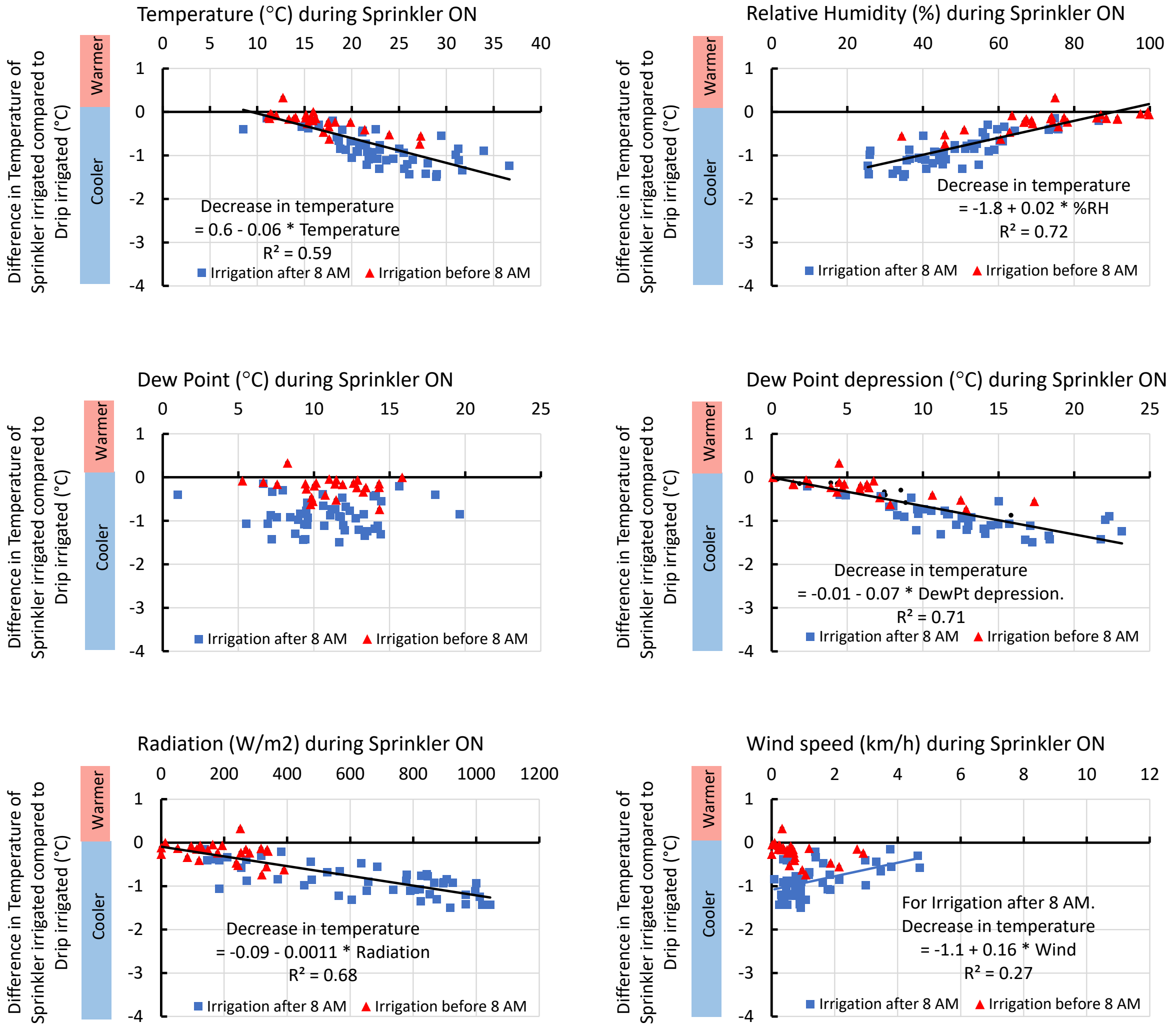


Figure 3-5. Relationship between the decrease in air temperature when Sprinkler irrigation was ON (restricted to when Drip irrigation was OFF) with the prevailing weather elements during those times in the 2020/21 season. Data have been segregated into those occasions when sprinkler irrigation commenced after 8 AM (blue squares) and when it commenced before 8 AM (red triangles). Points show mean values for the period the sprinklers were ON. Regression line with equations shown for all data unless stated.

SECTION 4. Development of rapid root quantification assay for *prunus* rootstocks

Key points

- A DNA based root identification and quantification assay has been developed for Prunus spp.
- The assay can detect 16 rootstock genotypes of relevance to the Australian almond industry
- Assay produces comparable outcomes to existing root assessment techniques
- Advantages include reduced labour inputs, minimal soil/root disturbance and rapid turnaround
- Initially developed as a quantitative, descriptive research tool, the assay could be further adapted into an indicator of tree health and root activity, useful as a guide to improve fertiliser and irrigation application
- Assay allows for multiple qPCR assays on the same sample such as the testing of free living nematodes and soil borne pathogens (Verticillium dahliae, Rhizoctonia solani and Phytophthora cinnamomi).
- The assay is now available for routine assessment of samples through SARDI's Molecular Diagnostic Centre and is relevant to any industry the employs Prunus spp. as rootstocks.

4.1 Background and aims

Root density and distribution is an important metric to:

- Evaluate water and nutrient use efficiency of almond orchards.
- Compare root development and architecture between almond rootstocks.
- Investigate root anchorage differences between different rootstocks.
- Assess the impact of soil constraints on almond root development.
- Assess the impact of soilborne disease on almond root development.
- Understand if root system is impacting on tree vigour, nut yield and quality.

Current systems available for the measurement of root architecture in almond orchards are time consuming and expensive (for example WinRhizo) or destructive (for example tree excavation), limiting their application in research programs and commercial agronomy.

The SARDI Molecular Diagnostic Centre has developed methods for the quantification of DNA in soil samples (Ophel-Keller et al., 2008). This testing can be used for detecting DNA of plant roots including tree crops (Bithell et al., 2015). With design of an assay for *Prunus* spp. this platform could be used for quantification of root proliferation in the soil profile of almond orchards, without the need to separate roots from the soil.

Development of a cost effective reliable rapid root quantification system to understand the depth and distribution of the active rootzone would assist research providers investigating unique varieties, rootstocks and production systems in the pursuit of improved resource use efficiencies.

Use of the SARDI PREDICTA platform would also enable specific pathogens of *Prunus* root systems to be quantified at the same time on the same sample. Examples of tests available are *Verticillium dahliae* and *Phytophthora cinnamomi*.

4.2 Assay development

qPCR test design

To detect root DNA of *Prunus* spp. rootstocks used in almond production in soil using qPCR, the internal transcribed spacer (ITS) was targeted; it is a region of the genome in multiple copies, allowing for sensitive detection.

New and reliable ITS sequence information was obtained to assist with test design. Direct sequencing did not provide good quality sequences due to the diversity and complexity of the *Prunus* rootstock parentage. Next generation sequencing (NGS) was used instead to resolve the ITS sequence of the main *Prunus* rootstocks currently used for almond production in Australia, Table 4-1.

Based on the sequenced information obtained and that available in public databases, five tentative ITS qPCR tests were designed.

Table 4-1. List of Prunus rootstocks used in the Australian almond industry and their parentage

Rootstock	Parentage *
D63-182	*P. dulcis x P. persica*
Barrier 1	*P. persica x P. davidiana*
Monegro	*P. dulcis x P. persica (Nemared)*
Krymsk 86	*P. persica x P. cerasifera*
Viking	*Multi-species hybrids*
Controller 6	*P. persica*
Atlas	*Multi-species hybrids*
Nemaguard	*P. persica*
Rootpac 40	*P. dulcis x P. persica*
GF 677	*P. dulcis x P. persica*
Rootpac 20	*P. besseyi x P. cerasifera*
Cornerstone	*P. dulcis x P. persica (Nemared)*
Controller 7	*P. persica*
Garnem	*P. dulcis x P. persica (Nemared)*
Felinem	*P. dulcis x P. persica (Nemared)*
Brights hybrid	*P. dulcis x P. persica*
Controller 9.5	*P. persica*

* Parentage info sourced from: UC Davis Foundation Plant Services, Agromillora and University of California Fruit Report

qPCR test evaluation

The five tentative qPCR tests were evaluated for sensitivity using root DNA extracted from the rootstock collection, Table 4-1 and Figure 4-1b. All tests detected most rootstocks with similar sensitivity except for Rootpac 20 that was poorly detected by most tests. The two most sensitive tests were further assessed for sensitivity using DNA extracted from almond orchard soil and for specificity using a collection of weed root DNA including *Medicago* sp. (medic), *Cyperus* sp. (nutgrass), *Conyza bonariensis* (flaxleaf fleabane), gazania, *Rumex hypogaeus* (three corner jack), *Tribulus terrestris* (caltrop), *Sonchus* sp. (dandelion), *Malva parviflora* (marshmallow), Figure 4-1c.

The two tests had similar sensitivity to detect almond root DNA in orchard soil, but one was more specific i.e., showed less cross reaction with weed DNA. The most specific test was selected for delivery. Test design is available to requesting parties under MTA.

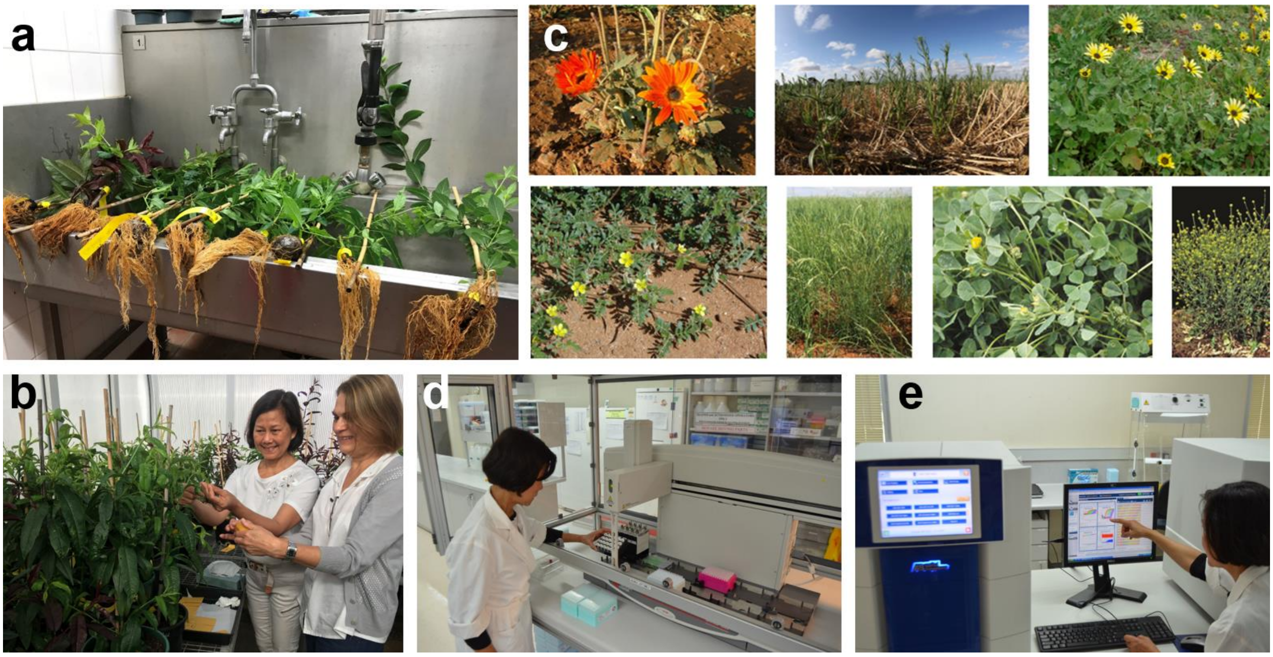


Figure 4-1. Steps in the development of DNA based *prunus* root quantification assay including collection of target prunus (a, b); and non-target (c) DNA samples; and analysis of extracts using qPCR test evaluation (d, e)

qPCR test calibration - rootstocks

To account for differences in ITS copy number and calibrate the ITS test across almond rootstocks, another qPCR test targeting a gene in single copy in the almond genome was designed (SG test).

For most rootstocks, the difference in results between the two tests has been used to calculate the ITS copy number in each rootstock and determine a correction factor against the reference rootstock Nemaguard, Table 4-2. Correction factor has not been determined for Rootpac 20, due to its poor detection with the ITS test. This rootstock is currently not widely used in the Australian almond industry.

To compare results between rootstocks, root DNA concentration determined using ITS test should be divided by the correction factor for the rootstock being evaluated. The correction factor accounts only for differences in ITS copy number but not for differences in root morphology and root efficiency that may influence interpretation of concentration of root DNA in a soil sample.

Field sample collection and preparation

The developed assay quantifies concentration of root DNA in soil samples. Key requirements of sample collection and preparation are:

- Maximise sample size within 500g limit and sampling purpose.
- Keep samples under 10°C until they can be dried.
- Dry sample as soon as possible after collection
  - Maximum temperature 40°C for drying
- Sieve dry samples to remove roots greater than 2mm in diameter.

Optimum field sampling protocols will vary depending on specific purpose of the research or evaluation being conducted. Development of protocols for collecting soil cores from the rootzone of almond trees was beyond the scope of this project.

Table 4-2. Calibration of the ITS qPCR test across major *Prunus* rootstocks using the single copy gene (SG) qPCR test. For each rootstock, the difference in cycle threshold (Ct) values between the two tests is directly related to the ITS copy number and can be used to calculate a correction factor.

Rootstock	Ct value		Correction factor for *Prunus* ITS
	ITS	SG	Nemaguard standard
D63182	14.0	22.8	1.99
Barrier 1	14.0	22.8	2.03
Monegro	14.9	22.9	1.16
Krymsk 86	17.2	23.7	0.40
Viking	13.6	22.7	2.52
Controller 6	15.4	22.6	0.71
Atlas	13.5	22.7	2.63
Nemaguard	14.8	22.6	1.00
Rootpac 40	14.7	23.7	2.30
GF 677	13.9	22.8	2.15
Cornerstone	14.2	22.7	1.69
Controller 7	15.0	22.6	0.86
Garnem	15.2	23.8	1.85
Felinem	15.2	23.1	1.14
Brights hybrid	14.1	22.8	1.96
Controller 9.5	15.1	22.7	0.88
Negative control	Not detected	Not detected	NA

4.3 Preliminary evaluation of *Prunus* ITS root assay for assessing root distribution

Comparison of *Prunus* ITS root assay with WinRhizo

Pot trial samples

Samples were collected in years 1 and 2 of a controlled environment salt tolerance trial (CSIRO project AL13009). Trees of three rootstocks (Cornerstone, Garnem, Nemaguard) were grown in 3 L pots for two seasons. Growth media used was UC coarse river sand and peat mix.

Duplicate samples, each consisting 2 soil cores 35 mm diameter by 110 mm depth were collected from individual pots on 17 December in Year 1 and 23 October in year 2. Total length of roots less than 2 mm in diameter in the soil cores was assessed using the WinRhizo technique (Zhou et al., 2020). The matching samples were dried and sieved to remove roots greater than 2mm in diameter, prior to quantification of DNA using the *Prunus* ITS root assay. *Prunus* ITS root assay results were adjusted for differences in copy number of the rootstocks using the correction factor listed in Table 4-2.

Results obtained with the *Prunus* ITS root assay were related (r^2 = 0.69 to 0.82) to the total length of roots less than 2 mm in diameter measured with the WinRhizo technique, Figure 4-2. Stronger relationships (r^2 = 0.81 to 0.99) were found when the data of the five replicates for each rootstock /salt treatment combination were averaged, Figure 4-3. Considerable variation of root growth was observed within pots, which indicates the importance of sampling method and sufficient replication in achieving comparable and repeatable results.

The slope of the plotted linear relationships between the *Prunus* ITS root assay and WinRhizo results varied between rootstock cultivars, indicating the results were not directly comparable between the varieties for the two methods. Possible reasons include differing cell density (DNA concentration) per mm of root length and different root morphology between rootstock varieties. The later could impact on both the *Prunus* ITS root assay and the WinRhizo results. It should also be noted that average root length measured by WinRhizo for Cornerstone was less than half that of Garnem and Nemaguard. These results suggest caution should be exercised in using either technique to compare between varieties of rootstock.

Orchard trial samples

Samples were collected in early February as part of a compost trial conducted in a commercial almond orchard (CSIRO project ref). Orchard was planted with Nonpareil on Nemaguard rootstock and irrigated by a dual line drip irrigation system. The field trial was evaluating five compost/fertiliser combinations with 5 replicates. Paired (neighbouring) soil cores of approximately 50 mm in diameter were collected to 75 cm depth (split 0-25, 25-50, 50-75cm) with a hydraulic soil corer from each replicate and treatment. Cores were taken opposite almond trunks 1200mm into the mid-row, within the wetted area of irrigation system.

Root presence was measured with the WinRhizo (length and dry weight of roots less than 2mm in diameter) and *Prunus* ITS root assay (kDNA copies /g soil sample) methods. Averaged data for compost/fertiliser treatments by each sampling depth are depicted in Figure 4-4. The bar charts indicate both WinRhizo dry weight and length and *Prunus* ITS root assay methods provided similar findings for root distribution as effected by treatment and sample depth.

There was a high level of variation in results for individual paired samples using the two different methods (eg root dry weight using WinRhizo and the *Prunus* ITS root assay), resulting in a poor relationship (r^2 = 0.27) between the two methods, Figure 4-5. The relationship was stronger (r^2 = 0.71) when data was averaged across five replicates. Results highlight the need to determine an adequate but cost-effective level of sampling when assessing root distribution in an almond orchard. Further work is required to confirm appropriate sampling protocols for use of the *Prunus* ITS root assay.

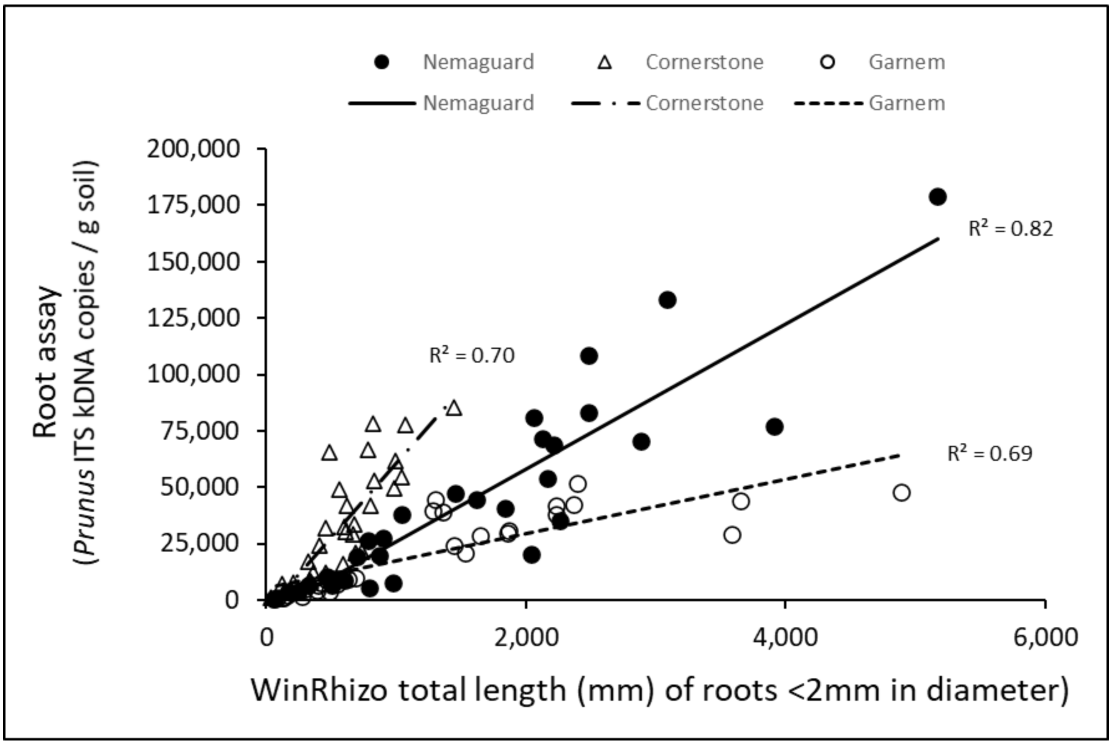


Figure 4-2. Relationship between total length of roots less than 2mm in diameter (WinRhizo) and DNA testing using *Prunus* ITS root assay (corrected for ITS copy number) for varieties Nemaguard, Cornerstone and Garnem grown in pots to investigate tolerance to salinity. Testing conducted on duplicate samples (each consisting of 2 cores 35 mm diameter by 110 mm depth) sampled from individual pots. Combined data from sampling in year 1 and 2.

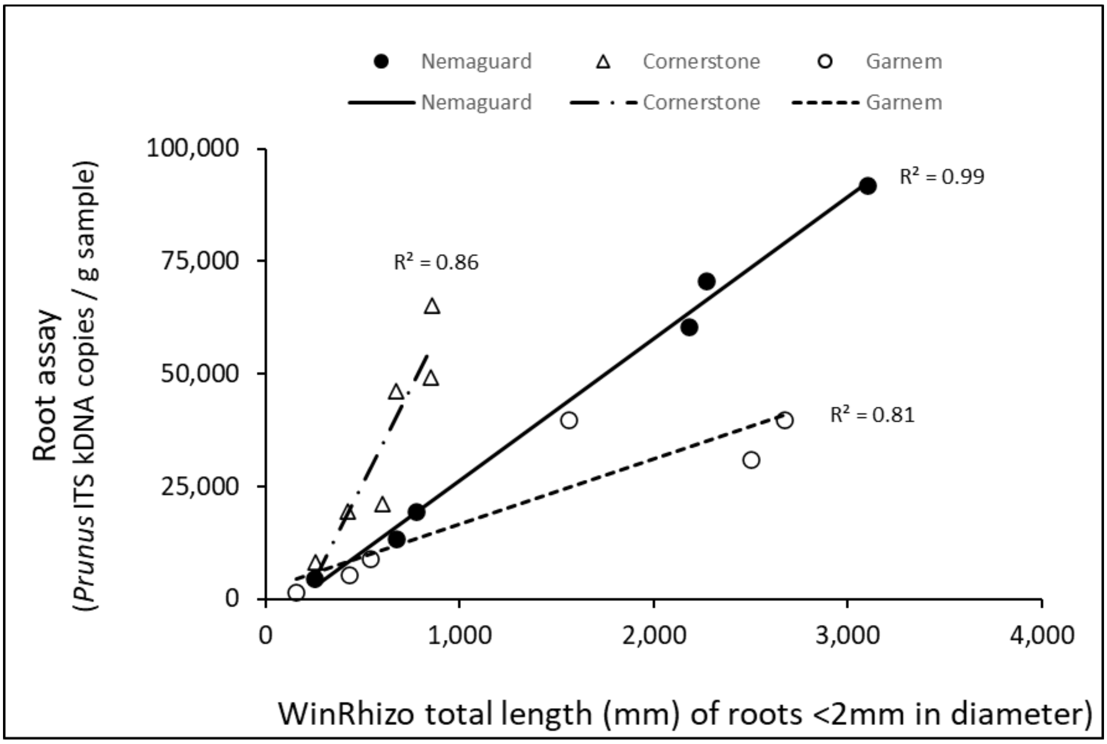


Figure 4-3. Relationship between average total length of roots less than 2mm in diameter (WinRhizo) and DNA testing using *Prunus* ITS root assay (corrected for ITS copy number) for varieties Nemaguard, Cornerstone and Garnem grown in pots to investigate tolerance to salinity. Each data point average of 5 replicates conducted on duplicate samples (each consisting of 2 cores 35 mm diameter by 110 mm depth) sampled from individual pots. Combined data from sampling in year 1 and 2.

Figure 4-4. Comparison root assessment by measurement of root dry weight and root length (roots less than 2mm diameter) using WinRhizo, and *Prunus* ITS root assay (roots less than 2mm diameter) obtained on samples from compost trial in an almond orchard (Nemaguard rootstock). Bars indicate Standard Error of the Mean.

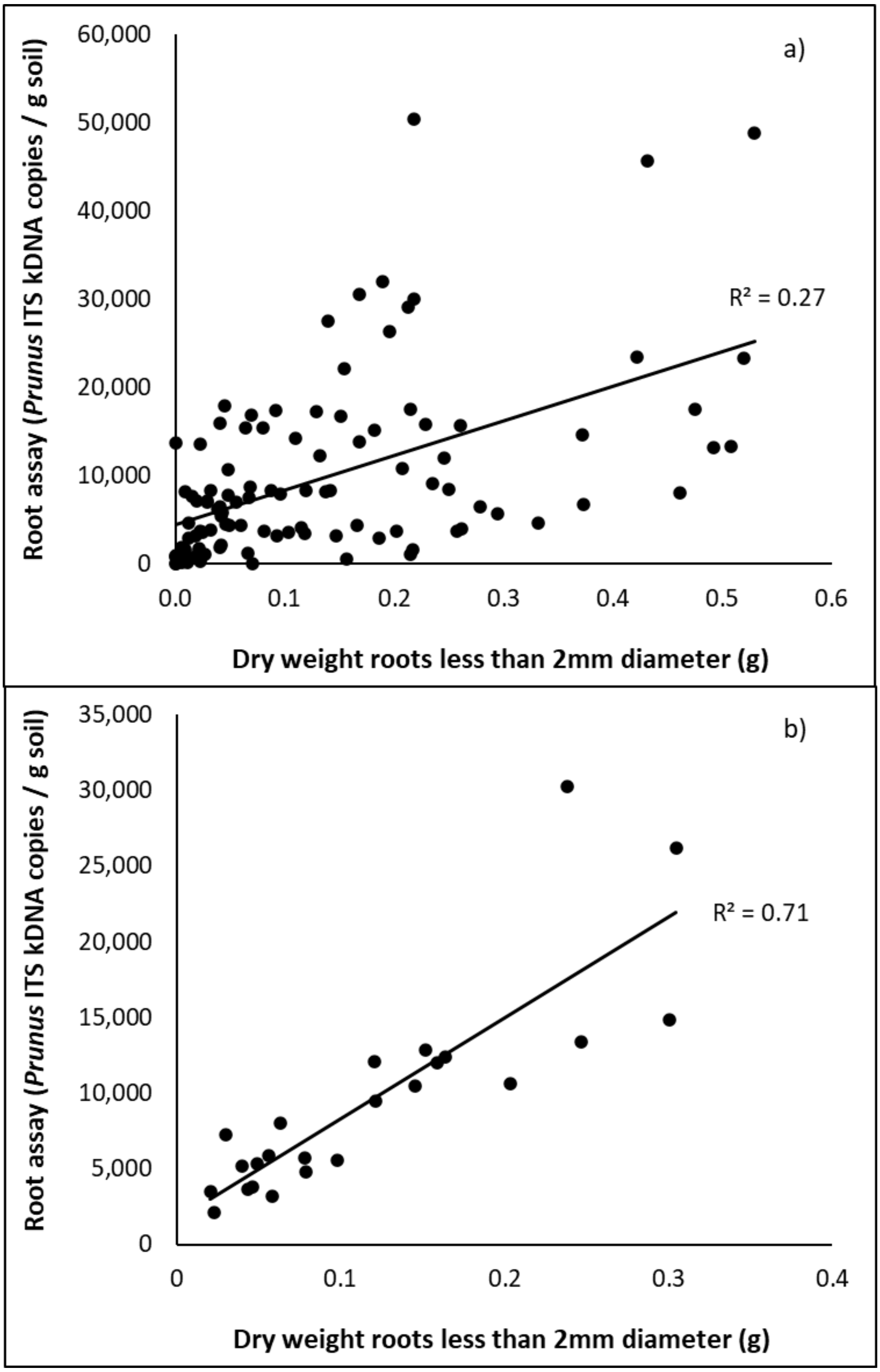


Figure 4-5. Relationship between dry weight of roots less than 2mm in diameter (WinRhizo) and *Prunus* ITS root assay (excluding roots greater than 2mm diameter) for a) individual paired samples and b) average of 5 replicates. Samples collected at three depths from compost trial in commercial almond orchard on Nemaguard rootstock.

4.4 Example of root distribution assessment

Soil samples from four replicates of six treatments of the soil amendment trial (SECTION 5) were collected in April. At time of sampling the Carina variety almonds on Garnem rootstocks were 3 years old. Soil profile was sampled at 0-10, 10-20, 20-30 and 40-50 cm with a 50 mm diameter corer, each sample weighing approximately 200 g. Cores were taken at 0, 45, 75 and 135 cm from the tree line. These distances were selected to include the tree line, 15 cm either side of the dripline in drip irrigated treatments, and 60 cm outside the drip line. Five of the treatments were drip irrigated. A sprinkler irrigated treatment was also sampled at the same positions. Samples were dried and sieved to remove roots greater than 2mm in diameter and tested with the *Prunus* ITS root assay.

Concentration of DNA measured with the *Prunus* ITS root assay at varying sampling locations and depths for the six treatments are depicted in Figure 4-6. Results were consistent with expected differences in root density between drip and sprinkler irrigated almonds. For drip irrigated trees most root DNA was found near driplines and decreased as depth increased. For sprinkler irrigation root distribution was found to be evenly spread at lower density over a much wider soil volume than under drip irrigation.

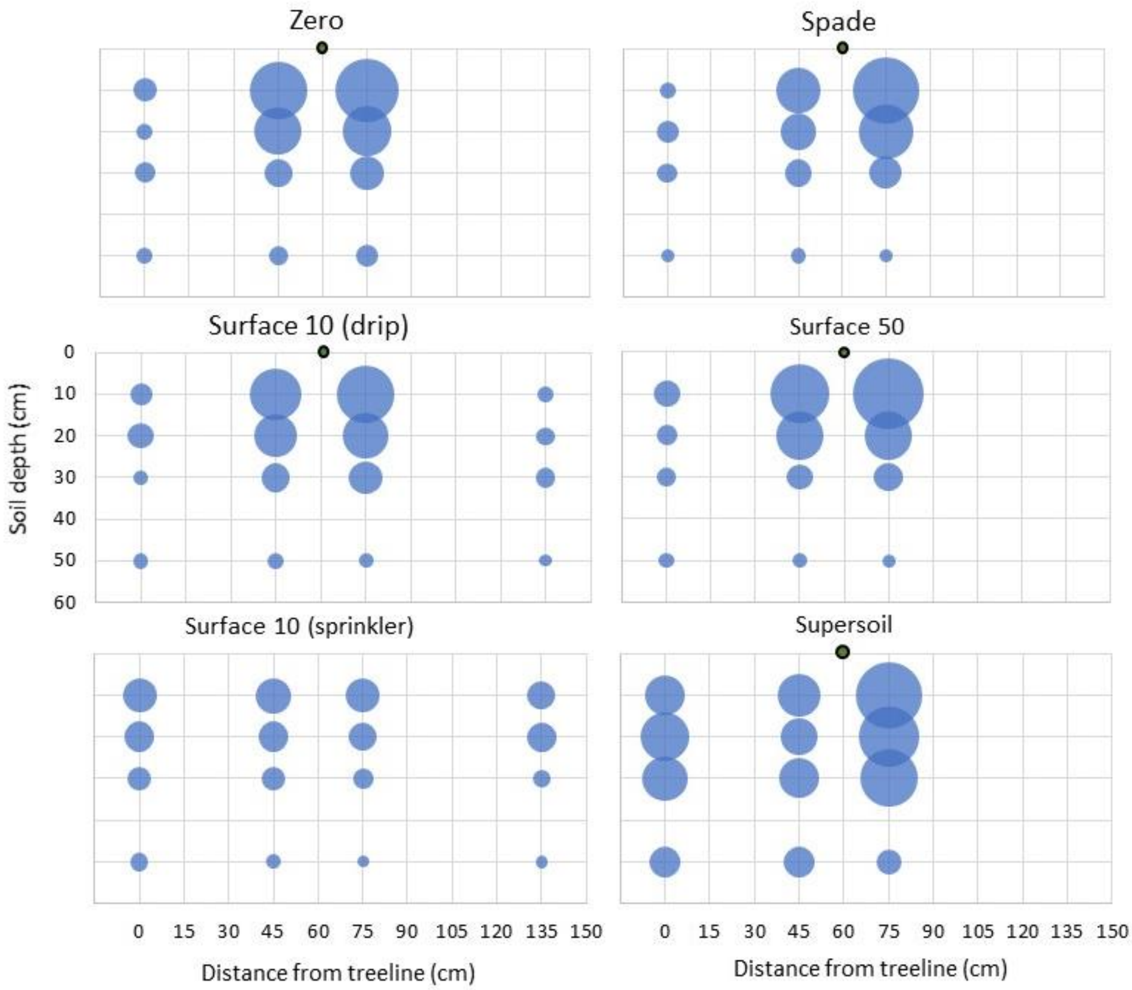


Figure 4-6. Results from *Prunus* ITS root assay, measuring concentration of DNA of *Prunus* roots in soil sampled from six soil amendment treatments in a 3-year-old almond orchard on Garnem rootstock. Values are represented by circle area. The largest circle represents the maximum recorded value of 51,000 kDNA copies /g soil. Dots at top of each graphic show location of the dripline in drip-irrigated treatments.

Use of the *Prunus* ITS root assay provided insight into differences in root distribution and density between soil amendments under drip irrigation. Based on the sampling locations and depths tested, the Supersoil amendment had the highest overall *Prunus* ITS DNA concentration of the drip irrigated treatments assessed, Figure 4-6. The higher concentration of roots 65 cm from the dripline and at depth confirm that soil conditions of the Supersoil mounds are promoting a larger root ball compared with other drip irrigated treatments. There were no substantive differences in root DNA amount between the other drip irrigated treatments (Zero, Surface 10, Surface 50 and Spade).

As root distribution under sprinkler irrigation is more evenly spread over a much wider area than under drip irrigation more extensive soil sampling would be required to compare the total amount of roots per tree to the five drip irrigated treatments.

The results demonstrate that the *Prunus* ITS root assay can be used to quantitively assess root distribution in established almond orchards to evaluate impact of soil, irrigation and orchard management on the size and distribution of the rootzone.

4.5 Example of soil health assessment

The Molecular Diagnostic Centre has developed a soil biological health index based on analysing the population structure of free living nematodes (FLN). Bacterial and fungal feeding nematodes consume only those microbes and are indicators of soil nutrient enrichment and system disruption. Omnivorous and carnivorous nematodes feed on nematodes and other organisms. They are relatively large, have longer life cycles and are sensitive to disturbance (Linsell et al., 2020) and thus are good indicators of community structure. Once lost from soils, they can take months or years to return and thus the presence of these larger nematodes in soils requires mature and well-balanced communities.

A preliminary investigation of the use of FLN community analysis in an almond orchard was conducted. Stored DNA extracted from soil cores used to investigate distribution of roots in the soil amendment trial (SECTION 5) were retested from 2 replicates using nine FLN assays to assess soil biological health. Position and depth of samples were selected to target the active rootzone area, that is from 0-30 cm depth taken 15 cm either side of the dripline in drip irrigated treatments. This position is also within the wetted zone for the sprinkler irrigated treatment.

Category 1 is the least desired and 4 the most desired soil biological condition, Figure 4-7. Higher soil biological health rating does not necessarily imply higher productivity, as many other factors influence tree growth, yield, and nut quality. Consistent with the Supersoil amendment having the highest overall *Prunus* ITS DNA concentration of the drip irrigated treatments, soils sampled in the main rootzone area of this treatment had a higher percentage of soil samples with a Soil Biological Health rating above 1. With exception of the Supersoil and Surface 50 amendments, soils from other treatments were dominated by ratings in Category 1, representing poor soil biological health.

The abundance, or total number, of FLN in soil is another measure of biological activity of a soil. The Supersoil and Surface 50 amendments were the only treatments which exceeded the adequacy threshold for FLN abundance, Figure 4-8.

When compared with results obtained in other cropping systems, results indicate there is considerable potential to improve soil biological health in this almond orchard. For example, recent testing found average FLN levels of 10,751 kDNA copies/g soil in cherry orchards and 1,596 kDNA copies/g soil in vineyards (SARDI Molecular Diagnostics Centre). FLN populations found in this almond orchard were below the average level of 364 kDNA copies/g soil found in intensively cropped brassica production systems.

This preliminary investigation of using the *Prunus* ITS root assay in combination with FLN community analysis indicates its potential as a tool to benchmark and monitor soil biological health in almond orchards. Relating results over time to parameters such as water and nutrient use efficiency, nut yield and quality would further increase value of these tests as soil health indicators in almond orchards.

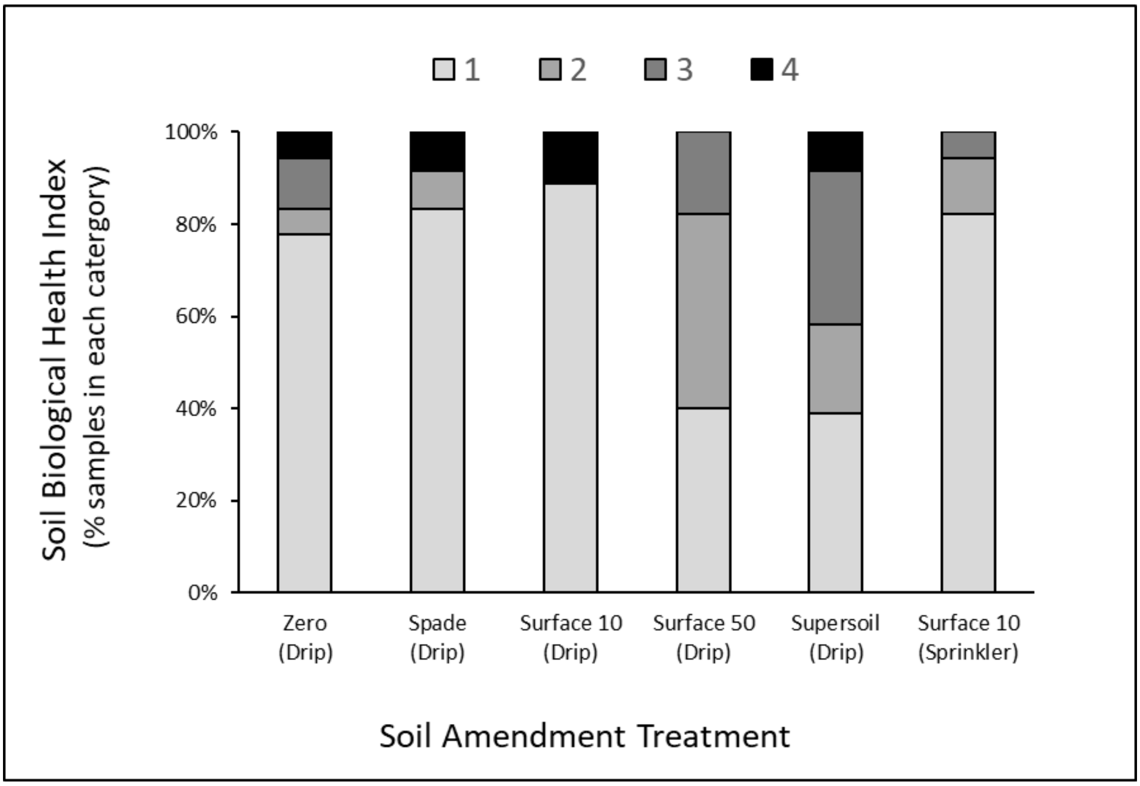


Figure 4-7. Comparison of Soil Biological Health ratings of soil sampled from six soil amendment treatments in a 3-year-old almond orchard on Garnem rootstock. Samples collected from 3 depths (0-10, 10-20, 20-30cm) at two positions (15 cm either side of drip line or equivalent for sprinkler irrigated treatment). Category 1 is the least desired and 4 the most desired soil health condition.

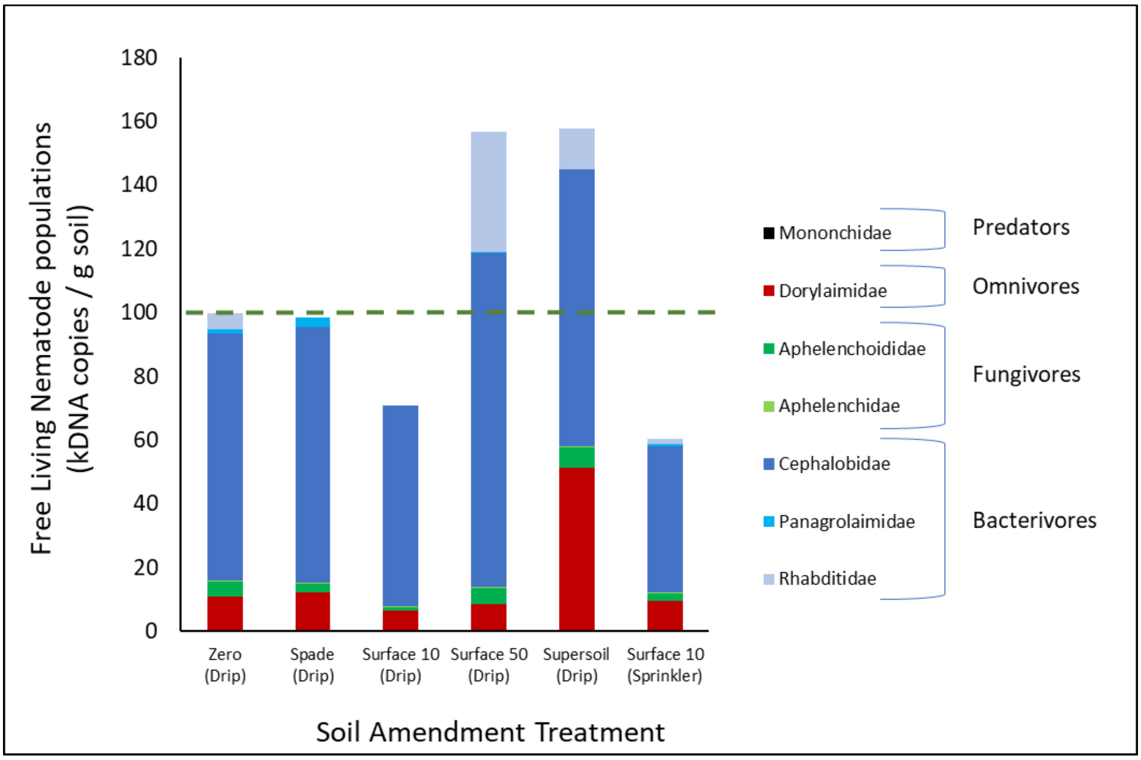


Figure 4-8. Comparison of Free Living Nematode (FLN) population structure in soil sampled from six soil amendment treatments in a 3 year old almond orchard on Garnem rootstock. Samples collected from 3 depths (0-10, 10-20, 20-30cm) at two positions (15 cm either side of drip line or equivalent for sprinkler irrigated treatment). Dashed line shows number below which soil is considered to have very low biological activity.

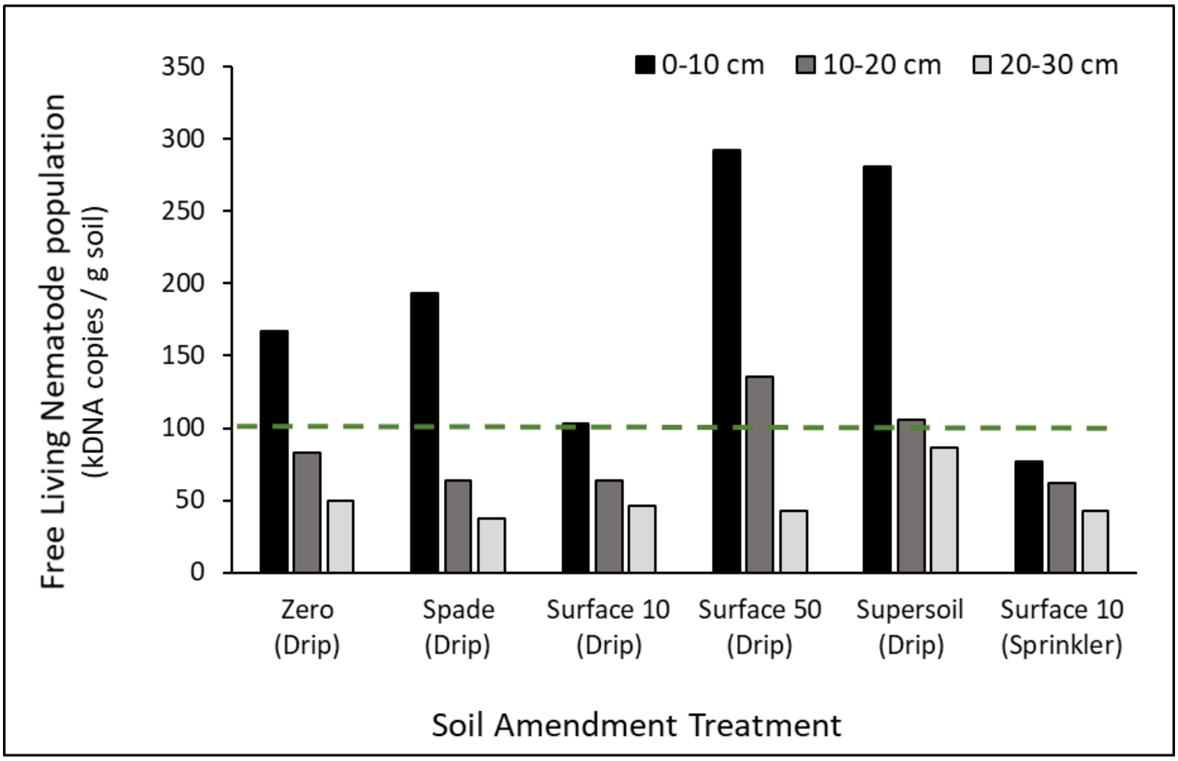


Figure 4-9. Comparison of Free Living Nematode (FLN) 'total' population in soil sampled at 3 depths (0-10, 10-20, 20-30cm) from six soil amendment treatments in a 3 year old almond orchard on Garnem rootstock. Samples collected at two positions (15 cm either side of drip line or equivalent for sprinkler irrigated treatment). Dashed line shows number below which soil is considered to have very low biological activity.

4.6 Conclusions

A root assay has been developed for the quantification of Prunus spp. DNA in soil.

It is available for use through SARDI's Molecular Diagnostic Centre.

Preliminary evaluation of the *Prunus* ITS root assay has demonstrated its capability to:

- Detect DNA (in soil samples) of major rootstocks used for almond production in Australia.
- Rapidly quantify the concentration of *Prunus* spp. DNA to characterise the root zone of almond trees in drip and sprinkler irrigated orchards.
- Evaluate impact of soil amendment, nutrient and irrigation treatments on root distribution and density in almond orchards.
- Rapidly characterise root density within pots of controlled environment trials, for example to assist with assessing salt tolerance of rootstocks used for almonds.
- Produce comparable outcomes to existing techniques that assess length and dry weight of roots of *Prunus* rootstocks (for example WinRhizo)

Advantages of the *Prunus* ITS root assay for quantifying root distribution and density in almond orchards include:

- High throughput allowing rapid assessment of hundreds of samples.
- Lower labour requirement than other methods to prepare and assess samples.
- Minimal soil and root disturbance in the orchard from sampling (similar to WinRhizo).

- Allows for multiple qPCR assays to be conducted on same sample at same time as Prunus ITS root assay, for example testing of free living nematodes (FLN) or soilborne pathogens such as *Verticillium dahliae*, *Rhizoctonia solani* and *Phytophthora cinnamomi*.

Current limitations and requirements for further development of the *Prunus* ITS root assay include:

- Optimise sampling protocols:
  - Number of cores per sample.
  - Number of replicate samples.
  - Root diameter to exclude.
  - Timing of sampling in orchard.
- Confirm calibration of field results for:
  - Differing root morphology
  - Differing root growth (under plant stress, during growth flush)
- For rootstocks not included in this study, check detection and calibrate the assay, prior to use.
- Foster adoption of the technology as a high throughput efficient method of quantifying root distribution in almond research.

Further analysis of data will be carried out with the intention to publish a peer reviewed article on application of the *Prunus* ITS root assay in almond research.

The *Prunus* ITS root assay is available for researchers and industry to undertake characterisation of root distribution and density. Use of the technology to understand if the root system is limiting tree vigour, nut yield and quality will assist investigation of varieties, rootstocks and production systems in the pursuit of improved resource use efficiencies.

SECTION 5. Soil amendment trial

Key points

- SARDI established a 7.4 ha soil amendment trial at ACE in 2018 testing pre- and post-plant applications of a commercial compost using different rates and methods
- Each amendment was either placed on the soil surface and incorporated by rotary hoe or spader, or injected as a slurry
- A separate treatment grew ryegrass for 12 months as a soil conditioner, then formed topsoil into tree mounds before planting
- Irrigation methods were drip, sprinkler, and drip plus sprinkler (supplementing winter cover crop)
- Measurements included tree growth, nut yield, root density, soil chemical, physical and biological parameters
- High rates of amendment improved soil fertility, water infiltration, microbial activity and decreased soil strength
- Mounded treatments improved water infiltration, microbial activity and root density and decreased soil strength, but trees in these treatments performed poorly due to difficulties managing weeds on steep mounds
- Cover crop reduced wind erosion
- Initial tree growth responded to spading amendment and high rate of rotary hoed amendment, but not to other treatments. Mounded treatments performed poorly
- Nut yield showed small and inconsistent responses to amendment. Mounded treatments performed poorly and sprinkler treatments yielded slightly less than drip treatments
- Treatment effects varied and declined over time
- The first machine harvest may not be a reliable indicator of yield from more mature trees. It is suggested that further harvests be carried out to obtain more stable yield data
- Drip irrigation, sprinkler irrigation and drip + sprinkler irrigation used 21.1, 36.8 and 28.7 ML/ha, respectively, through the first three years

5.1 Background and aims

Traditional almond orchards are characterised by bare, flat mid-row soils that facilitate mechanical harvest operations. If present, mid-row swards tend to be sprayed out in early spring to minimise frost risk and facilitate orchard floor sweeping associated with harvest operations. This lack of groundcover reduces the opportunity for biological activity and limits soil organic carbon accumulation. As a result, almond soils are exposed to a range of risks including structural degradation, unfavourable water holding characteristics and poor nutrient retention/availability.

The almond industry identified compost incorporation onto tree rows prior to planting new orchards as a management practice of interest. Anecdotally, around half of new orchards have compost incorporated into soil prior to planting. There is no information available on the effectiveness or value of this practice. As a result, SARDI established a large-scale field trial to test the effectiveness of soil amendment with organic matter (compost). Aims of the trial also include the evaluation of soil and irrigation treatments to improve tree growth and yield.

Table 5-1 presents a summary of the soil amendment trial layout.

Table 5-1 Summary of Soil Amendment planting

Rootstock	Scions	# Trees	Valves	Rows	Spacing	Density	Area
Nemaguard	Carina Nonpareil Vela Carmel	576 Car 576 NP 576 V 576 Ca **2304 Total**	11-16	105 – 152	7.0 x 4.5 m	317 trees/ha	7.26 ha 48 rows

5.2 Orchard establishment and methods

Amendment materials and application methods

Soil organic amendments consisted of 12mm screened compost for all treatments except Supersoil. In Supersoil treatments, the amendments were ryegrass grown for 12 months *in situ*, then lightly cultivated and drawn into a tree mound of topsoil. Compost treatments were applied to plots (or omitted in Zero treatment), either once before planting, or annually. Methods of compost addition were:

- Imported and applied to surface, then incorporated into topsoil by cultivation (rotary hoe)
- Imported and applied to surface, then incorporated into topsoil by spading
- Imported and injected into subsoil behind a ripping tine

and are shown in Figure 5-1 to Figure 5-4.

Figure 5-1. Compost application, incorporation and soil profile of Surface 50 treatment

Figure 5-2. Subsoil injection implement, surface condition and soil profile of Inject 50 treatment.

Figure 5-3. Surface annual implement, soil profile after compost reapplication and spader implement.

Figure 5-4. Soil mounding, friable soil with ryegrass roots and tree mounds with cover crop on Supersoil treatment.

Compost was derived from mixed plant material and animal manure and was applied to the trial at a nominal rate of either 10 or 50 t/ha. This is described as a nominal rate, as compost was applied in a strip 1m wide to the tree row. Tree rows on the trial were 7m apart, so this had the effect of concentrating the application and the effective application rates were 70 and 350 t/ha to the tree row for the 10 and 50 t/ha rates, respectively. Chemical composition of applied compost, and nutrients applied at the two rates, are shown in Table 5-2.

Table 5-2. Nutrient content of compost and rates applied at 10 and 50 t/ha.

	Analysis	Units	Amount applied at 10 t/ha			Amount applied at 50 t/ha		
			nominal	in tree row	units	nominal	in tree row	units
Carbon	14.1	%	0.7	4.8	t/ha	3.5	24.2	t/ha
Nitrogen	1.2	%	60.4	423	kg/ha	302	2115	kg/ha
Phosphorus	0.4	%	19.9	139	kg/ha	100	697	kg/ha
Potassium	1.1	%	51.9	364	kg/ha	260	1818	kg/ha
Sulphur	0.6	%	31.0	217	kg/ha	155	1086	kg/ha
Calcium	4.2	%	0.2	1.4	t/ha	1.0	7.2	t/ha
Magnesium	0.6	%	29.7	208	kg/ha	149	1040	kg/ha
Sodium	0.4	%	18.2	127	kg/ha	91	637	kg/ha
Boron	45	%	0.22	1.6	kg/ha	1.1	7.8	kg/ha
Copper	67	mg/kg	0.33	2.3	kg/ha	1.6	11.5	kg/ha
Iron	67	mg/kg	0.33	2.3	kg/ha	1.6	11.5	kg/ha
Manganese	223	mg/kg	1.09	7.7	kg/ha	5.5	38.3	kg/ha
Zinc	201	mg/kg	0.98	6.9	kg/ha	4.9	34.4	kg/ha
C:N ratio	12	ratio						
dry matter	49	%						

Trial design

Twelve treatments were replicated six times in a constrained Latin Square Design. Four almond varieties were planted in four rows per plot, with the two border rows (Carina and Carmel) straddling the two inner measurement rows (Nonpareil and Vela). Treatments are described in Table 5-3:

Table 5-3. Treatments applied to soil amendment trial.

TRT #	TRT name	TRT Description
1	Zero	no compost applied or soil disturbance in the tree row prior to tree planting, drip irrigated
2	Surface	Zero treatment plus 10 t/ha of compost dropped on soil surface of tree row and incorporated with rotary hoe before tree planting
3	Surface 50	same as Surface treatment but using 50 t/ha of compost
4	Surface ann	same as Surface, plus annual application of 10 t/ha compost to a shallow trench which was then covered with soil
5	Inject	10 t/ha of compost injected as slurry behind tines of specialized deep ripper
6	Inject 50	same as Inject treatment but using 50 t/ha of compost
7	Inject ann	same as Inject treatment, plus annual injection of 10 t/ha of compost along alternate sides of tree row
8	Spade	10 t/ha of compost applied as per surface treatment, but incorporated with a spader instead of a rotary hoe
9	Surface D+Spr	same as Surface treatment, with dripper irrigation for trees and also supplementary irrigation with sprinklers for cover crop
10	Surface Spr	same as Surface treatment but with sprinkler irrigation instead of dripper
11	Supersoil D+Spr	ryegrass mulch and soil mounding system, dripper irrigation for trees with supplementary sprinklers for ryegrass
12	Supersoil Spr	ryegrass mulch and soil mounding system, sprinkler irrigation instead of dripper irrigation

Irrigation and general management

All treatments were watered by drip irrigation, with the exception of the two sprinkler treatments (Surface Spr and Supersoil Spr) which were watered by full cover sprinklers on a separate schedule to the drip irrigation. Intermittent sprinkler irrigation (in autumn and spring) was carried out on the two drip+sprinkler treatments (Surface D+Spr and Supersoil D+Spr) to encourage cover crop growth. This was in addition to the full watering of these treatments by drip irrigation. All orchard management not directly related to imposition of treatments (e.g. weed control, fertiliser application, orchard maintenance) was carried out according to standard industry practice.

Tree size

Tree height and width was estimated by shadow size analysis from aerial drone imagery in June 2019. Tree height was measured using ground-based LiDAR in October 2020 and April 2021. Trunk diameter was measured using ground-based LiDAR in October 2020 and July 2021.

Almond yields

Individual trees which had harvestable nuts were hand-picked in March 2020. Three of the four almond varieties (Carina, Nonpareil and Vella) were machine harvested in March 2021. Carmel trees were not harvested due to extensive tree loss from wind damage in November 2019.

Soil physical and chemical analysis

In October 2019, 12 months post-amendment, soil samples were collected to test the impact of different soil amendment treatments. Sampling included both disturbed samples (n = 69) and intact cores (n = 192) taken from up to five depths (0-10, 10-20, 2-30, 30-40 and 40-50 cm) depending on treatment. Soil samples were collected from four selected treatments: Zero, Surface, Surface 50 and Supersoil Spr. Intact soil cores were analysed for saturated hydraulic conductivity, bulk density, field soil texture and water content at 3, 6, 60, 300 and 1500 kPa soil moisture tension. Disturbed soil samples were analysed for: soil organic carbon; extractable P, K, S, NO_3, NH_4 and B; exchangeable Ca, Mg, K, Na and Al; and effective cation exchange capacity.

Soil penetrometer resistance

Soil Penetrometer Resistance (SPR) was measured under Nonpareil almond trees in three replicates of five treatments (Zero, Surface, Surface 50, Spade and Supersoil D+Spr). Within each plot, a Rimix CP200 penetrometer with a 1.2 cm diameter cone was used to record SPR at 2.5 cm intervals to 30 cm depth. Tree spacing was 4.5 m apart, and a group of 10 insertions were carried out between each of five trees, resulting in four groups of insertions per plot. The series of insertions started at 1 m from the first tree and finished 1m from the second tree, resulting in 10 insertions at 25 cm intervals. SPR was measured adjacent to the irrigation dripline. SPR is generally measured at field capacity, which represents the water content of soil which has been saturated and then allowed to drain for 24 to 48 hours. This was by additional irrigation the day before measurement.

Soil cellulose breakdown

The rate of cellulose breakdown in soil was measured using the Tea Bag Index method (Keuskamp et al., 2013). Commercially available tea bags (green tea and Rooibos tea) were buried in soil near the dripper line of Nonpareil trees in selected treatments (Zero, Surface, Surface 50, Spaded and Supersoil Spr) on 12 March 2020. One green tea bag and one Rooibos tea bag were buried at 8 cm depth next to each of four trees in Zero, Surface, Surface 50 and Supersoil plots. Three green tea bags and three Rooibos tea bags were buried next to each of four trees in each Spaded plot. Three tea bags were used per location in the Spaded treatment to account for variation due to the irregular mixing pattern generated by the spader, and subsequent distribution of compost. Four replicates were installed, using a total of 112 each of the green and Rooibos tea bags. They were collected on 5 June 2020 (after 85 days), root material was removed, and the bags were dried and weighed to calculate the rate of microbial breakdown of the tea.

Soil DNA analysis

A soil DNA extraction-root qPCR method was used to quantify root DNA density, as described in SECTION 4. Samples were collected from a two-dimensional grid at each sampled tree. Three trees were sampled per plot, and the three samples were composited for each grid position. Four replicates were sampled per treatment. Grid positions were aligned with the tree row and located 1m along the tree row from the nearest tree. Grid positions are described below. All treatments (Zero, Spade, Surface, Surface Spr, Surface 50, Supersoil) were sampled at positions 1 to 12. Surface and Surface Spr were also sampled at positions 13-16 to compare root distributions near the midrow and further from the location of the dripline.

Table 5-4. Sampling locations for soil root DNA analysis

sampling	perpendicular distance from tree row (cm)			
depth (cm)	0	45	75	135
0-10	1	5	9	13
10-20	2	6	10	14
20-30	3	7	11	15
40-50	4	8	12	16

Samples were collected by hand auger, aggregated, then stored in the dark at 4°C for up to 24 hours before drying and analysis. Results are presented as 1000 x copies of DNA fragment Kilocopies per milligram of soil (kDNA /mg).

5.3 Results

Tree size

Tree growth response to treatments was small but statistically significant (Figure 5-5). Tree heights were equivalent between drip irrigated treatments although height Supersoil treatments initially lagged behind others. Trunk diameters were initially higher in drip irrigated treatments, but there were only small differences between treatments by the last measurement in 2021.

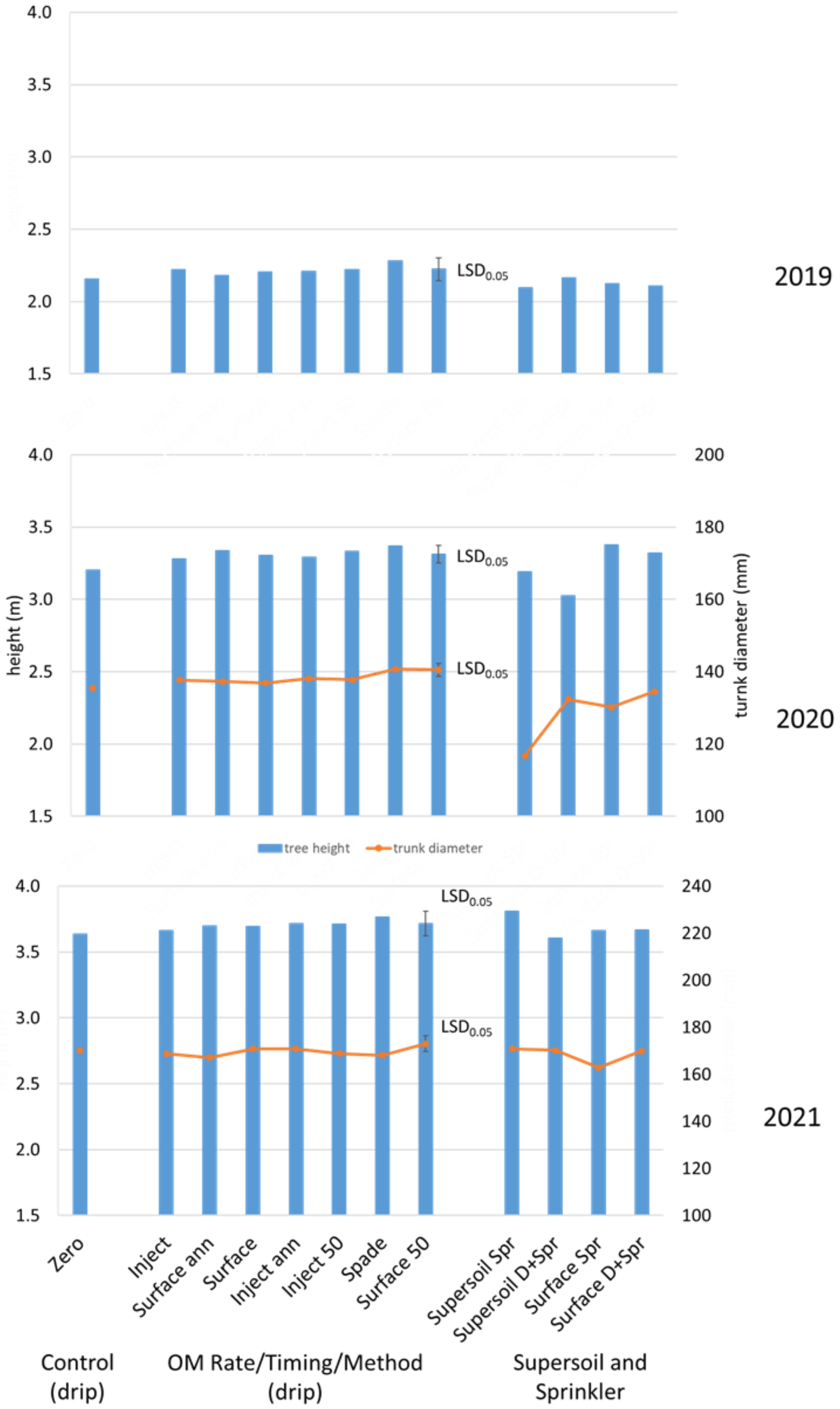


Figure 5-5. Effect of treatment on tree height (bars, all years) and trunk diameter (line, 2020, 2021) of all varieties in soil amendment trial.

There was little effect of soil amendment on the rate of tree growth, as measured by tree height and trunk diameter.

There was an effect of variety on tree height and trunk diameter. Nonpareil trees were the tallest (Figure 5-6), Carina and Vela were similar in height, and Carmel were the shortest.

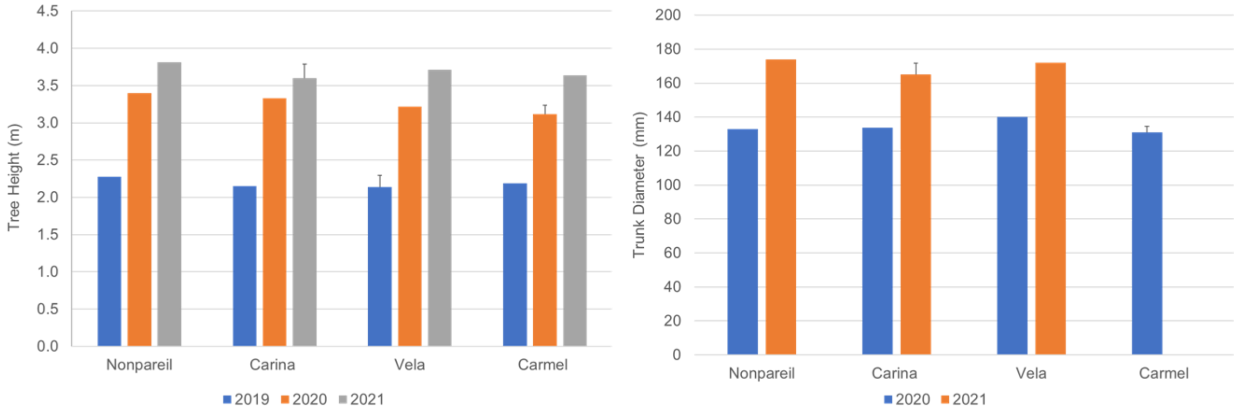


Figure 5-6. Impact of variety on tree height and trunk diameter in soil amendment trial. Error bars display LSD (0.05) within each year.

Overall height differences were relatively minor, with 2021 values ranging from 3.8 m (Nonpareil) to 3.6 m (Carina), Figure 5-5. Trunk diameter values were affected more by variety than treatment, Figure 5-6. In 2021 Nonpareil had the largest average diameter (174 mm) followed by Vela (172 mm). Carina had an average diameter of 165 mm and Carmel was not measured.

Almond yields

There was a light crop in 2020 (second leaf). A subset of the available measurement trees was hand harvested, Figure 5-7.

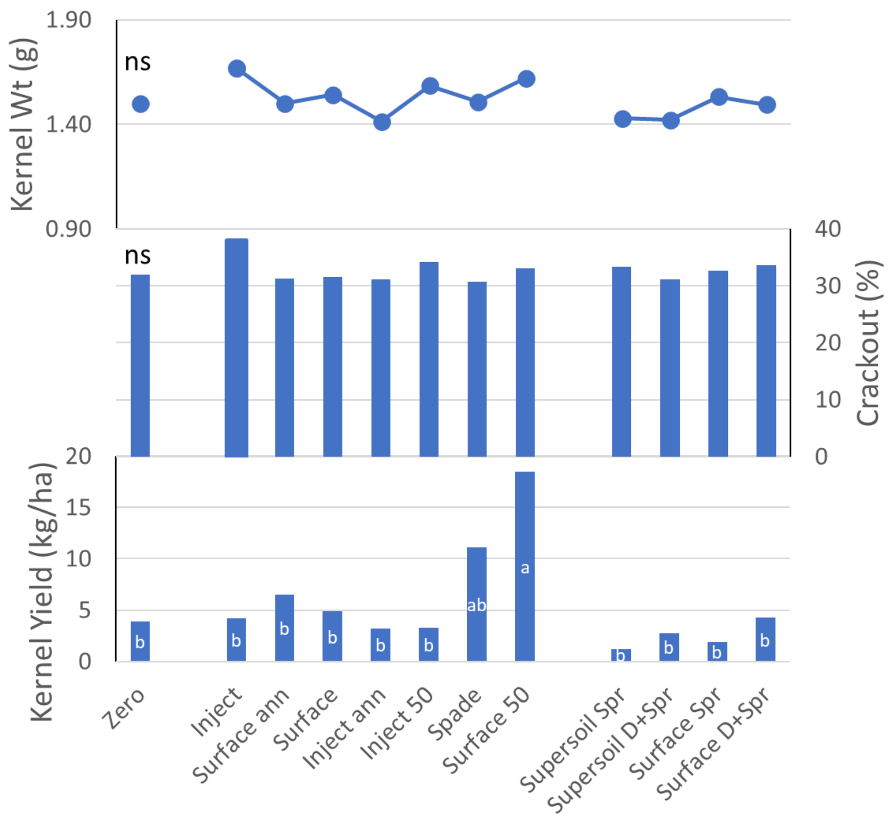


Figure 5-7. Hand-picked yield in soil amendment trial as affected by treatment (all varieties).

Surface 50 yielded most nuts in the initial harvest, followed by the Spaded treatment. This was consistent with early growth results, although the overall yields were economically insignificant. The trial's first commercial scale crop was harvested in 2021 using commercial shake, sweep and pickup machinery. Third leaf yield results are shown in Figure 5-8 to Figure 5-10.

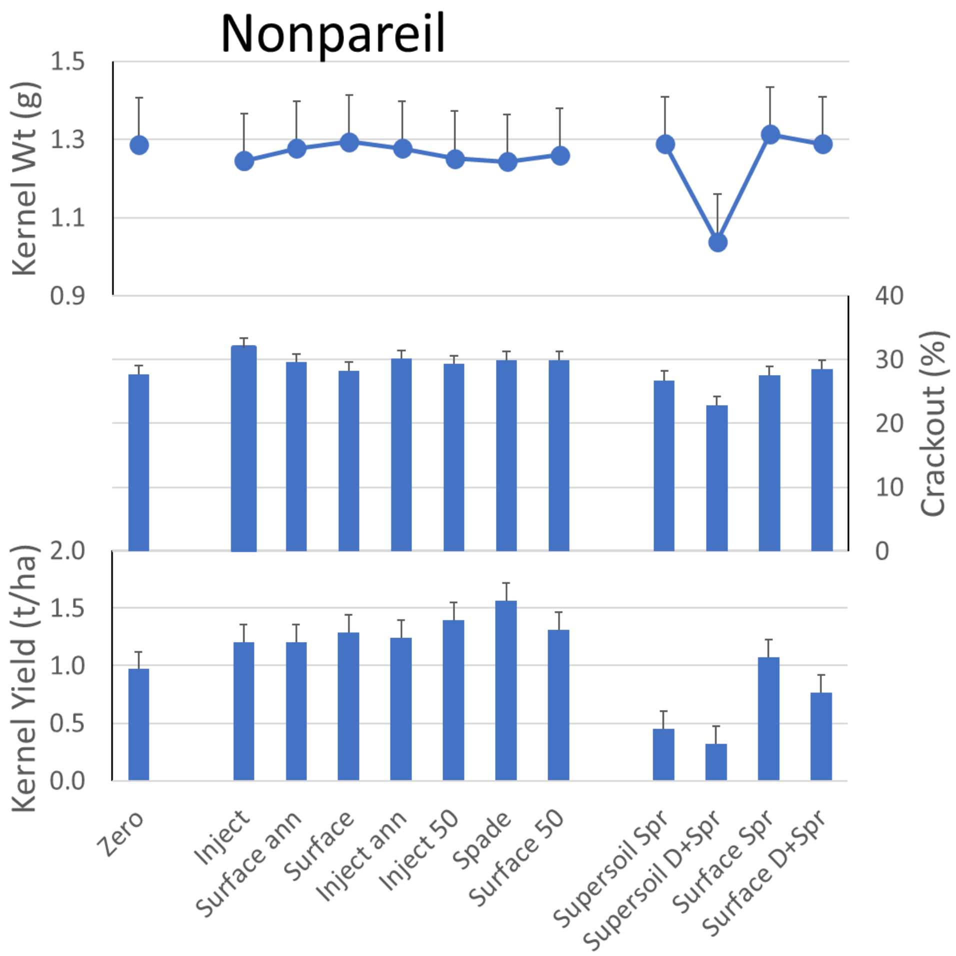


Figure 5-8. Kernel weight, crack-out and kernel yield of Nonpareil in the soil amendment trial. Error bars = SEM.

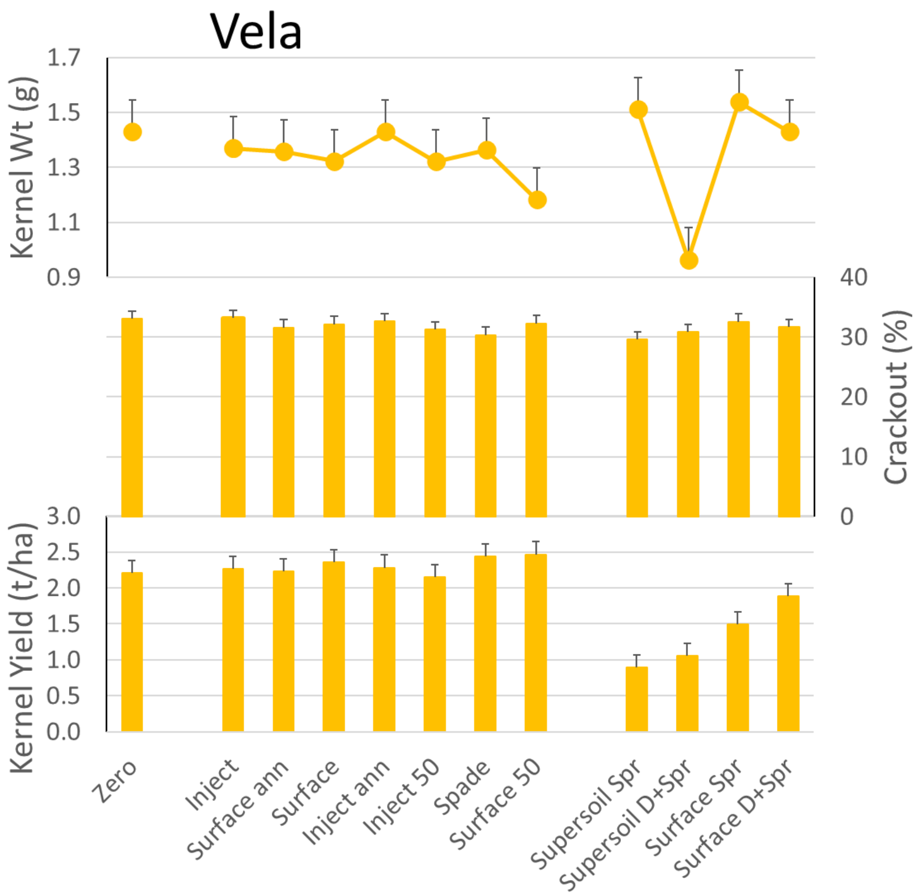


Figure 5-9. Kernel weight, crack-out and kernel yield of Vela in the soil amendment trial. Error bars = SEM.

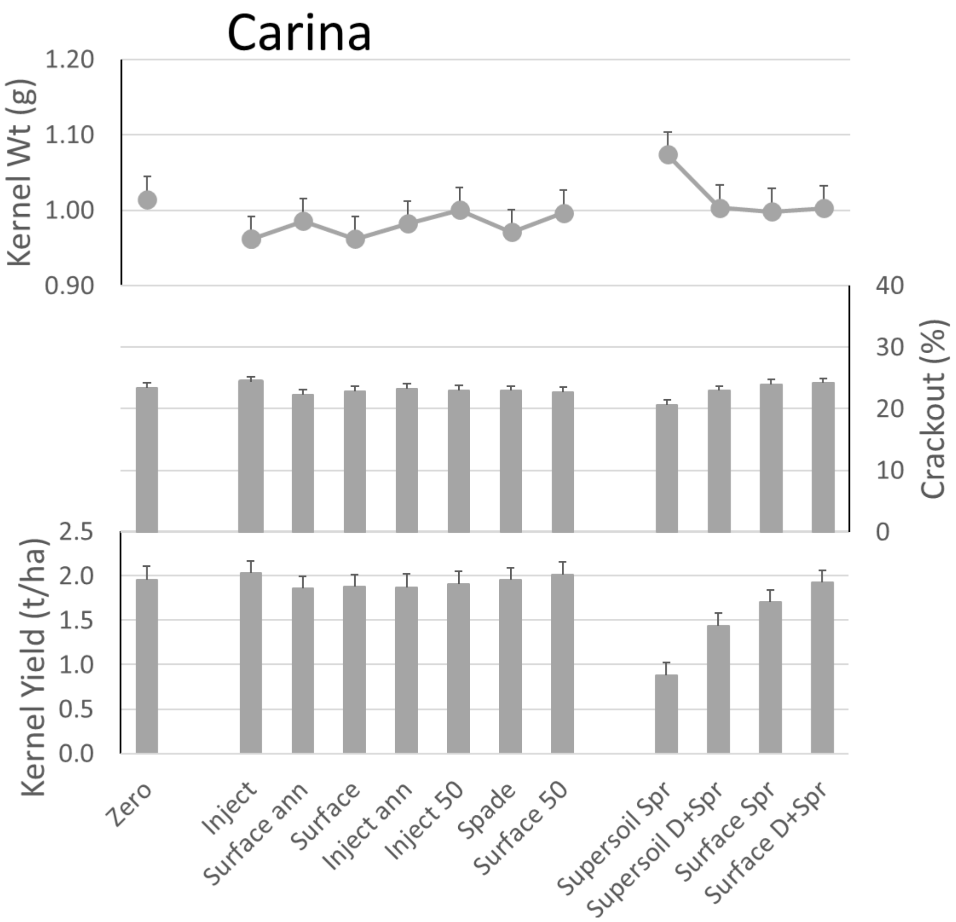


Figure 5-10. Kernel weight, crack-out and kernel yield of Carina in the soil amendment trial. Error bars = SEM.

In the first commercial scale harvest of this trial (2020/21), there were inconsistent effects of treatment on kernel weight and crack-out percentage across the three varieties assessed. Drip irrigated amendment treatments produced higher kernel yields than Zero treatments in Nonpareil, although there was little difference in Carina or Vela. Supersoil yielded less than other treatments. Sprinkler treatments yielded less than drip treatments. Kernel yield of Nonpareil seemed more sensitive to amendment treatments than the other varieties.

Kernel yield was more sensitive to amendment treatment than tree height and trunk diameter, as only Supersoil treatments had significantly less height and trunk diameter.

Soil physical and chemical analysis

Physical analysis of undisturbed soil cores

Intact soil cores from selected treatments (Zero, Surface, and Surface 50) were analysed for effects on soil physical characteristics as shown in Figure 5-11. Results are shown in Figure 5-12.

Figure 5-11. Soil cores ready for analysis, equipment for measuring saturated hydraulic conductivity, pressure chamber for soil moisture analysis.

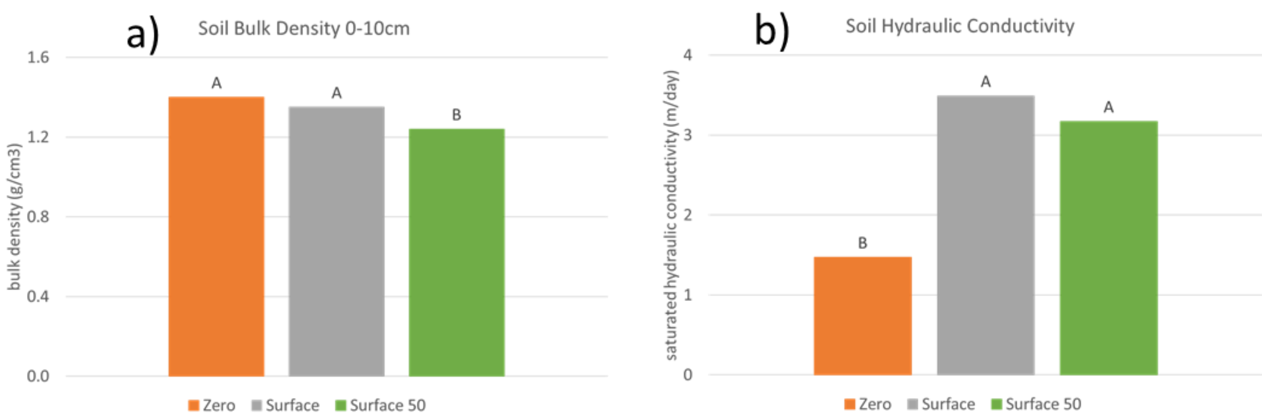


Figure 5-12. Soil bulk density (a) and hydraulic conductivity (b) as affected by amendment.

Compost amendment reduced soil bulk density and increased saturated hydraulic conductivity.

Water content from field capacity (6 kPa) down to irrigation refill point (60 kPa soil moisture tension) was considered to be Readily Available Water (RAW) and was not significantly affected by amendment treatment. This is shown below in Figure 5-13, where treated soils (filled bars) are compared to adjacent untreated soil (open bars).

RAW ranged from around 40 - 100 mm/m across the treatments. Organic amendment generally decreased RAW, although the effect was somewhat variable.

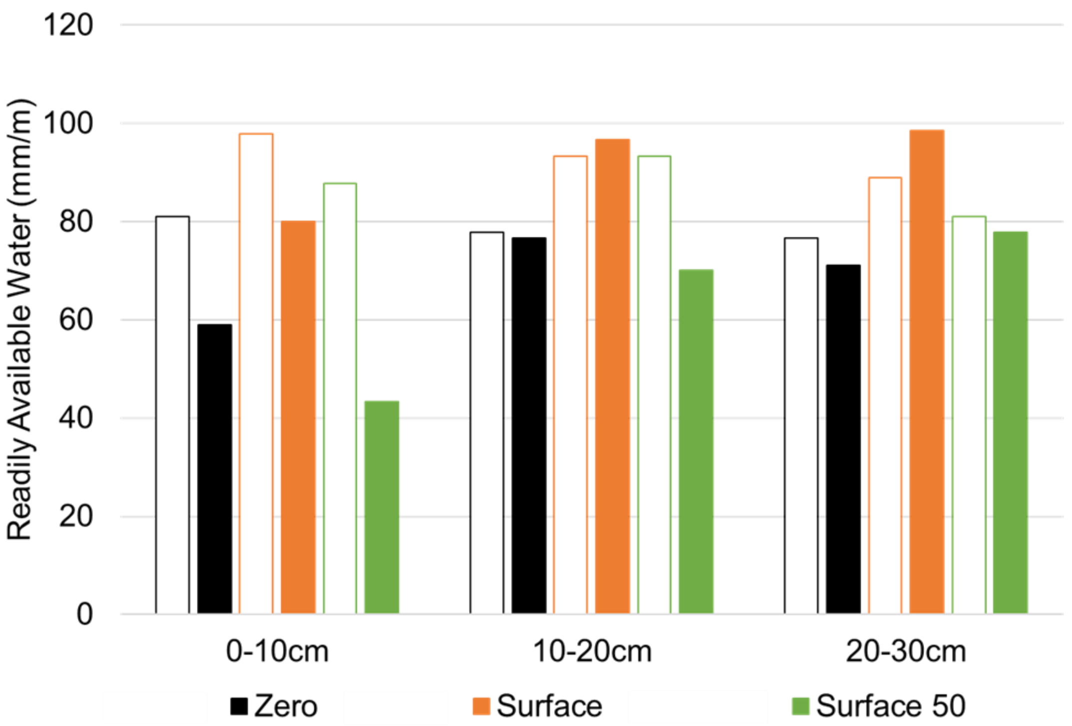


Figure 5-13. Plant available water from field capacity (6 kPa soil moisture suction) to refill point (60 kPa) as affected by treatment. Open bars indicate untreated soil and closed bars indicated treated soil.

Chemical analysis of disturbed samples

The effect of treatment on agronomic soil qualities (disturbed soil samples) was tested on four treatments – Zero, Surface, Surface 50 and Supersoil Spr. Results are summarized in Table 5-5. Where a significant treatment effect is reported, addition of compost increased the soil quality indicators.

Table 5-5. Summary of treatment effects on soil chemical fertility indicators in soil amendment trial.

Soil test	Treatment Effect	Comment
soil organic C	***	contained in added compost
Colwell P	***	contained in added compost
Colwell K	*	contained in added compost
KCl_{40} S	***	contained in added compost
ECEC (effective cation exchange capacity)	***	increased with soil organic matter, clay content
pH_{Ca}	ns	alkaline (free carbonate in soil)
pH_w	ns	alkaline (free carbonate in soil)
extractable NO_3	ns	high plant uptake, leaching
extractable NH_4	ns	high plant uptake
exchangeable Ca	ns	major component of CEC
exchangeable Mg	ns	component of CEC
exchangeable K	ns	minor component of CEC
exchangeable Na	**	low levels
EC	***	well below critical values
exchangeable Al	ns	low levels
hot water B	ns	low levels

ns = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Effect of treatment on soil organic carbon and cation exchange capacity is shown in Figure 5-14. Soil organic carbon was significantly increased in response to the addition of high rate of compost amendment, and in the Supersoil treatment. Surface treatment (standard commercial practice, 10t/ha) did not increase soil organic carbon over Zero treatment (no amendment).

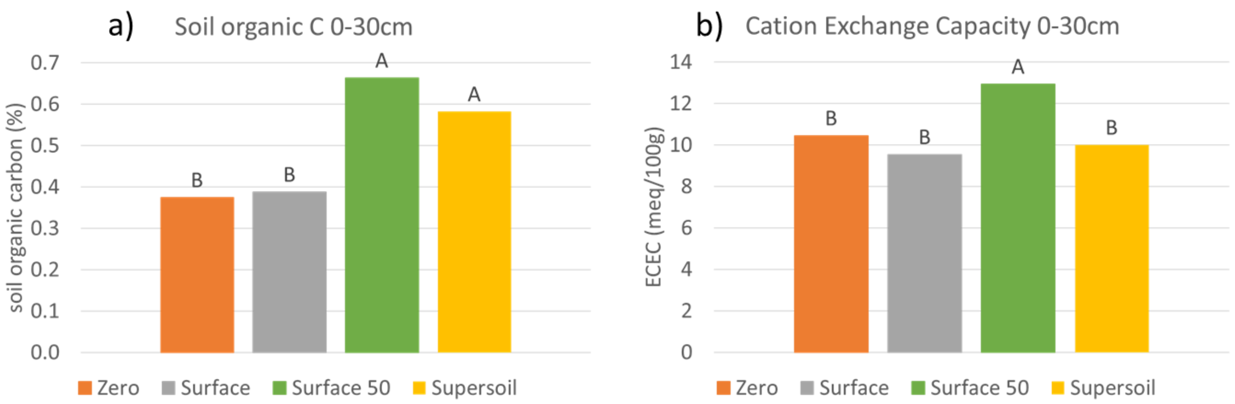


Figure 5-14. Soil chemistry as affected by rate of amendment. Soil organic carbon (a) and effective cation exchange capacity (b).

Effective Cation Exchange Capacity (ECEC) was significantly affected by treatment. Surface 50 treatment had higher ECEC than other treatments. Surface treatment did not significantly increase ECEC over the zero treatment.

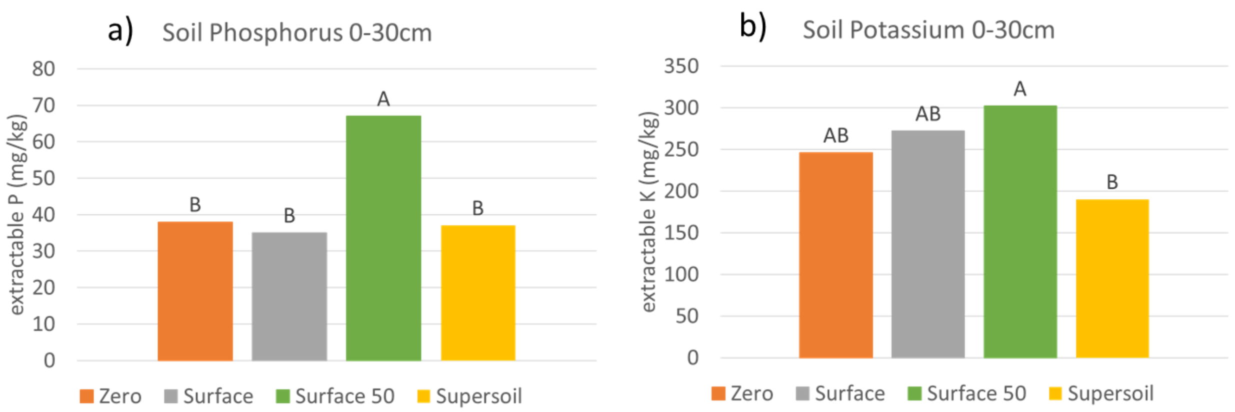


Figure 5-15. Soil chemistry as affected by rate of amendment. Extractable soil phosphorus (a) and potassium (b).

Extractable soil phosphorus (Colwell P) was significantly affected by treatment (Figure 5-15). Surface 50 treatment had elevated soil P levels compared to the other treatments. Surface and Supersoil treatments did not increase soil P over the zero treatment. Surface 50 treatment had the highest soil K level and Supersoil had the lowest soil K level.

Soil penetrometer resistance

Soil Penetrometer Resistance (SPR) was affected by treatment and is shown in Figure 5-16

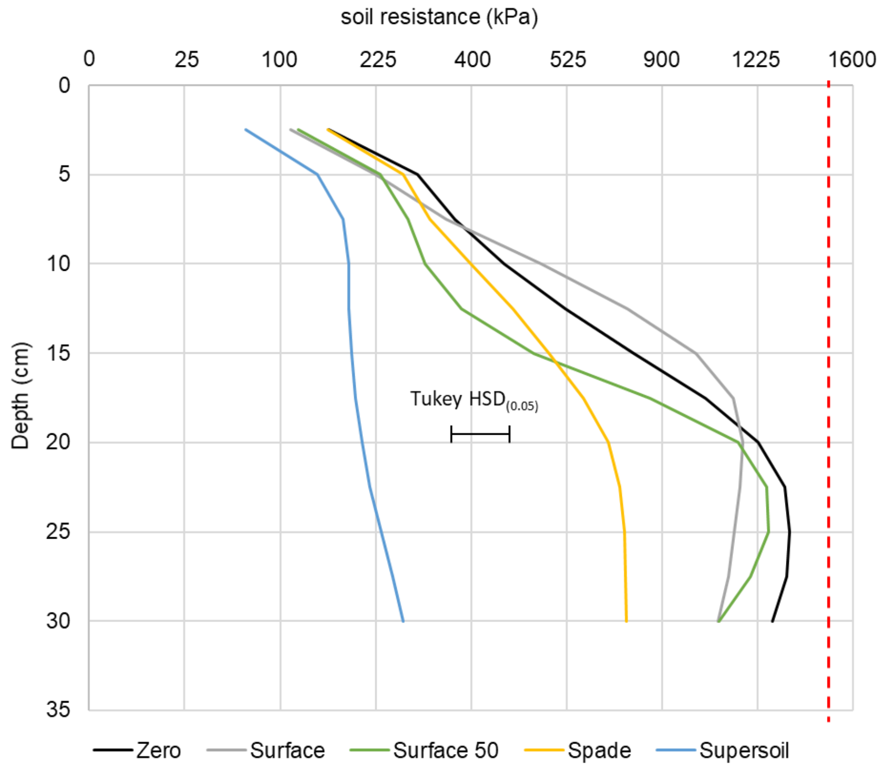


Figure 5-16. Effect of treatment on soil penetrometer resistance at various depths in the soil amendment trial. The red line indicates where root growth is considered to be restricted by soil strength (1500 kPa – note that axis values have been modified to reflect square root transformed data).

The Supersoil treatment had the lowest SPR, down to 30 cm depth. This was followed by the spaded treatment, then the Surface 50 t/ha treatment. There appeared to be some difference between the spade treatment and the zero and two compost treatments at 20-30 cm, below the depth of incorporation.

Figure 5-17 shows that all treatments had significantly different SPR values, in the order:

Supersoil < Spade < Surface 50 < Surface < Zero

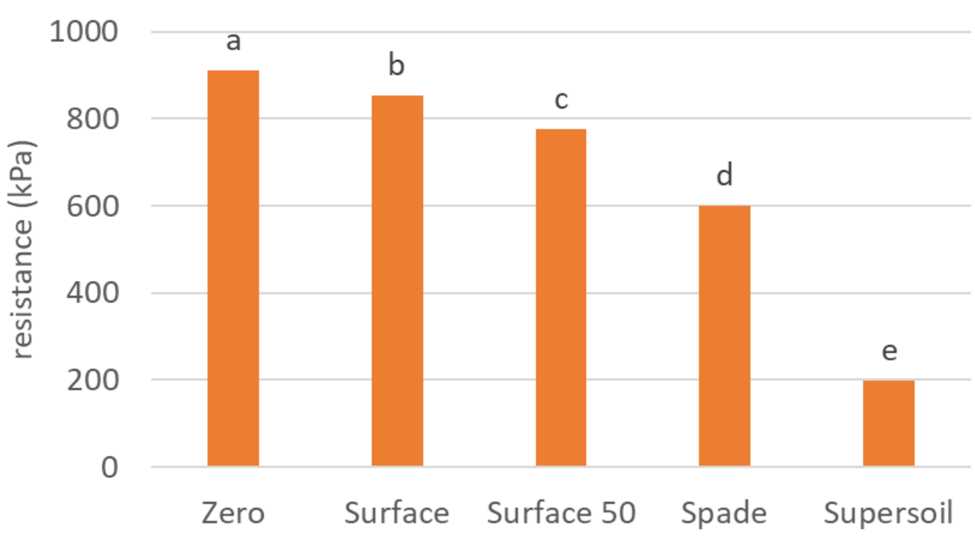


Figure 5-17. Effect of treatment on penetrometer resistance in soil amendment trial.

Soil cellulose breakdown

Soil biological activity was measured using a standardised cellulose breakdown (Tea Bag Index) method (Table 5-6, Keuskamp et al. (2013)). In this method, the decomposition rate represents the rate of short-term breakdown of new organic input and the stabilisation factor represents protection of labile carbon from further breakdown. Decomposition rates and stabilisation factors of teabags in the soil amendment trial are shown in Table 5-6.

Table 5-6. Effect of soil amendment upon rootzone biological activity using cellulose breakdown method

Treatment	Decomposition rate (k)	Stabilisation factor (S)
Supersoil	0.016 [a]	0.30 [a]
Surface 50	0.012 [ab]	0.24 [b]
Spade	0.012 [ab]	0.22 [b]
Zero	0.011 [ab]	0.20 [b]
Surface	0.009 [b]	0.22 [b]

The Supersoil treatment had the highest decomposition rate and stabilisation factor indicating favourable environment for microbial degradation of added organic matter. Surface 50 and Spade treatments trended higher than Surface or Zero treatments. The cellulose breakdown method did not indicate large differences in microbial activity between treatments. Further investigation of soil biology has been carried out with SARDI's Prunus root DNA assay (see below).

Soil root photographs

Soil profiles of selected treatments were photographed in September 2021, three years after initial amendment application.

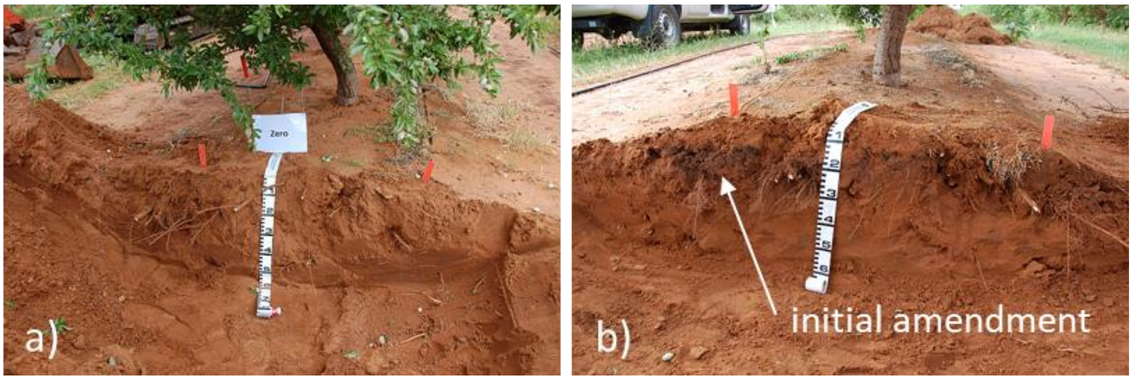


Figure 5-18. Soil profile under a) Zero and b) Surface 50 treatments. Orange flags mark dripline positions.

Note root growth clustered under driplines. No evidence of amendment in the Zero treatment, but amendment visible in Surface 50 soil.

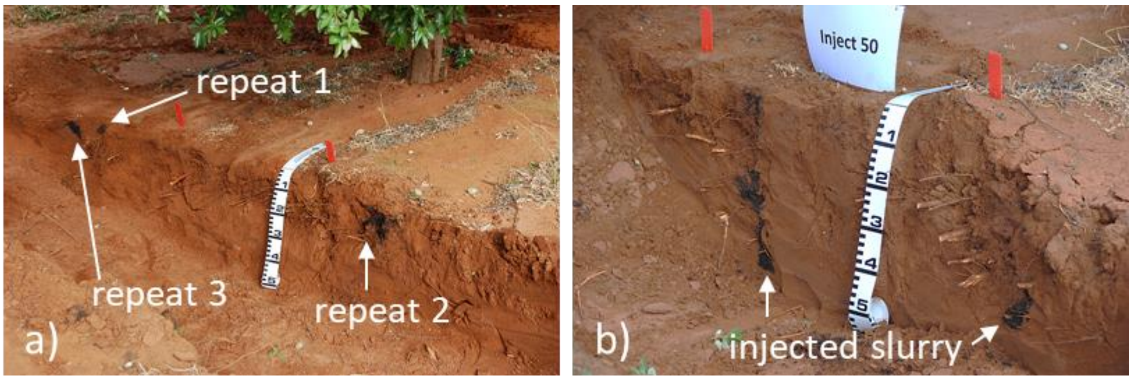


Figure 5-19. Soil profile under a) Surface ann and b) Inject 50 treatments.

Three years of repeat amendment application is visible in the Surface ann treatment, but there is no sign of the original amendment. Amendment is clearly visible in the Inject 50 treatment.

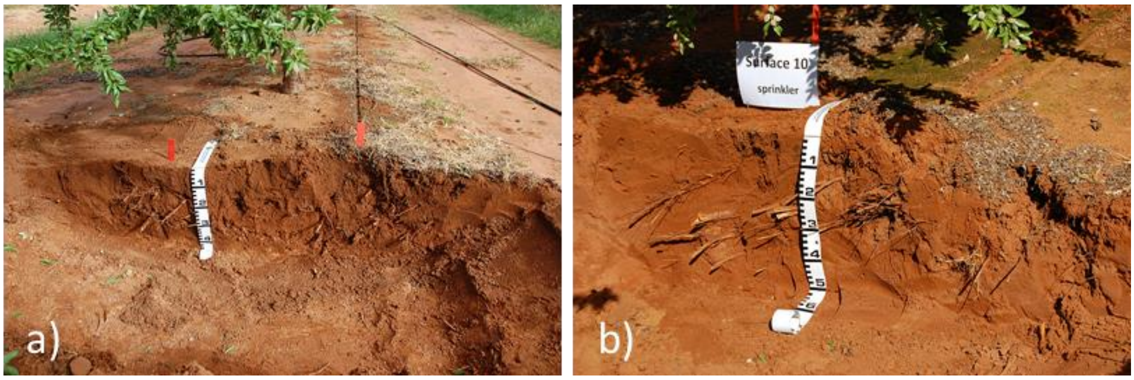


Figure 5-20. Soil profile under a) Surface and b) Surface Spr treatments.

Root growth is clustered near the driplines in Surface treatment, but widespread in Surface Spr treatment. The shallow mound visible in drip irrigated treatments was formed by early wind erosion and is absent in Surface Spr, but note the presence of moss growth due to soil dampness.

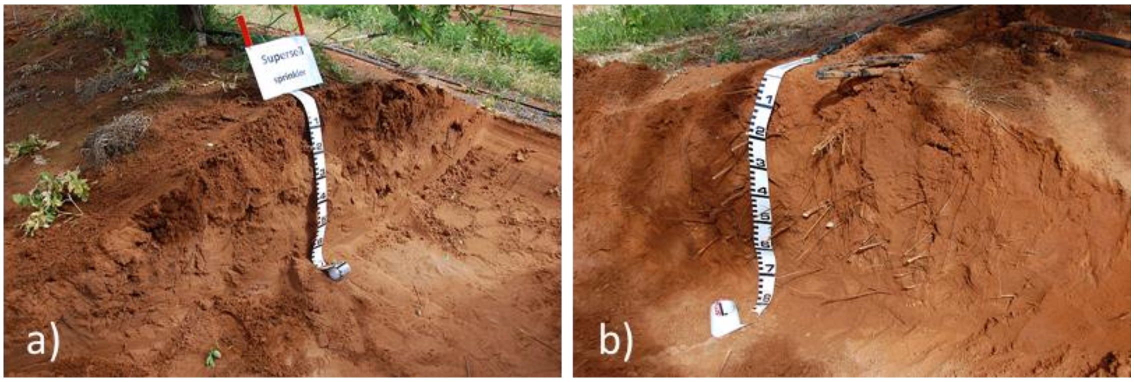


Figure 5-21. Soil profile under a) Supersoil Spr and b) Supersoil D+Spr treatments.

There was little root growth, and also dry soil below 30 cm depth in Supersoil Spr treatment. This may indicate poor water infiltration on the surface of the sloping mound. There is abundant root growth in the Supersoil D+Spr soil mound.

Soil DNA analysis

Sampling for root density and distribution in the soil amendment trial was carried out in April 2021 (Figure 5-22). Soils from four replicates of six treatments were sampled at 10, 20, 30 and 50 cm depths and characterised using SARDI's recently developed rapid fine Prunus root quantification assay (Figure 5-22).

Figure 5-22. Collection and processing of soils for determining impact of amendment treatments upon root density and distribution.

Soil samples were taken from six treatments at a range of distances from the tree line. In four of the treatments (Zero, Surface 50, Spade and Supersoil), samples were taken (0, 45 and 75 cm). These distances were designed to include the tree line and 15 cm either side of the dripline in drip irrigated treatments. In the other two treatments (Surface and Surface Spr) extra samples were taken at 135 cm, or 60 cm outside the drip line. These samples were taken to compare root distribution further towards the midrow, and away from the dripline under drip and sprinkler irrigation. Root distribution in the six treatments as measured by the prunus root assay is shown in Figure 5-23.

The highest density of root DNA was found immediately around the dripline of drip irrigated treatments, with less DNA found in drier areas near the tree row and at depth. When the 135 cm distance of Surface and Surface Spr was excluded from analysis, amounts of almond root DNA were larger in Supersoil treatment There were no significant differences between the other drip irrigated treatments (Zero, Surface, Surface 50 and Spade).

Root DNA content decreased with soil depth and varied by distance from tree line. There was a significant interaction of treatment by depth, as Supersoil treatment had more root DNA at depth than other treatments.

When root DNA content of all four distances was compared between Surface and Surface Spr, values were higher near the dripline than in the same locations in the sprinkler irrigated treatment, with the exception of 50 cm depth where they were similar. Root DNA content was higher in the tree row and mid row of the sprinkler treatment than in the drip treatment.

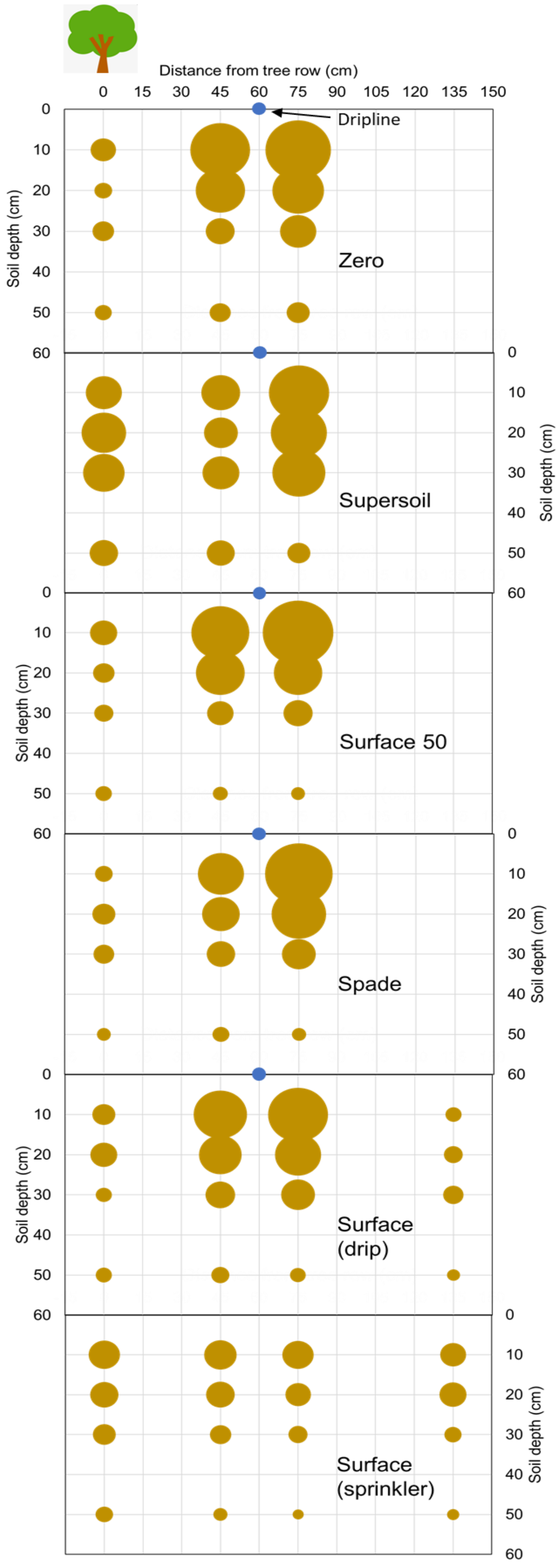


Figure 5-23. Results from SARDI's DNA Prunus Root Assay, measuring almond root density and distribution under soil amendment treatments at 16 locations (Surface and Surface Spr) or 12 locations (other treatments). Values are represented by circle area. The largest circle represents the maximum recorded value of 51.0 kDNA/mg soil.

Irrigation water use

Irrigation management aimed to provide adequate irrigation to all trees and was assisted by the use of Phytech® dendrometers as described SECTION 7. Annual irrigation application of the three systems in the soil amendment trial is shown in Figure 5-24 over the period of the study.

Drip irrigation used the least water over the three-year period at 21.1 ML/ha, followed by drip plus sprinkler (28.7 ML/ha) and sprinkler (36.8 ML/ha).

The differences in water use between drip and sprinkler irrigation reduced over time. In the first year, drip irrigation used 36% as much water as sprinkler irrigation, 58% in the second year and 74% in the third year.

The third irrigation system was drip plus supplementary sprinkler irrigation, which was used to promote growth of cover crop in autumn and spring (Figure 5-25) while meeting tree water requirements in summer through more efficient drip irrigation.

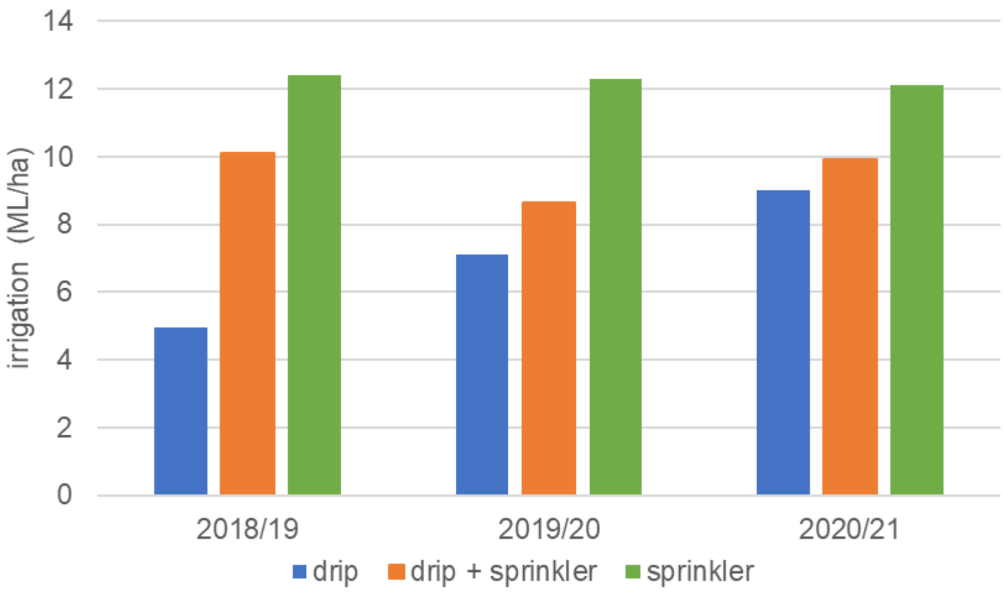


Figure 5-24. Water use by drip, drip plus supplementary sprinkler and sprinkler irrigated treatments in soil amendment trial.

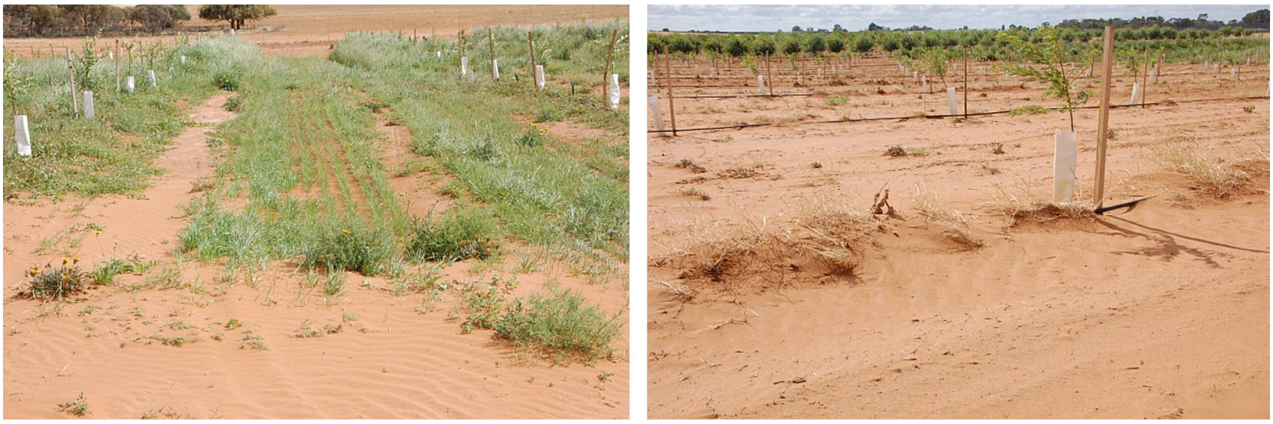


Figure 5-25. Wind erosion as affected by presence of cover crop in young orchard

Irrigating a cover crop in autumn and spring used 5.5 ML/ha over the three years, or 1.83 ML/ha/year. The cost of additional water and pumping is in addition to initial capital costs of installing sprinklers in a drip irrigation plot.

Wind damage

In November and December of 2019, the site received strong winds, gusting over 60 km/h. Any trees which blew over or were severely damaged were replanted in 2020. Only trees planted in 2018 could be harvested for nuts in the 2021 harvest, which was the first mechanical harvest for the trial. Around 25% of trees in the trial were severely damaged and subsequently removed. See Section 9: Climate Adaptation Review for further details of wind damage to this trial and others.

Tree damage was significantly related to both tree variety and experimental treatment, as shown below. Figure 5-26 shows the effect of variety on numbers of trees extensively damaged by wind.

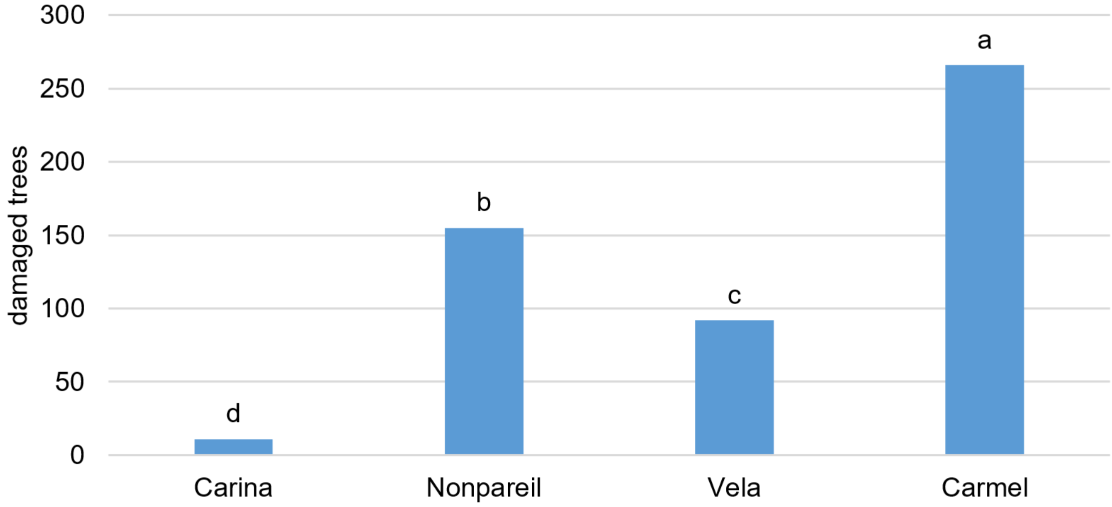


Figure 5-26. Extent of wind damage by genotype in soil amendment trial, assessed March 2020

Carina was by far the most resistant to wind damage, followed by Vela, then Nonpareil. Carmel was most affected by wind damage. The effect of treatment on wind damage is shown Figure 5-27. Supersoil D+Spr treatment was significantly more susceptible to wind damage than other treatments.

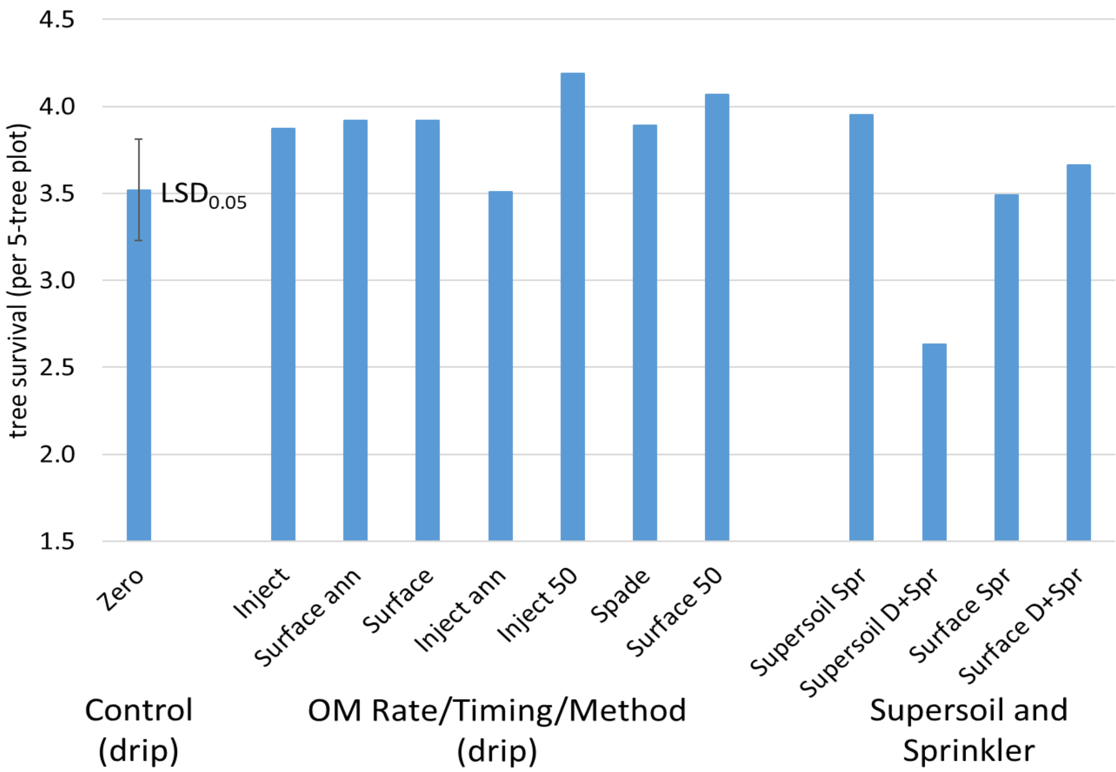


Figure 5-27. Effect of treatment on tree survival to harvest on soil amendment trial (all varieties).

5.4 Discussion

Effects of soil amendment

Compost application method and rate

Application of compost increased early tree growth at the high rate of surface incorporation. It also increased tree growth when applied using a spading implement. It is likely that the early boost from spading was due to the physical soil conditioning that the mechanical action of the spader produced. The same rate of compost had little effect when applied using rotary hoe or through injection.

Physical location of the applied compost also affected the tree growth response. Surface applied compost was dropped onto the surface of the tree row in a band one metre wide. After incorporation with a rotary hoe, trees were planted in the centre of the band. At this stage the compost was in the wetted soil zone and available to provide nutrition to the young trees. As the trees grew, driplines were gradually moved away from the tree row, to encourage wider root growth and as this occurred, the wetted zone moved from the tree row to a larger distance each side of the row. This caused the centre of the tree row area to become dry and less attractive for root growth. With each shift of the driplines, the dry central area became larger and after three years around half of the amended area was dry. This application strategy, common in many young orchards, would have reduced any beneficial effect that the compost could have had on tree nutrition and water relations. Spading may have better managed this effect by placing the compost at greater depth (around 300 mm) where the wetted area around the dripline was wider than nearer to the surface.

In a similar way, the injected compost was placed in two "sausages" of slurry, at 400-450 mm depth around 70 cm each side of the tree row. The wetted zones did not reach these locations until after two years. It may be that trees will better exploit these compost resources now that the roots are reaching this area of the soil profile. The same argument applies to repeat injected and annual amendments, as the annual amendments were placed in a shallow trench around 60 cm each side of the tree row.

The limited response of tree growth to soil amendment treatments was likely impacted by the ample availability of irrigation and nutrient resources. Eliciting a response to soil amendments by reducing water and nutrient inputs was not a focus of this trial.

The reduction of soil bulk density, soil penetrometer resistance, and increased saturated hydraulic conductivity from amendment treatment are all favourable changes for plant root growth. Soil with low bulk density is friable and less compacted, while increased hydraulic conductivity reduces ponding of irrigation water.

Part of this effect on soil bulk density was likely due to cultivation, as Zero treatment was not cultivated while the Surface and Surface 50 treatments were cultivated. However, there was a further effect of rate of compost, as Surface 50 treatment had the lowest bulk density. This is consistent with compost amendment increasing the number of large pores in soil, allowing higher rates of water entry (hydraulic conductivity) and greater pore space (lower bulk density). Because these are large pores, only the saturated water content of soil was increased.

Compost amendments generally decreased RAW. This was an unexpected result, as increased soil organic matter content is widely considered to increase available soil water. However, Duncan (2020a) found a similar result in an experiment on an almond orchard in California where there was no effect of organic amendment on soil water relations at comparable rates of addition. The lack of increased RAW may also be related to the particle size of the compost used for amendment. Wallace et al. (2020) found that direct application of compost did not increase RAW unless the compost was finely ground (passed through a 2 mm sieve), and increased effect was found with compost particles less than 0.25 mm in diameter. The compost used in this trial was relatively coarse – screened through a 12 mm sieve – and may need more time to break down into smaller particles before affecting RAW.

Compost amendment at the high-rate increased soil organic carbon and ECEC, which are known to be soil improvements. Increased ECEC can reduce leaching of some applied nutrients.

Extractable soil P and K was increased by the high rate of compost amendment. Large amounts of nutrient were added with amendment in the Surface 50 treatment, and this was reflected in the chemical soil fertility. The lower soil K level in Supersoil treatment may have been due to the soil mounds being constructed of topsoil, which was generally sandier than subsoil. The lower clay content of topsoil is consistent with lower K levels due to the absence of K-rich clay particles.

Compost is widely considered to increase microbial activity in soil. The cellulose breakdown test measured decomposition rates and stabilisation factors of added cellulose. Decomposition rates represent the rate of short-term breakdown of new organic input and stabilisation factors represent protection of labile carbon from further breakdown, which is relevant to carbon storage in soil.

The calculated decomposition rates and stabilisation factors were comparable to published values from similar production environments (Keuskamp et al., 2013). While the method did not show large differences in microbial activity between treatments, Supersoil treatment had the highest values, implying a more favourable environment for soil microbiota, while Surface 50 and Spade treatments trended higher than Surface or Zero treatments.

As described previously, compost amendment improved soil chemical fertility, penetrometer resistance and rate of water infiltration at the high rate of application. This was initially reflected in a slight growth response to Surface 50 treatment. Duncan (2020b) considered that organic amendments may be most effective in getting a yield response in problem soils, or where inputs are limited. In this trial there was abundant supply of water and nutrients and the soil types had been assessed as favourable for almond trees. It may be that there were few growth restrictions for organic amendments to overcome, as the lack of growth or yield response to organic amendment in almond trees has been found elsewhere. (Duncan, 2020a) found that after five years of study, the application of composted green waste or manure did not increase growth or yield of almond trees in two Californian orchards, nor did it reduce water stress.

However, at the time of writing, only one commercial scale mechanical harvest had been carried out on the soil amendment trial. These are relatively early results. It is likely that production from juvenile trees such as these may not represent the production of mature trees under the same conditions. It would be desirable to carry out further harvests in future to determine if the early results obtained to date reflect the production characteristics of mature trees, given the long-term nature of almond production.

Effects of irrigation

Drip irrigation vs sprinkler irrigation

Drip irrigation was the most efficient water application method. This was expected, as water is applied to a much smaller area within the orchard and tree roots grow around the water source. Sprinkler irrigation used more water given the full orchard floor was irrigated and necessitated a greater depth of application to meet tree needs. Irrigation of the full orchard floor resulted in water being lost to leaching as it was applied outside the root zone of the small trees, and also lost due to evaporation from the soils surface. The differences in water use between drip and sprinkler irrigation reduced over time. This was due to an increase in the volume of water applied by drip irrigation to support the tree canopies as they developed. It would be interesting to test if the amount of water used (and the water use efficiency) of drip and sprinkler irrigation became comparable once trees matured. If the water allocation for both drip and sprinkler irrigation was the same and production was similar, then the water savings from drip irrigation would be limited to the period of time taken for trees to reach full water allocation. After that, comparison between the irrigation methods would be based on other factors, such as maintenance costs, soil health benefits, reduced erosion, disease risks, etc.

Bryla et al. (2005) found that benefits of drip irrigation in peach trees appeared most related to the ability to apply frequent irrigations. Daily irrigations by drip maintained higher soil water content within the root zone and prevented cycles of water stress found between less frequent micro spray irrigations.

However, different outcomes may be found with almond trees. Espadafor et al. (2018) considered that under localized irrigation, even when applying non-limiting amounts of water, transpiration could be restricted due to a limited wetted soil volume in the absence of spray irrigation. They concluded that there are situations in the field where almond tree transpiration is limited by an insufficient wetted soil volume, even when supplied with adequate water. This is due to high soil hydraulic resistance during times of peak evaporative demand and implies that in some situations the ability of sprinklers to supply effective irrigation water is superior to that of drippers. In a fully mature almond orchard, when canopy closure has occurred, there may be some reduction in soil evaporation from sprinkler irrigation, further reducing the disadvantage compared to drip irrigation.

For these reasons, drip and sprinkler irrigation treatments were included in the soil amendment trial, allowing comparison of water use efficiency between the two systems.

Root distribution between trees in drip and sprinkler irrigated treatments varied widely, both visually and as assessed by the root DNA soil test. The highest density of root DNA was found immediately around the dripline of drip irrigated treatments, with less DNA found in drier areas near the tree row and at depth. This is consistent with expected fine root distribution near water and nutrients. When root DNA content was compared between Surface and Surface Spr, values were higher near the dripline than in the same locations in the sprinkler irrigated treatment. Root DNA content was higher in the tree row and mid row of the sprinkler treatment than in the drip treatment. This is consistent with the wider spatial coverage of water under sprinkler irrigation. Surface Spr had the lowest absolute root DNA values. This was also expected, as the root mass under sprinkler irrigation is spread over a much wider area than under drip irrigation. Root density near a dripline would be higher than the same location in a sprinkler irrigated plot. However, there would be higher root density under sprinkler irrigation away from these locations.

The DNA Prunus Root Assay was effective at detecting the presence and distribution of fine almond tree roots under different irrigation systems.

Supplementary irrigation for cover crop

Cover crops offer numerous benefits such as the potential to increase soil organic matter and fertility, improve soil structure, reduce erosion, promote water infiltration, and limit pest and disease outbreaks (Allen, 2021). Cover crops may also reduce the risk of equipment bogging at harvest, due to soil stabilisation. However, they may not show an economic benefit, or may take a long time to do so (DeVincentis et al., 2020).

Three irrigation systems were installed on the soil amendment trial. Firstly, full drip irrigation, secondly full sprinkler irrigation and thirdly full drip irrigation with additional sprinkler irrigation which could be operated separately to encourage cover crop growth in autumn and spring, while avoiding cover crop growth in summer when this would compete with trees for water and nutrients. Cover crop growth under the three watering systems is shown in Figure 5-28.

Figure 5-28. Cover crop in plots irrigated by full sprinkler (foreground), supplementary sprinkler (middle ground) and dripper (background) in soil amendment trial, June 2019.

The aim of the supplementary sprinkler treatment was to extend the growing season of winter cover crop, in order to maximise the benefits derived from a cover crop. Typically, around 2 ML/ha would increase the growing season of a cover crop by 3-4 months. Without supplementary irrigation a cover crop is reliant on rainfall, when opening rains may occur between April (2020) and July (2021), and spring rain can abruptly cease in September (2019), or carry through to late October (2020), as shown in Table 5-7. In a young orchard, prior to canopy closure, summer weed growth is also an issue with full sprinkler irrigation but less so with the other irrigation systems. Irrigation of cover crop greatly reduced wind erosion in the first few years after tree planting.

Table 5-7. Irrigation system and cover crop parameters on soil amendment trial

Irrigation system	Typical cover crop growing season	Summer weeds?
Drip	June to September	no
Drip + Sprinkler	May to November	no
Sprinkler	May to November	yes

The economic benefits of cover crops are somewhat difficult to assess, although DeVincentis et al. (2020) recently produced an economic model of the benefits of cover crops in almond orchards. There are some assumed production benefits to cover crops, but these are not always realised, and the model focuses on the likely benefit and length of payback periods when using cover crops.

The installation of a separate sprinkler irrigation system for the D+Spr treatment is unlikely to be economic based on the production benefits of a cover crop (DeVincentis et al., 2020). However, the ability to pre-wet a soil profile with sprinkler irrigation before commencing drip irrigation may have production benefits under severe water stress, as discussed above.

Ryegrass pre-treatment and soil mounding (Supersoil)

The aim of the Supersoil treatment was to provide an hospitable environment for plant roots to grow. Ryegrass growth as a soil treatment, and formation of soil mounds appears to have provided good soil conditions for root growth. The soil was soft, friable, allowed free water entry and good aeration. Soil in the Supersoil treatment was much softer than other treatments to the full depth tested, and root DNA testing showed that abundant roots were widespread through the drip irrigated mounds. However, the potential benefits of these soil factors could not be expressed in tree growth or almond yield, due to the difficulty of managing active growth on these steep mounds. Trees suffered moisture stress at early stages due to competition from ryegrass and weeds. Control of non-tree growth was very difficult, in part due to apparent herbicide resistance of the ryegrass and broadleaf weeds. Various means were used to bring mound growth under control, including self-propelled slasher, whipper snipper and manual weeding.

Vegetation is no longer being grown on the soil mounds. It is possible that the trees will be able to take advantage of soil conditions in the absence of competition for soil moisture. This may be evident in future harvests.

Trees in Supersoil D+Spr treatment were especially susceptible to wind damage. It is difficult to explain why this occurred. While Supersoil mounds were much softer than unmounded treatments, little of the tree damage was due to anchorage failure. Most damaged trees had branches and, in some cases trunks, snapped off by the wind. Supersoil Spr treatment also suffered much less wind damage than Supersoil D+Spr.

Steep mounding of topsoil is not recommended for almond orchards due to management difficulties, despite the presence of improved soil conditions.

5.5 Conclusions

- organic soil amendments were applied at various rates and by various methods
- there was little effect on tree growth or yield
- amendment improved soil chemical, physical and biological parameters but this was not reflected in yield
- drip irrigation was more efficient than sprinkler irrigation, but the difference reduced over time
- the growth period of cover crop was extended by several months with 2 ML/ha extra water
- Supersoil treatment (ryegrass and soil mounds) was unsuccessful due to difficulty managing vegetative growth on steep soil mounds, despite improvements in all measured soil parameters and increased root growth
- yield results are based on the first harvest from juvenile trees and may not reflect yield produced by more mature trees as soil management treatments are generally a longer-term investment

SECTION 6. Rootstock and scion compatibility screens

Key points

- SARDI established 2.2 ha of rootstock and scion compatibility screens containing 148 distinct graft combinations at medium (H2) and high (H3) planting densities.
- These genotype compatibility screens are suited to characterising yield performance, canopy/fruit disorders and genotype specific canopy architectures that may be suited to alternate production systems/densities.
- Results of early assessments have been integrated into variety factsheets that compare performance across multiple rootstocks. Factsheets to remain as live documents that are updated annually with seasonal performance metrics.
- Controller 7 (C7) rootstock was found to be unsuitable for shallow calcareous sand over limestone, common soil condition in the Riverland.
- Early results suggest that Garnem is the most promising of the 3 ABA licenced Spanish rootstocks.
- Barrier 1 rootstock produced strong early yields (particularly when grafted to Vela) and, in the third leaf, was clearly well adapted to shallow calcareous sand over limestone soils.
- Atlas and Krymsk 86 rootstocks appear well suited to high density plantings with scions of spreading, slightly weeping form. Currently performing well with precocious scion genotypes.

6.1 Background and aims

The majority of Australian almond orchards are planted to traditional variety mixes on poorly adapted, full vigour rootstocks planted at a traditional 317 trees per hectare (H1). Sedgley and Wirthensohn (2007) observed that the Australian industry had been built on the use of these older cultivar and rootstock combinations and that they weren't well suited to Australian conditions. At that time, the observation was made that there needed to be an assessment of new scion and rootstock cultivars and their suitability for varieties relevant to the Australian industry.

Further to this, the Australian industry is keen to pursue greater orchard production efficiencies through higher tree densities. With the understanding that reduced individual tree yields would be offset by gains from having more trees per hectare. In California it was demonstrated that when tree spacing was reduced, yield increased. This was also shown in the stone fruit and apple industries. The yield advantage in California was highly dependent on tree vigour, with smaller stature variety/rootstock combinations (*e.g.,* those on Nemaguard, regarded as approx. 90% size compared to Hansen) benefiting more from tightly spaced trees.

Selecting self-fertile varieties would further enable monocultures or limited cross pollination systems, smoothing out yield fluctuations due to pollination issues and improving production efficiencies. However, to do this the yield and quality of the self-fertile variety needs to be carefully considered and closely aligned to the qualities of Nonpareil, the premium quality nut type in world markets.

New varieties that repeat bear from the same spurs may be key to smaller tree architectures. Smaller trees allow better spray coverage to manage pests and diseases, easier nut removal during harvesting with lighter machinery for less soil compaction, tree damage and equipment maintenance. Godini and Camposeo (2010) observed that compact shape of some cultivars of olive were well adapted to super high-density orchards, almond genotype screens need to identify similarly suited almond cultivars.

Rootstocks also contribute a range of genetically conferred vigour traits, which may manifest in some size controlling of the scion. Root competition at close tree spacing may also supply some measure of vigour control as it does in close planted stone fruit orchards. It is therefore important to test a wide range of rootstocks for their adaptability to high density planting.

Genetic incompatibility (or graft incompatibility) is ever present risk between some scions and rootstocks of widely differing back grounds, and while this may be evident at an early stage, some incompatibilities can take many years to manifest. Therefore, extended evaluation as a risk management tool is warranted.

Long term data is required for making well considered decisions on orchard design for new growing systems. Shapiro and Wortmann (2006) use this fact to explain why relatively few experiments have been carried out in fruit trees to determine optimum intra-row density, compared with annual crops. This is yet another important aspect of a new high density growing system that should be considered.

Australian almond growers are able to access many new rootstocks and scion varieties of foreign and domestic origin for which there is very little performance data under Australian conditions. The complexity of selecting the appropriate rootstock and scion combination grows exponentially as new scion varieties and rootstocks are released to the industry. Rootstock and compatibility screening aims to identify where compatibility issues may occur, and to identify combinations that possess characteristics helpful in the future development of more sustainable and productive growing systems. The development of higher density growing systems will likely rely heavily on favourable combinations being identified to naturally offset some of the cultural challenges faced.

SARDI's contribution to identifying suitable cultivar combinations was to establish two rootstock compatibility trials:

Trial 5 (T5) Rootstock and density focussed compatibility screen.

Aiming to test a range of new, self-fertile, 'Nonpareil like', replacement varieties on a wide range of newly available rootstocks of differing vigour.

Nonpareil included as comparator.

Planted at medium (H2) and high (H3) densities.

Trial 6 (T6) Scion focussed compatibility screen.

Aiming to test a wide range of new scion genotypes, offering either high early production or novel architecture, for their suitability for alternate production systems.

Largely drawn from the secondary evaluation phase of the University of Adelaide almond breeding program. Several genotypes with novel traits possibly suited to high density systems were also speculatively included.

In recognition of the higher risk of adverse outcomes with these cultivars, tree numbers were limited by grafting to fewer rootstock combinations (but representing a gradient in vigour) and at only medium density (H2)

6.2 Orchard establishment and methods

Both trials were established as cost effective screens, rather than replicated trials, to ensure that the greatest possible number of combinations could be assessed and better inform decisions on likely combinations for next generation (replicated) density trials. Five trees of each combination were planted as observation blocks at H2 (6.5 x 3m) density, and seven trees at H3 (4.5 x 2) density (T5 only), to keep observation blocks of the same size (~15 m in length) with reasonable buffering to limit external influences. Whilst experimental measurement units were a reasonable size they were not replicated and only allowed for observational measures of tree health, vigour and yield under low and moderate competition levels.

Standard site management was employed with inputs applied consistently across the planting. ABA staff were in communication with SARDI prior to application of any non-standard management inputs.

Summaries of T5 and T6 plantings are shown in Table 6-1 and Table 6-2 below.

Table 6-1 Summary of Trial 5: Scion/Rootstock Compatibility Trial planting

Rootstocks	Scions	# Trees	Valves	Spacings	Area	Planted
Nemaguard	Nonpareil	173 NP	25	6.5 x 3.0 m	1.18 Ha	2018
Controller 6	Vela	173 Ve		4.5 x 2.0 m	10 rows	
Controller 7	Almond 21	173 #21				
Controller 9	Shasta	173 Sh				
Rootpac 20	Almond 12	173 #12				
Rootpac 40		**865 Total**				
Rootpac R						
Krymsk 86						
Cornerstone						
Atlas						
Garnem						
Felinem						
Monegro						
Barrier 1						

Table 6-2 Summary of Trial 6: New Scion/Rootstock Compatibility Trial planting

Rootstocks	Scions	# Trees	Valves	Spacings	Area	Planted
Garnem	Nonpareil	97[1]	25	6.5 x 3.0 m	0.98 Ha	2018
Nemaguard	Carina (A1)	20			7 rows	
Rootpac 40	Maxima (A3)	20				
Controller 7	Mira (A5)	20				
	Vela (A10)	20				
	Almond #16	20				
	Almond #18	20				
	Almond #24	20				
	Almond #28)	20				
	Almond #32	20				
	Almond #33)	20				
	Almond #34)	20				
	Almond #45	20				
	Almond #52	20				
	Almond #53	20				
	R36T195	20				
	R36T199	20				
	R36T212	20				
	R38T208	20				
	R43T17	20				
	R43T107	20				
		497 Total				

[1] Includes additional barrier trees to complete rows

Planting dates

Combinations on Monegro, Felinem, Garnem, Cornerstone, Barrier 1, Nemaguard, Atlas and Krymsk 86 were planted in spring 2018, with only odd trees required to fill shortfalls after that time. Rootpac R, Controller 9.5, Controller 7, Controller 6, Rootpac 40 and Rootpac 20 were planted in spring 2019.

Tree Training

First season pruning and training activities focussed on promoting early branching whilst trying to avoid cross-over of major scaffold limbs or excessive stress from too many limbs in a single section of trunk. After this initial setup training, trees were minimally pruned, to enable canopies to express their natural form, until the end of the third leaf when trees were skirted with hedging equipment.

Trunk Diameter Measurements

Trunk diameter recordings were taken by hand in November 2018 during their first season's growth, and by SARDI's Mobile Orchard Phenotyping Platform (MOPP) thereafter. Only the readings from 3rd leaf trees going into their 4th leaf in 2021 will be discussed as these have had the opportunity to be sufficiently influenced by rootstock and early cropping levels.

Harvesting

Harvest was performed on some two-year-old trees (2nd leaf) by hand picking in March 2020. In 2021 complete tree blocks were harvested by standard commercial machinery, being shaken onto the ground before being blown and swept into windrows and picked up by a commercial pickup machine. Hulls, shells and kernels from each plot were delivered into a trailing bin mounted on load cells, allowing bulk weights to be recorded.

Sub-samples of approximately 2 kg were taken in mesh bags, labelled and weighed, before being dried at 40°C in fan forced drying ovens to constant moisture or for 14 days (equating to approximately 3% moisture), before being processed (hulled and cracked). Processing was done using a cracking machine (Jessee® mini almond huller and sheller; Jessee equipment manufacturing, Chico, California, USA) to separate kernels from hulls and shells. Kernel samples were then separated, cleaned and weighed by hand, before 50 kernel sub-samples were counted and weighed to determine average kernel weight and determine crack out percentage (percentage of kernel in the sub-sample) and overall yields in kernel per hectare for each treatment plot.

Figure 6-1. SARDI's 2021 harvest operations. ABA pickup and reservoir cart adapted to enable yield assessments of large-scale experimental plots, and hulling operation in ACE shed. Almond Centre of Excellence, SARDI Loxton (2021).

Tree descriptions

Pre-harvest disease and compatibility surveys were conducted in both 2020 and 2021. These surveys assessed more than 35 pathogenic and compatibility disorders in a modified version of the AS16005 disease incidence screen. In 2021, pre- and post-harvest assessments of tree structure and habit were also conducted. These canopy assessments assigned quantitative and qualitative scores to multiple metrics of interest for each variety/rootstock combination.

The metrics characterised included tree size (height, width & overall size), tree habit (uprightness, spreading & weeping), branch type density (scaffold, secondary, spurring, overall), secondary and tertiary branch angles, extension growth (branch terminals & spurs), branch tip feathering, internode compression, leaf size, nut bearing location (spurs & twigs or spurs), hull split percentage (at February 15th 2021), nut drop, visual crop load, number and condition of trees in plot, mite damage, physiological disorders (chlorosis, necrosis, leaf rolling/cupping, leaf brittleness and twig/spur death), tree age and other pertinent comments. Following this an attempt was made to quantify the overall perceived value of the combinations based on these observations, later adding measured yields to validate these conclusions.

Variety description sheets

All rootstock combinations of varieties in Trial 5 (Nonpareil, Shasta, Vela A12, A21) and those grafted to the better performing varieties from Trial 6 (Mira, Maxima, A16, A18, A28, A52, A53 and R38T208) were integrated into variety performance factsheets, Sections 6.4 and 6.5. These sheets detail the early yields and canopy observations made on these developing graft combinations. An opportunity exists with this variety by rootstock information to develop an organic, grower friendly, web-based resource that is added to year on year to extend known knowledge in a single reference site.

6.3 Results & Discussion

While only early in their productive life, these compatibility screens are already suggesting some interesting graft combinations. However, of more immediate value are the observations of genotypes to be avoided under Riverland growing conditions. This is most obviously demonstrated with the Controller 7 rootstock whose severe chlorosis symptoms were noted within the first 12 months from planting. To a lesser degree, Controller 9.5 was showing the same symptoms making it difficult to recommend either stock for the South Australian Riverland.

In T6, consideration must be given to replanting trees on Controller 7 (and possibly Controller 9.5). The site has served its purpose with this rootstock and it is timely to remove these trees and plant with an alternative rootstock to maximise the demonstration/education opportunity of the site.

It was also noted that a scion specific disease/disorder in variety R36T199 was becoming apparent in the form of spotting on one year old terminal extension growth late in the third leaf (Garnem less affected than Nemaguard rootstocks). The symptoms later developed into a more generalised necrosis and bud failure. Two attempts to isolate pathology have failed and the issue remains undiagnosed. The significance of the issue will continue to be tracked.

A range of tree architectures are displayed in the trials, from upright to spreading and slightly drooping forms. There are varying degrees of natural secondary branching of different angles from upright to flat. Some of these may be advantageous, as natural shape and tree architecture can have the advantage of reducing manual training operations (Costes et al., 2010). Breeding programs in the past have given preference to heavily spurring types as a major driver of nut production per unit area, along with self-fertility, precociousness and high early cropping as general natural moderators of tree vigour and growth.

In 2021, the more productive combinations produced exceptional yields for third leaf trees (see Section 6.4 and 6.5). In particular, Vela grafted to either Barrier-1, Atlas or Garnem rootstock, each of which exceeded 3.3 tonnes kernel/ha at H2 and 5.7 tonnes kernel/ha at H3. Almond #21 also performed well on these rootstocks. The best yielding Nonpareil trees were those grafted to Barrier-1 and these averaged 2.8 tonnes kernel/ha at H2 and 4 tonnes kernel/ha at H3. The industry standard combination of Nonpareil on Nemaguard produced 1.7 tonnes kernel/ha at H2 and 3.4 tonnes kernel/ha at H3.

The effect of density on the third leaf yield is summarised in Figure 6-2, where the varietal performance reflected average yield across multiple rootstocks. Individual tree yields at H2 and

H3 were 3.8 and 3.2 kg/tree on average. The high-density planting of the H3 trees (1,111 trees/ha) resulted in significantly greater early returns on investment. The opportunity for future years' assessments is the characterisation of yields in the context of establishment and management costs.

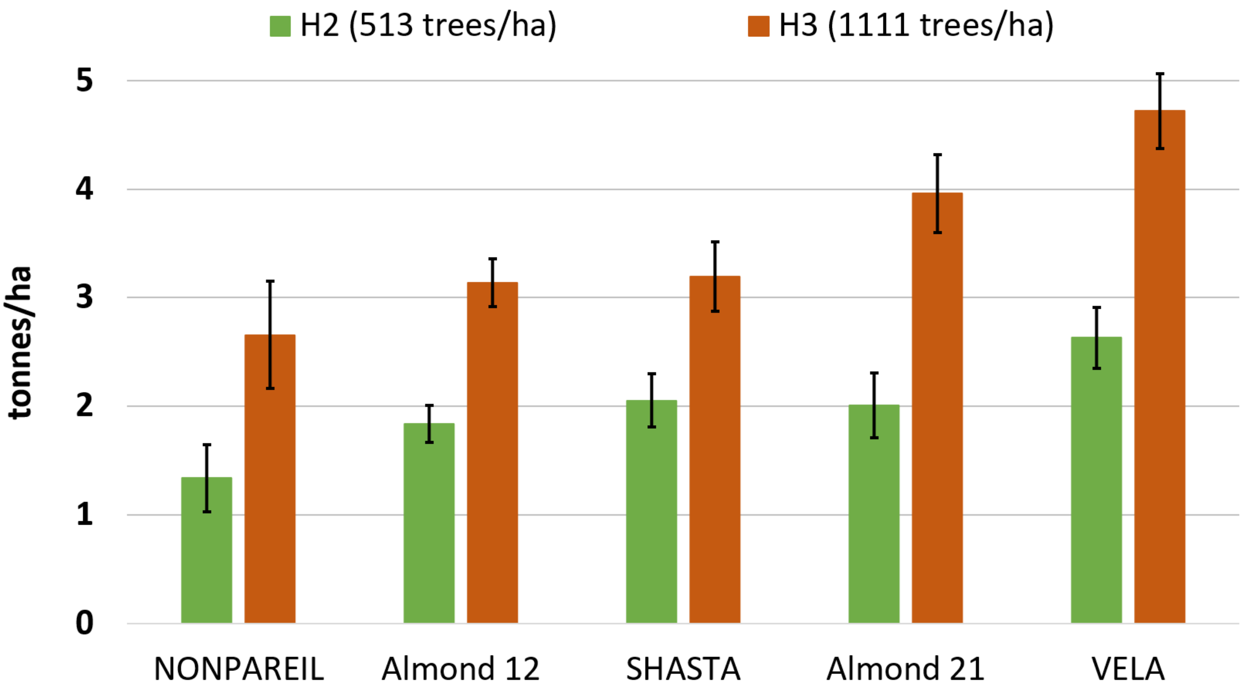


Figure 6-2 Effect of density on yield response of third leaf varieties planted in SARDI's genotype compatibility trials. Data are average yields across multiple rootstocks. Almond Centre of Excellence, SARDI Loxton (2021).

It is important that harvest assessments are carried out in future years, to better characterise the longevity of the early production gain and also highlight any increased inputs or compromises required to ensure practical management of the higher density plantings. Suitability of various variety and rootstock combinations must consider the practicalities of orchard management and resource use, not just the yield/quality metrics.

In this context, recent personal communications with Jose Maria Lainez of Agrolainez (Spain), and John Slaughter, Prima-Wawona (California), suggest that super high-density systems can be successfully established using high vigour rootstocks (like Cornerstone, Garnem and GF677). Vigour can be controlled through planting in poor/shallow soils or through orchard management practices such as well controlled irrigations during specific fruit growth stages.

Variety description sheets

As described above, early results have been summarised in variety performance factsheets, Section 6.4 and 6.5. There are various supporting datasets behind these factsheets including disease incidence surveys, photographic and qualitative observations of rootstock/scion combinations, objective (remotely sensed) canopy size measures from SARDI's Mobile Orchard Phenotyping Platform and yield metrics from younger trees. These early datasets are available as contextual metrics for future analysis but are not presented in this report. The variety factsheets have been produced for the most promising combinations to date. They have been designed to be updated annually and supplement the information generated by the developers of genotypes included in the trials.

6.4 Trial 5 – Variety x Rootstock x Density Factsheets

Key to data table abbreviations:

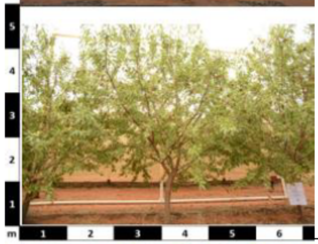
C	Compact
F	Flat
G	Good
H	High
L	Long/Light
Lg	Large
LM	Light Medium
M	Moderate/Medium
MF	Moderately Flat
MH	Moderately High
MS	Moderately Spreading
N	Normal
P	Poor
S	Short
S&T	Spurs &Twigs
Sev.	Severe
SF	Slightly Flat
Sl.	Slightly
Sl.C	Slightly Compact
Sm	Small
Sp	Spurs
SS	Slightly Spreading
T	Twigs
U	Upright
VG	Very Good
VH	Very High
VS	Very Spreading
1	Very small
2	Small
3	Moderately small
4	Moderately large
5	Large (Nonpareil on Nemaguard)
6	Very large

Nonpareil

(513 & 1,111 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Nonpareil** is a standard comparator and open access variety. This guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices



TREE

Growth habit	Moderately upright, moderately spreading
Branch density	Moderately high
Bloom	Early season (18 August 2021)
Pollination	Not self-fertile (S7S8). Cross pollination required
Pollinators	Carina, Maxima, Vela, Shasta
Cropping	Precocious, high early yields on all trial trees
Harvest timing	Early-season. ~3 March

NUT

Nut shape	Cordate
Kernel size	Large (1.5 g)
Crack-out %	22%
Shell texture	Soft shell
Kernel appearance	Attractive, skin colour medium to light

NONPAREIL – Yield history in ACE compatibility screen * ‡

Rootstock (Age)	H2 (513 trees/ha) Yield (t/ha) 2020	H2 Yield (t/ha) 2021	H2 Crack-out (%)	H2 Kernel size (g)	H3 (1,111 trees/ha) Yield (t/ha) 2020	H3 Yield (t/ha) 2021	H3 Crack-out (%)	H3 Kernel size (g)
Monegro (3)	-	0.16	28	0.00	-	0.38	24	1.32
Felinem (3)	-	1.05	30	1.24	-	2.49	29	1.17
Garnem (3)	-	2.09	30	1.16	-	4.36	32	1.19
Cornerstone (3)	-	1.62	29	1.23	-	3.26	28	1.13
Barrier 1 (3)	0.04	2.82	34	1.25	-	4.05	29	1.14
Nemaguard (3)	-	1.65	30	1.34	-	3.42	29	1.12
Controller-9.5 (2)	-	0.06	28	-	-	0.20	28	-
Atlas (3)	-	0.57	32	1.43	-	1.12	34	1.26
Rootpac-R (2)	-	-	-	-	-	-	-	-
Krymsk 86 (3)	-	0.73	24	1.43	-	2.19	28	1.32
Controller-7 (3)	-	-	-	-	-	-	-	-
Rootpac-40 (2)	-	0.09	23	-	-	0.09	23	1.24
Controller 6 (2)	-	-	-	-	-	-	-	-
Rootpac-20 (2)	-	-	-	-	-	-	-	-

* Yield estimates based on single plots of five trees
‡ Crack-out and kernel size from 2021 data only

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Nonpareil' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

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OBSERVATION ON TREE CHARACTERISTICS OF NONPAREIL ON DIFFERENT ROOTSTOCKS

		Mon	Fel	Gnm	Cstn	Bar	Nem	C9.5	Atlas	RR	K86	C7	R40	C6	R20
Age	Years	2	3	3	3	3	3	2	3	2	3	2	2	2	2
Tree Size (1 = v. small, 6 = very large)	Av. Size	4	6	5	5	5	5	4	5	4	5	2	3	3	2
	Height	4	6	5	5	5	5	3	5	2	4	3	3	3	2
	Width	4	5	6	5	5	5	4	5	2	5	3	4	3	2
Tree Habit	Upright	U	U	U	U	U	U	U	U	U	U	U	U	U	U
	Spread	SS	SS	SS	MS	SS	SS	SS	VS	SS	VS	SS	SS	SS	SS
	Weep														
Branch density	1° Scaffolds	MH	M	M	M	M	M	MH	MH	M	L	MH	MH	M	L
	2° Branches	MH	M	M	M	M	M	MH	MH	M	LM	MH	MH	M	LM
	Spurs	M	MH	MH	MH	H	MH	H	M	MH	H	M	H	MH	MH
	Av. Overall	MH	MH	M	M	MH	M	MH	M	M	MH	MH	H	M	LM
2° Branch Angles		SF	SF	MF	MF	MF	SF	SF	MF	F	SF	SF	MF	MF	SF
Extension Growth	Terminals	M	M	S	M	S	S	L	M	M	L	M	M	M	M
	Spurs	Sl.	Sl.	N	N	Sl.	Sl.	Sl.	Sl.	N	N	N	Sl.	N	N
	Feathered tips	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	Internodes	Sl.	N	Sl.	N	N	N	Sl.	N	M	N	M	Sl.	Sl.	C
Leaf Size		Lg	M	Sm	M	M	M	M	M	M	M	M	Lg	Lg	M
Nut Bearing	Spurs or twig	S&T	S&T	S&T	S&T	S&T	S&T	S&T	Sp	Sp	Sp	Sp	Sp	Sp	Sp
Pests, Diseases & Disorders	Mites														
	Chlorosis									M		Sev			M
	Necrosis									Sl.					
	Leaf roll/cupping									Sev					Sev
	Brittle leaves									Yes					
	Twig death					Yes									
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only presents those relevant at the time of publishing.													
Tree Numbers within ACE planting		5	7	7	7	7	7	7	7	7	7	6	7	7	6
Combination		Ok	G	G	Ok	Ok	Ok	Ok	Ok	P	Ok	P	G	G	P

SUMMARY

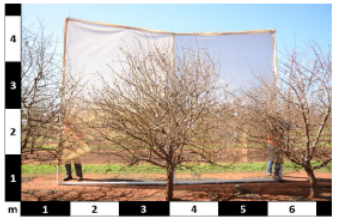
Nonpareil is similar to Shasta although tends to be slightly lower yielding on the same rootstock, the exceptions to date are the better performances on Nemaguard (3.4t/ha) and Cornerstone (3.3t/ha) at H3 densities. Best yield performances to date came on Garnem (2.09 and 4.4 t/ha) and Barrier 1 (2.82 and 4t/ha) at H2 and H3 densities respectively. As can be seen doubling the density H2 (513 trees/ha) to H3 (1,111 trees/ha) greatly increases yield in the 3rd leaf. Rootpac R and R20 appear to have incompatibilities with Nonpariel. Atlas and Krymsk 85 seem poor architectural partners for Nonpariel producing fewer branches, lower yields have reflected this. At ACE the variety does not seem suited to Rootpac R, Controller 7 or Rootpac 20 due to soil conditions or incompatibility. Garnem and Barrier 1 seem the best partner rootstocks at this stage.

Almond #12

(513 & 1,111 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #12** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #12** was developed by the University of Adelaide, national Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflects the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed by standard industry practices.



TREE

Growth habit	Slightly upright, very spreading, moderately weeping (compact with flat branch angles)
Branch density	Medium heavy to heavy
Bloom	Early season (-3 days Nonpareil)
Pollination	Self-fertile (S8Sf).
Pollinators	Peerless, Rhea, Monterey, Shasta
Cropping	Precocious, good early yields on all full vigour rootstocks
Harvest timing	Early-season. ~3 March (Nonpareil, Carina, Mira, Maxima)

NUT

Nut shape	Cordate
Kernel size	Moderately large (1.4 g)
Crack-out %	24-30 %
Shell texture	Soft shell
Kernel appearance	Attractive, skin colour medium to light

ALMOND #12 – Yield history in ACE compatibility screen * ‡

	H2 (513 trees/ha) Yield (t/ha)		Crack-out (%)	Kernel size (g)	H3 (1,111 trees/ha) Yield (t/ha)		Crack-out (%)	Kernel size (g)
Rootstock (Age)	2020	2021			2020	2021		
Monegro (3)	-	1.13	21	1.45	-	2.83	30	1.49
Felinem (3)	-	1.83	24	1.13	-	3.54	26	1.37
Garnem (3)	-	2.07	24	1.34	-	2.60	24	1.35
Cornerstone (3)	0.05	1.63	24	1.39	0.02	3.25	28	1.30
Barrier 1 (3)	0.28	2.59	28	1.37	0.11	3.79	27	1.28
Nemaguard (3)	-	2.34	25	1.23	0.24	2.04	25	1.29
Controller-9.5 (2)	-	0.06	28	-	-	-	-	-
Atlas (3)	-	1.43	26	1.46	-	3.87	32	1.46
Rootpac-R (2)	-	-	-	-	-	0.09	28	-
Krymsk 86 (3)	-	1.69	20	1.43	-	3.21	29	1.42
Controller-7 (3)	-	-	-	-	-	-	-	-
Rootpac-40 (2)	-	-	-	-	-	0.25	28	-
Controller 6 (2)	-	-	-	-	-	-	-	-
Rootpac-20 (2)	-	-	-	-	-	-	-	-

* Yield estimates based on single plots of five trees
‡ Crack-out and kernel size from 2021 data only

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Almond #12' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

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OBSERVATION ON TREE CHARACTERISTICS OF ALMOND-12 ON DIFFERENT ROOTSTOCKS

		Mon	Fel	Gnm	Cstn	Bar	Nem	C9.5	Atlas	RR	K86	C7	R40	C6	R20
Age	Years	3	3	3	3	3	3	2	3	2	3	2	2	2	2
Tree Size (1 = v. small, 6 = very large)	Av. Size	6	5	5	4	4	4	3	5	3	4	2	3	3	2
	Height	6	5	5	4	4	4	3	5	2	4	2	3	3	2
	Width	5	6	6	4	5	5	4	5	3	5	3	4	4	3
Tree Habit	Upright	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.
	Spread	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS	VS
	Weep	M	M	M	M	M	M	M	M	M	Sl.	M	M	M	M
Branch Density	1° Scaff	MH	MH	MH	MH	MH	MH	MH	MH	MH	H	H	H	MH	MH
	2° Branch	H	H	H	MH	H	H	H	H	H	MH	H	H	MH	H
	Spurs	MH	MH	MH	H	H	H	H	H	H	MH	H	H	H	H
	Av. Overall	H	H	MH	H	MH	H	H	H	MH	MH	VH	VH	H	H
2° Branch Angles		F	F	F	F	F	F	F	F	F	F	F	F	F	F
Extension Growth	Terminals	L	L	M	S	M	M	L	L	M	M	L	L	M	M
	Spurs	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	M	No	Sl.	Sl.	Sl.	Sl.	Sl.
	Feathered tips	No	No	No	No	No	No	No	Sl.	No	Sl.	No	No	No	No
	Internodes	N	N	N	Sl.	Sl.	N	Sl.	Sl.	C	N	Sl.	Sl.	M	C
Leaf Size		M	M	M	M	M	M	M	M	M	M	M	Lg	M	M
Nut Bearing	Spurs or twig	S&T	S&T	S&T	S&T	S&T	S&T	Sp	S&T	S&T	S&T	S&T	S&T	Sp	Sp
Pests, Diseases & Disorders	Mites														
	Chlorosis				Sl.			Sl.		M		M			M
	Necrosis														
	Leaf roll/cupping							M		Sev		M	Sl.	Sl.	Sev
	Brittle leaves														
	Twig death	Yes	Yes								Yes				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only presents those relevant at the time of publishing													
Tree Numbers within ACE planting		7	7	7	7	7	7	7	7	7	7	7	7	7	7
Combination		G	G	Ok	G	Ok	VG	Ok	VG	?	VG	Ok	G	G	Ok

SUMMARY

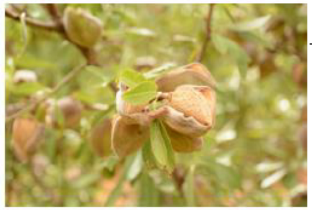
Almond #12 is a slightly upright, very spreading and moderately weeping scion in general, it produces well early on all the full vigor rootstocks but seems to do particularly well under the lower branching and greater uprightness conferring Atlas and Krymsk 86 rootstocks. There is a general positive yield response to moderately increased density and Atlas and Krymsk 86 rootstocks look to have value in future super high density (SHD) plantings at this stage. The trees appear well leafed, slightly compact with flat branch angles and extension growth inside the canopy, nuts appear large and well-sealed but slightly sticky to remove. At ACE the variety does not seem suited to Controller 9.5, Rootpac R, Controller 7 or Rootpac 20 due to soil conditions or incompatibility. Barrier 1 and Atlas seem the best partner rootstocks at this stage.

Almond #21

(513 & 1,111 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #21** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #21** was developed by the University of Adelaide, national Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices



TREE

Growth habit	Upright, moderately spreading
Branch density	Moderately high
Bloom	Mid-season (+4 days Nonpareil)
Pollination	Self-fertile (S8Sf).
Pollinators	Nonpareil, Maxima, Mira
Cropping	Precocious, good early yields on all full vigour rootstocks
Harvest timing	Early-season. ~3 March (Carina, A18, Mira, Maxima)

NUT

Nut shape	Ovate
Kernel size	Large (1.5 g)
Crackout %	28%
Shell texture	Soft shell
Kernel appearance	Attractive, skin colour medium to light

ALMOND #21 – Yield history in ACE compatibility screen * ‡

	H2 (513 trees/ha)				H3 (1,111 trees/ha)			
	Yield (t/ha)		Crack-out (%)	Kernel size (g)	Yield (t/ha)		Crack-out (%)	Kernel size (g)
Rootstock (Age)	2020	2021			2020	2021		
Monegro (3)	-	2.72	27	1.03	-	3.05	26	1.18
Felinem (3)	-	2.12	26	1.21	-	4.65	29	1.15
Garnem (3)	-	2.47	26	1.14	-	3.28	22	1.14
Cornerstone (3)	-	1.81	22	1.20	-	3.23	27	1.19
Barrier 1 (3)	-	3.23	29	1.16	-	5.66	30	1.13
Nemaguard (3)	-	0.72	26	1.27	-	2.91	28	1.20
Controller-9.5 (2)	-	0.38	28	-	-	0.21	28	-
Atlas (3)	-	1.99	25	1.27	-	2.92	29	1.25
Rootpac-R (2)	-	0.19	28	-	-	0.14	22	1.29
Krymsk 86 (3)	-	0.99	21	1.30	-	3.99	25	1.20
Controller-7 (3)	-	-	-	-	-	0.14	21	1.43
Rootpac-40 (2)	-	-	-	-	-	0.66	27	1.25
Controller 6 (2)	-	-	-	-	-	-	-	-
Rootpac-20 (2)	-	-	-	-	-	-	-	-

* Yield estimates based on single plots of five trees
‡ Crack-out and kernel size from 2021 data only

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Almond #21' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

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OBSERVATION ON TREE CHARACTERISTICS OF ALMOND #21 ON DIFFERENT ROOTSTOCKS

		Mon	Fel	Gnm	Cstn	Bar	Nem	C9.5	Atlas	RR	K86	C7	R40	C6	R20
Age	Years	3	3	3	3	3	3	2	3	2	3	2	2	2	2
Tree Size (1 = v. small, 6 = very large)	Av. Size	5	4	5	5	5	5	3	4	3	4	3	3	3	2
	Height	5	4	4	4	4	5	4	4	3	4	3	3	3	2
	Width	5	5	5	5	5	5	3	4	4	3	3	4	3	2
Tree Habit	Upright	U	U	U	U	U	U	U	M	M	U	M	M	U	U
	Spread	MS	MS	MS	MS	MS	MS	MS	MS	MS	SS	MS	MS	SS	SS
	Weep							Sl.				Sl.	Sl.		
Branch density	1° Scaffolds	MH	MH	MH	MH	MH	MH	MH	MH	MH	M	M	M	M	MH
	2° Branches	M	M	M	M	M	MH	H	MH	MH	M	H	H	H	MH
	Spurs	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	Av. Overall	MH	MH	MH	MH	MH	H	H	MH	H	M	H	MH	MH	MH
2° Branch Angles		SF	SF	SF	SF	MF	MF	MF	MF	MF	SF	F	MF	MF	SF
Extension Growth	Terminals	M	M	M	M	S	M	L	M	M	M	M	L	L	M
	Spurs	No	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.
	Feathered tips	Sl.	Sl.	Sl.	M	M	M	M	M	Sl.	M	Sl.	Sl.	Sl.	No
	Internodes	Sl.	Sl.	Sl.	N	N	N	Sl.	Sl.	C	Sl.	Sl.	C	Sl.	C
Leaf Size		M	M	M	M	M	M	M	M	M	M	M	M	M	M
Nut bearing	Spurs or twig	S&T	S&T	S&T	S&T	S&T	S&T	Sp	S&T	Sp	Sp	Sp	Sp	Sp	Sp
Pests, Diseases & Disorders	Mites														
	Chlorosis							Sl.		Sl.		Sl.			Sl.
	Necrosis														
	Leaf roll/cupping														Sl.
	Brittle leaves														
	Twig death														
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only presents													
Tree Numbers within ACE Planting		5	7	7	7	7	7	5	7	7	7	7	7	7	7
Combination		G	G	VG	VG	VG	VG	Ok	Ok	G	G	Ok	G	G	G

SUMMARY

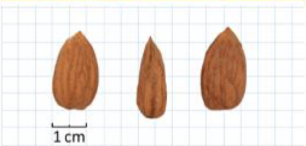
Almond #21 is an upright, moderately spreading scion in general, with good early cropping potential presumably due in part to this more spreading habit. It produces very well on all the full vigor rootstocks but does particularly well under the lower branching and more uprightness conferring Krymsk 86 rootstock. Kernel size has been reported as large (1.55g) from older secondary trials but to date has been a more modest 1.3g at ACE. There is a general positive yield response to moderately increased density and Atlas and Krymsk 86 rootstocks look to have value in future super high density (SHD) plantings at this stage. At ACE the variety seems more suited to Controller 9.5, Rootpac R, Controller 7 or Rootpac 20 than most scions however these are only early results and issues may manifest more strongly over time. Krymsk 86 and Atlas produce attractive compact trees with this scion. Barrier 1 and Krymsk 86 seems the best partner rootstock at this stage.

Vela

(513 & 1,111 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Vela (syn-Almond #10 or A10)** is a protected variety. A signed non-propagation agreement is required before tree delivery. Vela was developed by the University of Adelaide, national Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices.



TREE

Growth habit	Moderately upright, moderately spreading, slightly weeping
Branch density	Moderately high to high
Bloom	Early season (with Nonpareil)
Pollination	Self-fertile (S7Sf). Cross pollination not required
Pollinators	Carmel, Monterey, Carina, Capella, Maxima
Cropping	Precocious, extremely good early yields on all full vigour rootstocks
Harvest timing	Mid-to late season (17 march)

NUT

Nut shape	Cordate
Kernel size	Large (1.8g)
Crack-out %	34-36%
Shell texture	Soft shell
Kernel appearance	Attractive, skin colour medium to light

VELA – Yield history in ACE compatibility screen * ‡

	H2 (513 trees/ha)				H3 (1,111 trees/ha)			
	Yield (t/ha)		Crack-out (%)	Kernel size (g)	Yield (t/ha)		Crack-out (%)	Kernel size (g)
Rootstock (Age)	2020	2021			2020	2021		
Monegro (3)	-	1.86	35	1.41	-	2.90	38	1.40
Felinem (3)	-	2.12	34	1.39	-	4.30	34	1.39
Garnem (3)	-	3.32	36	1.30	-	5.06	34	1.30
Cornerstone (3)	-	2.88	34	1.33	0.02	5.03	34	1.32
Barrier 1 (3)	0.11	3.73	37	1.33	0.13	5.66	33	1.31
Nemaguard (3)	-	1.48	34	1.53	-	4.83	35	1.30
Controller-9.5 (2)	-	0.32	35	1.44	-	0.49	35	1.39
Atlas (3)	-	3.25	38	1.39	-	5.95	37	1.37
Rootpac-R (2)	-	0.20	20	1.31	-	0.56	31	1.34
Krymsk 86 (3)	-	2.41	34	1.43	-	4.03	34	1.37
Controller-7 (3)	-	0.12	28	1.43	-	0.28	34	1.34
Rootpac-40 (2)	-	0.24	27	1.57	-	0.39	29	1.64
Controller 6 (2)	-	-	-	-	-	0.16	23	1.58
Rootpac-20 (2)	-	-	-	-	-	0.08	19	1.33

* Yield estimates based on single plots of five trees
‡ Crack-out and kernel size from 2021 data only

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Vela' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

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OBSERVATION ON TREE CHARACTERISTICS OF VELA ON DIFFERENT ROOTSTOCKS

		Mon	Fel	Gnm	Cstn	Bar	Nem	C9.5	Atlas	RR	K86	C7	R40	C6	R20
Age	Years	3	3	3	3	3	3	2	3	2	3	2	2	2	2
Tree Size (1 = v. small, 6 = very large)	Av. Size	6	5	5	4	4	4	4	4	3	4	3	3	3	3
	Height	6	5	5	5	5	4	4	4	3	4	3	3	3	3
	Width	5	5	5	4	4	4	4	4	4	4	3	4	4	3
Tree Habit	Upright	M	M	M	M	M	M	M	Sl.	M	U	M	M	M	M
	Spread	SS	MS	MS	MS	MS	MS	SS	MS	MS	MS	MS	MS	MS	MS
	Weep	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.
Branch density	1° Scaffolds	MH	MH	MH	H	H	MH	MH	M	MH	M	H	H	MH	H
	2° Branches	H	H	H	MH	MH	MH	H	MH	MH	MH	H	H	MH	MH
	Spurs	H	H	H	MH	MH	MH	H	MH	H	H	H	H	H	MH
	Av. Overall	MH	MH	MH	MH	MH	MH	H	MH	H	MH	H	H	H	MH
2° Branch Angles		SF	SF	SF	SF	MF	SF	SF	MF	SF	SF	MF	MF	MF	MF
Extension Growth	Terminals	M	M	S	M	M	M	L	M	L	S	L	L	L	L
	Spurs	Sl.	N	N	Sl.	N	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.	Sl.
	Feathered tips	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	Internodes	N	N	Sl.	Sl.	Sl.	Sl.	N	N	Sl.	Sl.	M	Sl.	Sl.	C
Leaf Size		M	M	M	M	M	M	M	M	M	M	Sm	M	M	M
Nut Bearing	Spurs or twig	S&T	S&T	S&T	S&T	S&T	S&T	S	S&T	Sp	Sp	Sp	Sp	Sp	Sp
Pests & Disorders	Mites														
	Chlorosis									Sl.		Sl.	Sl.	Sl.	M
	Necrosis														Sl.
	Leaf roll/cupping							Sl.		M		Sl.	Sl.	Sl.	Sev
	Brittle leaves														
	Twig death														
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only presents those													
Tree Numbers within ACE planting		5	7	7	7	7	7	5	7	7	7	7	7	7	7
Combination		Ok	G	G	G	G	G	G	G	Ok	G	Ok	G	G	G

SUMMARY

Vela is a moderate sized tree with moderately upright, moderately spreading and slightly weeping scion in general, with great natural precocity and early cropping potential presumably due in part to this habit. It produces extremely well on all the full vigor stocks but does particularly well under the lower branching and more uprightness conferring Atlas and Krymsk 86 rootstocks. At ACE the variety does not seem suited to Rootpac R or Rootpac 20 due to soil conditions or incompatibility. Over several years of secondary evaluation trials, it has performed from year 3 onwards with early precocity, out yielding Nopareil by 12% over 5 years of yield assessments with 12% less canopy size. While also reported to have a large kernel size of 1.8g in these trials at ACE we have only achieved a more modest 1.4g average across stocks to date. Garnem, Cornerstone, Barrier 1 and Atlas seems the best partner rootstock at this stage.

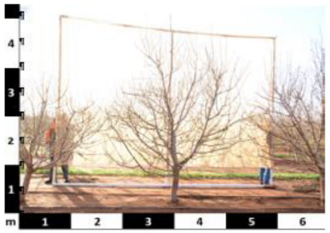
Hort Innovation | australian almonds | The University of Adelaide Australia | Government of South Australia, Department of Primary Industries and Regions | SARDI South Australian Research and Development Institute

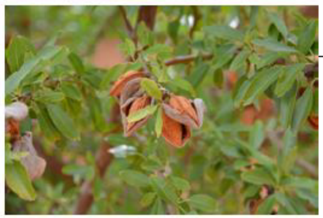
Shasta

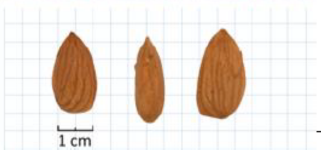
(513 & 1,111 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Shasta** is a new early season self-fertile soft shell international variety from the Burchell Nursery, Californian almond breeding program, being tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Australian licensee, Mossmont Nurseries Australia is the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density in Australia.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices







TREE

Growth habit	Upright, slightly spreading
Branch density	High
Bloom	Early season (-6 Days Nonpareil)
Pollination	Self-fertile.
Pollinators	Peerless, Rhea, Monterey, A12
Cropping	Precocious, good early yields on all full vigour rootstocks
Harvest timing	Early-season. ~3 March (Carina, A18, Mira, Maxima)

NUT

Nut shape	Cordate
Kernel size	Medium-Large (1.4 g)
Crack-out %	28-30 %
Shell texture	Soft shell
Kernel appearance	Attractive, skin colour medium to light

SHASTA – Yield history in ACE compatibility screen * ‡

	H2 (513 trees/ha)				H3 (1,111 trees/ha)			
	Yield (t/ha)		Crack-out (%)	Kernel size (g)	Yield (t/ha)		Crack-out (%)	Kernel size (g)
Rootstock (Age)	2020	2021			2020	2021		
Monegro (3)	-	2.1	28	1.37	0.11	3.6	37	1.33
Felinem (3)	-	2.5	32	1.34	0.05	4.4	39	1.33
Garnem (3)	0.10	2.9	33	1.26	0.29	4.4	32	1.26
Cornerstone (3)	0.12	2.0	29	1.3	0.57	2.1	30	1.25
Barrier 1 (3)	1.00	2.3	27	1.31	1.09	3.5	31	1.24
Nemaguard (3)	0.26	2.5	28	1.36	0.37	2.8	29	1.2
Controller-9.5 (2)	-	0.2	28	-	-	0.2	28	-
Atlas (3)	0.14	1.5	30	1.38	0.42	2.6	32	1.35
Rootpac-R (2)	-	0.2	21	1.33	-	0.2	20	1.49
Krymsk 86 (3)	0.03	0.7	28	1.35	0.05	2.3	27	1.30
Controller-7 (3)	-	0.10	28	-	-	0.0	-	-
Rootpac-40 (2)	-	0.06	28	-	-	0.08	25	1.39
Controller 6 (2)	-	-	-	-	-	0.23	25	1.52
Rootpac-20 (2)	-	-	-	-	-	0.0	-	-

* Yield estimates based on single plots of five trees
‡ Crack-out and kernel size from 2021 data only

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Shasta' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

Further information about this guide is available from Darren Graetz - SARDI | M: +61 401 122 141 | E: darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF SHASTA ON DIFFERENT ROOTSTOCKS

		Mon	Fel	Gnm	Cstn	Bar	Nem	C9.5	Atlas	RR	K86	C7	R40	C6	R20
Age	Years	3	3	3	3	3	3	2	3	2	3	2	2	2	2
Tree Size	Av. Size	6	5	5	5	4	5	4	5	4	5	3	4	4	1
(1 = v. small, 6 = very large)	Height	6	5	5	5	4	5	4	5	4	5	3	4	4	1
	Width	6	5	5	5	6	5	4	6	4	4	3	4	4	1
Tree Habit	Upright	U	U	U	U	U	U	U	U	U	U	U	U	U	U
	Spread	SS	SS	SS	SS	MS	SS	SS	MS	SS	VS	SS	SS	SS	SS
	Weep														
Branch density	1° Scaffolds	H	MH	M	LM	M	M	MH	MH	MH	LM	MH	MH	M	L
	2° Branches	H	MH	M	LM	MH	M	H	H	LM	LM	MH	MH	M	LM
	Spurs	MH	MH	MH	M	H	MH	H	MH	H	H	MH	H	H	H
	Av. Overall	H	H	MH	M	H	MH	H	H	H	LM	MH	H	H	M
2° Branch Angles		SF	MF	SF	SF	MF	SF	SF	MF	MF	SF	SF	SF	MF	MF
Extension Growth	Terminals	M	VL	LM	LM	M	M	H	M	M	L	L	L	L	M
	Spurs	N	N	N	N	Sl.	Sl.	Sl.	Sl.	N	N	Sl.	Sl.	Sl.	Sl.
	Feathered tips	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	Internodes	N	N	N	N	N	N	N	N	N	N	N	Sl.C	N	C
Leaf Size		M	Sm	M	M	M	M	Lg	M	M	M	Sm	Sm	M	Sm
Nut Bearing	Spurs or twig	S&T	S&T	S&T	S&T	S&T	S&T	Sp	S&T	S&T	Sp	Sp	Sp	Sp	Sp
Pests, Diseases & Disorders	Mites							Yes		Yes			Yes	Yes	
	Chlorosis							Sl.		Sl.	Sl.	Sev	Sl.		Sl.
	Necrosis											Sl.			
	Leaf roll/cupping									M		M	M		Sev
	Brittle leaves														
	Twig death														
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only presents those													
Tree Numbers within ACE planting		5	7	7	7	7	7	6	6	7	7	7	7	7	7
Combination		Ok	G	G	Ok	G	G	G	G	Ok	Ok	P	G	G	P

SUMMARY

Shasta, an early upright scion, produced best on the full vigor Spanish stocks of Garnem, Fellinem and Monegro, and also Barrier 1. Yields are greatly improved at the higher H3 density. Interestingly Cornerstone (on which the variety has been mainly released in Australia) and Nemaguard produced similar competitive yields at H2 but a very flat response to the higher density at this early stage. The main full vigor rootstocks seem to produce a relatively compact tree with good cropping in the 3rd leaf and these appear to be good choices for higher densities. Shasta is known to crop heavily in its third leaf to the detriment of 4th leaf crops which looks like it may be occurring at ACE currently, and this situation should be managed for to avoid excessive vigor in the 4th leaf, especially in high density applications. At ACE the variety does not seem suited to Rootpac R, Controller 7, Rootpac 40 or Rootpac 20 due to soil conditions or incompatibility. Garnem seems the best partner rootstock at this stage.

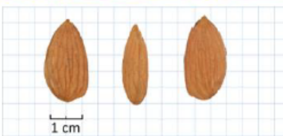
6.5 Trial 6 – Variety x Rootstock Factsheets

Almond #16

(513 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #16' (syn R3BT85, A16)** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #16** was developed by the University of Adelaide, National Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices.



TREE

Growth habit	Moderately upright, moderately spreading (Medium size tree with flatter branch angles)
Branch density	Moderately high
Bloom	Early season (-6 days Nonpareil)
Pollination	Not self-fertile (S8S25). Cross pollination required
Pollinators	Nonpareil, Carina, Vela, Monterey, A12
Cropping	Precocious, high early yields on all trial trees
Harvest timing	Early-season. ~3 March (Carina, Shasta, Nonpareil, Maxima)

NUT

Nut shape	Cordate
Kernel size	Very Large (2.2 g)
Crack-out %	31-38%
Shell texture	Soft shell
Kernel appearance	Attractive, skin colour medium to light

YIELD (2021) at ACE (513 trees/ha)*‡

Variety/Rootstock (Age)	Yield (t/ha)	Crack-out (%)	Kernel size(g)
A16/Nemaguard (3)	3.17	38	1.5
A16/Garnem (3)	2.59	38	1.4
NP/Nemaguard (3)	1.28	26.5	1.4
NP/Garnem(3)	2.09	30	1.2

* Yield estimates based on single plots of five trees
‡ Other rootstocks under investigation with this variety include Rootpac-40 and Controller-7 (no data)

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Almond #16' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

Further information about this guide is available from Darren Graetz - SARDI | **M:** +61 401 122 141 | **E:** darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF ALMOND #16 ON DIFFERENT ROOTSTOCKS

		Controller 7	Rootpac 40	Nemaguard	Garnem
Age	Years	2	2	3	3
Tree Size (1 = v. small, 6 = very large	Av. Size	3	2	5	5
	Height	3	2	5	5
	Width	3	2	5	5
Tree Habit	Upright	M	M	M	M
	Spread	Sl.	M	M	M
	Weep				
Branch density	1° Scaffolds	M	M	MH	MH
	2° Branches	MH	MH	MH	MH
	Spurs	MH	MH	MH	MH
	Av. Overall	MH	MH	MH	MH
2° Branch Angles		SF	MF	MF	SF
Extension	Terminals	L	L	M	M
	Spurs	Sl.	Sl.	Sl.	Sl.
	Feathered tips	Sl.	N	Sl.	Sl.
	Internodes	Sl.	C	N	N
Leaf Size		M	M	M	M
Nut Bearing	Spurs or twig			S&T	S&T
2021 Full Bloom		16-Aug	9-Aug	10-Aug	10-Aug
Pests, Diseases & Disorders	Mites				
	Chlorosis	Sev.			
	Necrosis	Sl.			
	Leaf roll/cupping	Sl.	M		
	Brittle leaves				
	Twig death				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only			
Tree Number within ACE planting		5	5	5	5
Combination		Poor	Poor	Good	Good

SUMMARY

Almond #16 is moderately upright, moderately spreading scion and has cropped extremely well in its 3rd leaf, being one of few scions to crop more on Nemaguard (3.17t/ha) than Garnem (2.59t/ha). It appears to produce a very nice medium sized tree with flat laterals, nut characters need further review as although they are large and thick, they can be poorly sealed and with some gumming, making them harder to remove and resulting in mummies. Kernel size has been rereported as very large (2.2g) but our best results have in the 1.4-1.5g range. Interestingly A16 has a significantly larger mean trunk diameter than most scions despite not being a noticeably larger tree and producing high early yields. On Nemaguard and Garnem mean trunk diameters were 142mm and 138mm respectively. What effect this may have longer term with respect to cropping limits and sustainability are yet to be determined.

Almond #18

(513 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #18 (syn R8BT58 or A18)** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #18** was developed by the University of Adelaide, National Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices.

TREE

Growth habit	Moderately upright, moderately spreading (Smaller tree, well spurred lateral growth)
Branch density	Moderately high
Bloom	Early season (with Nonpareil)
Pollination	Not self-fertile (S1S8). Cross pollination required
Pollinators	Nonpareil, Carina, Vela, Mira
Cropping	Precocious, high early yields on all trial trees
Harvest timing	Early -season. ~3 March (Carina, A18, Mira, Maxima)

NUT

Nut shape	Ovate
Kernel size	Very Large (2.3 g)
Crack-out %	32-33
Shell texture	Paper shell
Kernel appearance	Attractive, skin colour medium

YIELD (2021) at ACE (513 trees/ha)*‡

Variety/Rootstock (Age)	Yield (t/ha)	Crack-out (%)	Kernel size(g)
A18/Garnem (3)	3.11	33	1.8
A18/Nemaguard (3)	2.85	32	1.8
NP/Ganem(3)	2.09	30	1.2
NP/Nemaguard (3)	1.28	26.5	1.43

* Yield estimates based on single plots of five trees
‡ Other rootstocks under investigation with this variety include Rootpac-40 and Controller-7 (no data)

Further information about this guide is available from Darren Graetz - SARDI | **M:** +61 401 122 141 | **E:** darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF ALMOND #18 ON DIFFERENT ROOTSTOCKS

		Controller 7	Rootpac 40	Nemaguard	Garnem
Age	**Years**	2	2	3	3
Tree Size (1 = v. small, 6 = very large)	**Av. Size**	2	3	5	5
	Height	2	3	5	5
	Width	2	3	5	5
Tree Habit	**Upright**	M	M	M	M
	Spread	M	M	M	M
	Weep				
Branch density	**1° Scaffolds**	M	M	MH	MH
	2° Branches	H	MH	MH	H
	Spurs	MH	MH	MH	MH
	Av. Overall	M	MH	MH	MH
2° Branch Angles		F	F	F	F
Extension Growth	**Terminals**	M	M	M	M
	Spurs	Sl.	Sl.	Sl.	Sl.
	Feathered tips	Sl.	Sl.	Mod	N
	Internodes	Sl.	Sl.	N	N
Leaf Size		M	M	M	M
Nuts	**Spurs or twig**		Sp	Sp	Sp
2021 Full Bloom		15-Aug	15-Aug	16-Aug	16-Aug
Pests, Diseases & Disorders	**Mites**				
	Chlorosis	Sev.			
	Necrosis	Sl.			
	Leaf roll/cupping	Sl.			
	Brittle leaves				
	Twig death				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only			
Tree Numbers within ACE planting		5	5	5	5
Combination		Poor	Ok	Good	Good

SUMMARY

Almond #18 is a moderately upright, moderately spreading scion and has cropped extremely well in its 3rd leaf at 2.85t/ha on Nemaguard and 3.11t/ha on Garnem, as it did in secondary evaluation trials. It produces a smaller, not overly upright tree with lots of well spurred lateral growth, a very good structure and overall mix of vegetative and fruiting characters. Having Maxima parentage, this self-infertile variety (S1S8) clearly has great yield potential. As yet we are still to see the kernel sizes of 2.3g reported from older plantings but are well on the way with 1.8 g from very young trees. Almond #18 has a slight mid leaf wrinkle as a distinctive feature and was noted as having an excellent 4th leaf flowering giving confidence in good yields continuing.

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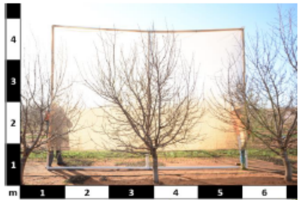
Almond #28

(513 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #28 (syn R24AT90 or A28)** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #28** was developed by the University of Adelaide, National Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices



TREE

Growth habit	Moderately upright, moderately spreading
Branch density	Medium heavy
Bloom	Early season (with Nonpareil)
Pollination	Not self-fertile (S1S8). Cross pollination required
Pollinators	Nonpareil, Carina, Vela, Mira
Cropping	Precocious, high early yields on all trial trees
Harvest timing	Mid-season. ~3 March (Carina, A18, Mira, Maxima)

NUT

Nut shape	Cordate
Kernel size	Large (1.5 g)
Crack-out %	22-25 %
Shell texture	Semi-hard
Kernel appearance	Attractive, skin colour medium to light Flatter than A18

YIELD (2021) at ACE (513 trees/ha)*‡

Variety/Rootstock (Age)	Yield (t/ha)	Crack-out (%)	Kernel size(g)
A28/Garnem (3)	3.52	25.2	1.44
NP/Garnem (3)	2.03	27.4	1.19
A28/Nemaguard (2)	0.16	21.8	1.55
A28/Nemaguard (3)	2.61	23.5	1.49
NP/Nemaguard (3)	1.28	26.5	1.43

* Yield estimates based on single plots of five trees
‡ Other rootstocks under investigation with this variety include Rootpac-40 and Controller-7 (no data)

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Almond-12' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

Further information about this guide is available from Darren Graetz - SARDI | **M:** +61 401 122 141 | **E:** darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF ALMOND #28 ON DIFFERENT ROOTSTOCKS

		Controller 7	Rootpac 40	Nemaguard	Garnem
Age	**Years**	2	2	3	3
Tree Size (1 = v. small, 6 = very large)	**Av. Size**	2	3	5	5
	Height	2	3	5	5
	Width	2	3	5	5
Tree Habit	**Upright**	M	M	M	M
	Spread	M	M	M	M
	Weep				
Branch density	**1° Scaffolds**	MH	MH	MH	MH
	2° Branches	MH	M	MH	H
	Spurs	H	H	H	H
	Av. Overall	H	MH	MH	MH
2° Branch Angles		MF	MF	SF	MF
Extension Growth	**Terminals**	L	L	L	L
	Spurs	Sl.	Sl.	Sl.	Sl.
	Feathered tips	Sl.	Sl.	Mod	Sl.
	Internodes	Sl.	C	N	N
Leaf Size		Sm	Lg	M	M
Nut Bearing	**Spurs or twig**		Sp	S&T	S&T
2021 Full Bloom		18-Aug	13-Aug	10-Aug	10-Aug
Pests, Diseases & Disorders	**Mites**				
	Chlorosis	Sev.			
	Necrosis	M			
	Leaf roll/cupping	Sl.	Sl.		
	Brittle leaves				
	Twig death				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only			
Tree Numbers within ACE planting		5	5	5	5
Combination		Poor	Ok	VG	VG

SUMMARY

Almond #28 is a vigorous, moderately upright, moderately spreading, heavy spurring tree, bearing on twigs and spurs. At the 3rd leaf stage, Garnem trees yielded 3.52t/ha and appeared to be slightly more compact, filled and spurred, with lighter calliper branching than Nemaguard which yielded 2.61t/ha. This could be a result of heavy 3rd leaf cropping. As heavily cropped 3rd leaf trees Garnem trees had a harvest timing slightly in front of lower vigour Nemaguard. These results support those obtained by the University of Adelaide secondary evaluation trials on Nemaguard in 2016, 1085kg/ha (highest yield that year), 2017 1345kg/ha indicating these high yields are reproducible in different areas. A28 demonstrates some of best the productivity of all scions being investigated at this early stage.

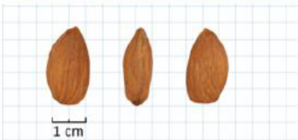
Trees on both Nemaguard and Garnem appear well set up and ordered with an increased branch density reflective of their early precociousness. Secondary branch angles were generally moderately flat and heavily spurred, showing repeat budding on harvested nut sites, with many new buds evident for the next crop. Garnem appears to be the best rootstock paring investigated for A28 to date.

Almond #52

(513 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #52 (syn R43T138 or A52)** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #52'** was developed by the University of Adelaide, national Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices



TREE

Growth habit	Upright, slightly spreading
Branch density	Medium heavy
Bloom	Early season (-2 days Nonpareil)
Pollination	Not self-fertile (S1S8). Cross pollination required
Pollinators	Nonpareil, Carina, Vela, Mira
Cropping	Very precocious, good early yields on all trial trees.
Harvest timing	Mid-season. 23 March

NUT

Nut shape	Cordate
Kernel size	Large (1.9 g)
Crack-out %	25-30%
Shell texture	hard
Kernel appearance	Attractive, skin colour medium

YIELD (2021) at ACE (513 trees/ha)*‡

Variety/Rootstock (Age)	Yield (t/ha)	Crack-out (%)	Kernel size(g)
A52/Garnem (2)	0.57	25	-
A52/Garnem (3)	2.73	34	1.3
A52/Nemagaurd (2)	0.16	21	-
A52/Nemagaurd (3)	2.19	30	1.3
NP/Garnem (3)	2.09	30	1.2
NP/Nemaguard (3)	1.28	26.5	1.4

* Yield estimates based on single plots of five trees
‡ Other rootstocks under investigation with this variety include Rootpac-40 and Controller-7 (no data)

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Almond #52' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

Further information about this guide is available from Darren Graetz - SARDI | **M:** +61 401 122 141 | **E:** darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF A52 ON DIFFERENT ROOTSTOCKS

		Controller 7	Rootpac 40	Nemaguard	Garnem
Age	**Years**	2	2	3	3
Tree Size (1 = v. small, 6 = very large)	**Av. Size**	2	3	5	6
	Height	2	3	5	6
	Width	2	3	5	5
Tree Habit	**Upright**	U	M	U	U
	Spread	Sl.	Sl.	Sl.	Sl.
	Weep				
Branch density	**1° Scaffolds**	M	M	MH	MH
	2° Branches	MH	MH	MH	MH
	Spurs	MH	MH	MH	MH
	Av. Overall	M	M	MH	MH
2° Branch Angles		SF	MF	F	U
Extension Growth	**Terminals**	L	L	L	L
	Spurs	Sl.	Sl.	Sl.	Sl.
	Feathered tips	Sl.	Sl.	M	Sl.
	Internodes	Sl.	C	Sl.	N
Leaf Size		M	M	Lg	Lg
Nut Bearing	**Spurs or twig**		Sp	S&T	S&T
2021 Full Bloom		25-Aug	23-Aug	15-Aug	15-Aug
Pests, Diseases & Disorders	**Mites**				
	Chlorosis	Sev.			
	Necrosis	Sl.			
	Leaf roll/cupping				
	Brittle leaves				
	Twig death				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only presents those relevant at the time of publishing			
Tree Numbers		5	3	5	5
Combination		Poor	Ok	VG	Good

SUMMARY

Almond #52 trees are upright, slightly spreading, neat and ordered have performed nearly identically in cropping to date compared to A53 despite their divergent architectures. A53 appears very precocious having unusually high 2nd leaf crops of 0.57 t/ha on and then backing up in their third leaf with crops of 2.2 t/ha on Nemagard and 2.8t/ha on Garnem. A52 showed some signs of crop stress having notably reduced leaf size internally. To date the large kernel size of 1.9g from older secondary evaluation trials has yet to be seen with sizes on young trees of 1.3g

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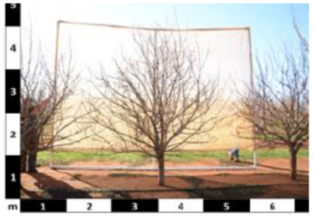
Almond #A53

(513 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #53 (syn R43T118 or A53)** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #53'** was developed by the University of Adelaide, National Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices.



TREE

Growth habit	Moderately upright, moderately spreading
Branch density	Moderately high
Bloom	Early season (+3 days Nonpareil)
Pollination	Not self-fertile (S1S8). Cross pollination required
Pollinators	Nonpareil, Carina, Maxima, Mira
Cropping	Very precocious, high early yields on all trial trees
Harvest timing	Early-season. ~3 March

NUT

Nut shape	Cordate
Kernel size	Medium (1.4 g)
Crack-out %	31%
Shell texture	Paper shell
Kernel appearance	Attractive, skin colour medium

YIELD (2021) at ACE (513 trees/ha)*‡

Variety/Rootstock (Age)	Yield (t/ha)	Crack-out (%)	Kernel size(g)
A53/Garnem (2)	0.61	27	-
A53/Garnem (3)	2.80	29	1.5
A53/Nemaguard (2)	0.79	25	-
A53/Nemaguard (3)	2.22	29	1.5
NP/Garnem (3)	2.09	30	1.2
NP/Nemaguard (3)	1.28	26.5	1.43

* Yield estimates based on single plots of five trees
‡ Other rootstocks under investigation with this variety include Rootpac-40 and Controller-7 (no data)

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Almond #53' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

Further information about this guide is available from Darren Graetz - SARDI | **M:** +61 401 122 141 | **E:** darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF A53 ON DIFFERENT ROOTSTOCKS

		Controller 7	Rootpac 40	Nemaguard	Garnem
Age	**Years**	2	2	3	3
Tree Size (1 = v. small, 6 = very large)	**Av. Size**	3	3	5	6
	Height	3	3	5	6
	Width	3	3	6	6
Tree Habit	**Upright**	M	M	M	M
	Spread	M	M	M	M
	Weep				
Branch density	**1° Scaffolds**	M	MH	MH	MH
	2° Branches	MH	MH	MH	MH
	Spurs	H	H	H	H
	Av. Overall	MH	H	H	H
2° Branch Angles		SF	MF	MF	SF
Extension Growth	**Terminals**	L	M	Sl.	Sl.
	Spurs	Sl.	Sl.	Sl.	Sl.
	Feathered tips	N	N	N	N
	Internodes	Sl.	C	Sl.	Sl.
Leaf Size		M	Lg	M	M
Nut Bearing	**Spurs or twig**			S&T	S&T
2021 Full Bloom		25-Aug	22-Aug	21-Aug	21-Aug
Pests, Diseases & Disorders	**Mites**				
	Chlorosis	Sev.			
	Necrosis				
	Leaf roll/cupping		M		
	Brittle leaves				
	Twig death				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35 different pest, disease and incompatibility disorders. This sheet only presents those relevant at the time of publishing			
Tree Numbers within ACE plantings		5	4	5	4
Combination		Poor	Poor	Good	Good

SUMMARY

Almond #53 (moderately upright, moderately spreading) has performed nearly identically in cropping to date to A52 despite their divergent architectures. Both having unusually high 2nd leaf crops. A53 recorded 0.79 t/ha and 0.61t/ha on Nemaguard and Garnem respectively. Then backing up in their 3rd leaf with crops of 2.2 t/ha on Nemagard and 2.8t/ha on Garnem. Kernel size has been good at 1.5g compared to older secondary evaluation trials at 1.4g. Trees look to be slightly smaller with mid-range branch angles, balanced branching and good spurring, producing a well-structured tree. Garnem seems to be the best rootstock paring for this variety.

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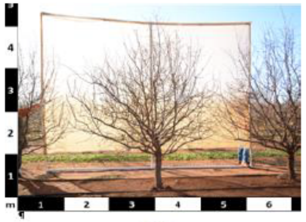
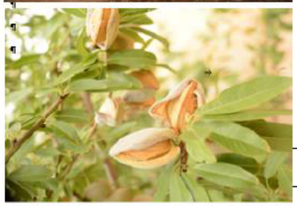
Maxima

(513 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Maxima** is a protected variety. A signed non-propagation agreement is required before tree delivery. **Maxima** was developed by the University of Adelaide, National Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices





TREE

Growth habit	Moderately upright, moderately spreading
Branch density	Moderately High
Bloom	Mid-season (+4 days Nonpareil)
Pollination	Not self-fertile (S3S8). Cross pollination required
Pollinators	Nonpareil, Carmel, Monterey, Mira, Wood Colony, Capella
Cropping	Precocious, high early yields on all trial trees
Harvest timing	Early-mid season. ~3 March

NUT

Nut shape	Cordate
Kernel size	Very Large (2.1 g)
Crack-out %	25-28%
Shell texture	Semihard
Kernel appearance	Attractive, skin colour light bright

YIELD (2021) at ACE (513 trees/ha)*‡

Variety/Rootstock (Age)	Yield (t/ha)	Crack-out (%)	Kernel size(g)
Maxima/Garnem (3)	3.31	28	1.4
Maxima/Nemaguard (3)	2.93	25	1.5
NP/Garnem (3)	2.09	30	1.2
NP/Nemaguard (3)	1.28	26.5	1.4

* Yield estimates based on single plots of five trees
‡ Other rootstocks under investigation with this variety include Rootpac-40 and Controller-7 (no data)

Further information about this guide is available from Darren Graetz - SARDI | **M:** +61 401 122 141 | **E:** darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF MAXIMA ON DIFFERENT ROOTSTOCKS

		Controller 7	Rootpac 40	Nemaguard	Garnem
Age	**Years**	2	2	3	3
Tree Size (1 = v. small, 6 = very large)	**Av. Size**	2	3	5	5
	Height	2	3	5	5
	Width	2	3	5	5
Tree Habit	**Upright**	M	M	M	M
	Spread	Sl.	M	M	M
	Weep				
Branch density	**1° Scaffolds**	M	M	MH	MH
	2° Branches	MH	MH	MH	MH
	Spurs	H	H	H	H
	Av. Overall	M	MH	MH	MH
2° Branch Angles		SF	MF	MF	MF
Extension Growth	**Terminals**	M	M	S	S
	Spurs	Sl.	Sl.	Sl.	Sl.
	Feathered tips	M	M	M	M
	Internodes	C	C	Sl.	Sl.
Leaf Size		Sm	Sm	Sm	Sm
Nut Bearing	**Spurs or twig**		Sp	S&T	S&T
2021 Full Bloom		21-Aug	21-Aug	20-Aug	20-Aug
Pests, Diseases & Disorders	**Mites**				
	Chlorosis	Sev.			
	Necrosis	Sl.			
	Leaf roll/cupping	Sl.	Sl.		
	Brittle leaves				
	Twig death				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35			
Tree Numbers within ACE plantings		5	5	5	5
Combination		Poor	Ok	Good	Good

SUMMARY

Maxima produced excellent 3rd leaf yields of 2.93 and 3.31 t/ha on Nemaguard and Garnem respectivey at the H2 density but negligible 2nd leaf crop. Kernel size was down at 1.4-1.5g compared to the 2g reported in older trees in secondary evaluation trials. Maxima is a moderately upright, moderately spreading tree, that looks ordered and well balanced. Heavily cropped trees on Garnem (80%) appeared more advanced than similar Nemaguard (50%) trees at hull split in 2021. Garnem also showed some signs of crop stress with smaller leaves internally. A precocious, highly spur bearing tree with very high cropping capacity and little to no alternate bearing on Nemaguard. In secondary evaluation trials it has out yielded Nonpareil by over 20%, over eight years of yield assessment. Early results at ACE suggest Garnem may be an even more productive rootstock pairing.

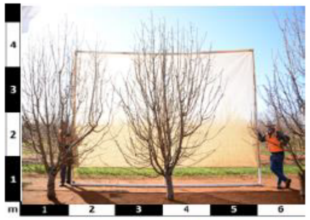
Good ventilation and cover sprays may be necessary for bacterial spot control.

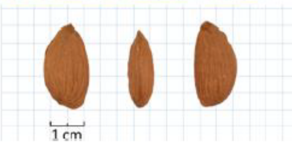
Almond #R38T208

(513 trees/ha, multiple rootstocks)

The purpose of this Grower Information Guide is to provide information to help growers make an informed decision on the planting of this almond variety on an appropriate rootstock and density. **Almond #R38T208** is a protected variety. A signed non-propagation agreement is required before tree delivery. Trees may be available for trial planting by arrangement with the breeder. **Almond #R38T208** was developed by the University of Adelaide, National Almond Breeding Program and then tested on a range of rootstocks by SARDI at the Almond Centre of Excellence (ACE), Loxton, South Australia. The Breeder (UofA) remains the primary point of contact for variety information and tree availability, this guide is intended to extend knowledge about growing system performance data relating to rootstock and density.

The data presented in this guide reflect the performance of trees grown at ACE planted in 2018 or 2019 on the rootstock indicated. Performance on other rootstocks is untested. Soils at ACE are shallow sand over limestone. Trees were minimally pruned and were managed as per standard industry practices





TREE

Growth habit	Upright, slightly spreading (Vigorous, large trunk and dense scaffold)
Branch density	Moderately High
Bloom	Early season (-4 days Nonpareil)
Pollination	Unknown
Pollinators	Shasta, Carina, Vela, Monterey, A12 (by timing only)
Cropping	Precocious, good early yields on all trial trees
Harvest timing	Mid-season. ~26 March

NUT

Nut shape	Cordate
Kernel size	Medium (1.2 g)
Crack-out %	33%
Shell texture	Soft shell
Kernel appearance	Long thin golden coloured

YIELD (2021) at ACE (513 trees/ha)*‡

Variety/Rootstock (Age)	Yield (t/ha)	Crack-out (%)	Kernel size(g)
R38T208/Rootpac40 (2)	0.19	33	1.2
R38T208/Nemaguard (3)	2.68	33	1.1
R38T208/Garnem (3)	2.68	33	1.2
NP/Garnem (3)	2.09	30	1.2
NP/Nemaguard (3)	1.28	26.5	1.4

* Yield estimates based on single plots of five trees
‡ Other rootstocks under investigation with this variety include Controller-7 (no data)

Disclaimer
This variety is unproven in commercial production. Testing has not been completed over a range of regions, rootstocks and management conditions. Growers wishing to plant 'Almond #R38T208' should exercise appropriate caution.
This variety may be supplied with no guarantee of any kind and the purchasers accept all risks in connection with their possession or use of the variety. The variety may be supplied without warranty, express or implied, of fitness for any particular purpose.

Further information about this guide is available from Darren Graetz - SARDI | **M:** +61 401 122 141 | **E:** darren.graetz@sa.gov.au

OBSERVATION ON TREE CHARACTERISTICS OF Almond #R38T208 ON DIFFERENT ROOTSTOCKS

		Controller 7	Rootpac 40	Nemaguard	Garnem
Age	**Years**	2	2	3	3
Tree Size (1 = v. small, 6 = very large)	**Av. Size**	2	3	4	5
	Height	2	3	4	5
	Width	2	3	4	5
Tree Habit	**Upright**	U	U	U	U
	Spread	Sl.	M	M	M
	Weep				
Branch density	**1° Scaffolds**	M	M	M	MH
	2° Branches	H	MH	MH	MH
	Spurs	H	H	MH	MH
	Av. Overall	H	MH	MH	MH
2° Branch Angles		SF	MF	MF	MF
Extension Growth	**Terminals**	M	M	M	M
	Spurs	Sl.	Sl.	Sl.	Sl.
	Feathered tips	M	Sl.	Sl.	M
	Internodes	C	C	Sl.	Sl.
Leaf Size		Sm	Sm	Sm	Sm
Nut bearing	**Spurs or twig**		Sp	S&T	S&T
2021 Full Bloom		23-Aug	19-Aug	14-Aug	13-Aug
Pests, Diseases & Disorders	**Mites**				
	Chlorosis	Sev.			
	Necrosis	M			
	Leaf roll/cupping	Sl.	Sl.		
	Brittle leaves				
	Twig death				
	Other disorders	All variety/rootstock combinations are surveyed annually for more than 35			
Tree Numbers within ACE plantings		5	5	5	5
Combination		Poor	Good	Good	Good

SUMMARY

Almond #R38T208 is a very unusual scion, being very upright and slightly spreading. The tree appears very vigorous and upright with a large trunk, dense scaffold and dense spurring. It tends to have very large leaves, which on R40 point very atypically upwards in rosettes.On Garnem and Nemaguard they are somewhat flatter and more normal but there is still a hint of difference about its appearance. Nut size was small,(1.2g) but yields were good 2.68t/ha on Nemaguard and 2.76t/ha on Garnem. As R38T208 trees go into their 3rd leaf they have very strong upright "fish pole" growth habit along which masses of flower buds are clumped in clusters. It will be very interesting to see what develops from this structure. This scion produces a soft-shell nut with a long thin golden kernel and has Spanish genetics in its background and does not appear rust sensitive. This scion also displays by far the largest mean trunk diameter of 155mm for Nemaguard and 152mm for Garnem which given its good early cropping and consistency across the two rootstocks would appear to be largely genetically determined. What effect this may have longer term with respect to cropping limits and sustainability are yet to be determined.

6.6 Conclusions

- Continued monitoring of these compatibility screens (particularly if output is integrated with other rootstock trials) would provide important learnings around the longevity of production, genotype compatibility and resource use efficiency beyond the orchard's juvenile phase
- Controller 7 is unsuitable for the shallow calcareous soils at the ACE experimental orchard. Trees grafted to this rootstock rapidly developed severe iron chlorosis that could not be adequately managed. Its use should be discontinued, and the suite of varieties grafted to this stock replaced with either Rootpac 20, Controller 6 or the less dwarfing D63.182 (a Cadaman x Cornerstone cross from Burchell Nursery, California, USA).
- Almond #36 (R33A T75) should be added to Trial 6 in place of a poor performing scion. This variety has worked its way up secondary evaluation performance lists and is currently close to being the best performer in the University of Adelaide's breeding program (M Wirthensohn 2021, pers comm).
- Continue to track the performance of full vigour rootstocks in the Super High Density (H3) plantings in light of the very high early cropping with some of the scions investigated and the clear advantages they may offer for shallow soils. This path may present the need/opportunity to investigate the use of plant growth regulators (PGR's) to decrease extension growth and increase lateral precocity or spurring. PGR's should be trialled in order to determine if a productive but spreading variety/selection can be managed to allow it's adaptation into higher densities in a more columnar form.

SECTION 7. Optimised planting density; Low (Horizon 1) to Medium (Horizon 2)

Key points

- SARDI's Low to Medium Density Optimisation Trial contains four varieties, including three new potential Nonpareil replacement varieties. Trees were planted in 6.5 m rows, with between tree spacings ranging from 5.0 down to 2.5 m, giving six tree density treatments ranging from 308 to 615 trees/ha. All treatments were replicated six times.
- The trial was planted in 2018 with growth metrics monitored over the life of the planting, and yield was measured in 2020 and 2021. Other measurements collected from the trial include soil water content (from six plots), soil solution constituents (from two plots), Leaf Area Index (LAI) and light interception (across all plots), and tree shape and architecture.
- Early results suggest that both variety and planting density significant impact on almost all parameters, including tree size and yield. In general, high-density plots produced smaller trees carrying fewer nuts, but that these densities translated to greater per hectare yields than the low-density plots.
- The per hectare yield response for Nonpareil and Vela represented the lowest and highest yields recorded in 2021, the first commercial harvest of this third leaf trial.
- On average, Vela out-yielded Nonpareil by 0.7 tonnes per hectare. Yields increased with density, particularly for Nonpareil whose individual tree yield was less constrained by competition at the higher density. Nonpareil produced less than 1.5 tonnes kernel/ha at 308 trees/ha but more than 2.3 tonnes kernel/ha for trees planted at 615 trees/ha. Vela yielded 2.3 to 2.6 tonnes kernel/ha for the same density range. Average crack-out exceeded 28% for Nonpareil and 30% for Vela with the largest kernels tending to be associated with the lower yields on the low-density treatments.

7.1 Background and aims

While the vast majority of almond plantings to date in Australia are at a traditional low density spacing (Horizon 1), there have been minor commercial plantings of medium density (Horizon 2) plantings, as defined by the Almond Strategic Investment Plan 2017-21 (HortInnovation, 2017) . These H2 plantings may be an easier step for many towards higher density plantings, as familiar genetic material, basic operating practices and machinery of H1 plantings can still be used. However, the optimum planting density, and how this influences yield and sustainability, remains unknown. This fully replicated trial addresses these questions in an ordered 6 step density progression from 308 to 615 trees/ha.

The trial also assesses the response of Nonpareil, two of the more promising varieties developed by the University of Adelaide breeding program, viz; Carina and Vela, and Shasta, a recently released Californian variety. All trees are grafted to the newly available full vigour Garnem rootstock.

The greatest benefit of this trial is the accessibility of results for growers looking to optimise new orchards using existing plant and equipment. It's arguable that optimising in the H1 to H2 (low to medium) density range would be a less challenging step for current commercial systems than optimising in the more ambitious H3 (high) density range, particularly as the practicalities and challenges associated with establishing and maintaining H3 (high) density plantings are still being characterised.

While this early dataset is an encouraging step towards informing realistic production efficiency improvements, SARDI recommends persisting with these investigations beyond the third leaf. A further three to five years of yield and resource use assessments would give confidence that the reported trends are real and would arm almond growers with the knowledge required to optimise traditional planting systems and capitalise on the almond industry's investment in establishing and measuring the trial.

7.2 Orchard establishment and methods

This large-scale (5 ha) planting was established in July 2018 using four varieties (Nonpareil, Carina, Vela and Shasta) all grafted to Garnem rootstock.

Row spacings were fixed at 6.5 m. Within each row, tree planting distances decreased from 5 to 2.5 m at 0.5 m increments to produce six density treatments ranging from 308 to 615 trees/ha,

Table 7-1. Treatments were replicated six times with the 36 experimental plots laid out in a Latin Square design. Each experimental plot comprised six rows, four measurement varieties bordered by two buffer rows, and ranged in length from 31 to 35 m. Depending on planting density, five to eleven buffered measurement trees were available for data collection from each of the four varieties.

Table 7-1. Summary of Low (H1) – Medium (H2) Optimised Density Trial planting

Rootstock	Scions	# Trees	Valves	Rows	Spacings	Density (trees/ha)	Area
Garnem	Carina	540 Cr	23 – 25	217 – 252	6.5 x 5.0 m	308	5.02 Ha
	Nonpareil	540 NP			6.5 x 4.5 m	342	36 rows
	Vela	540 Ve			6.5 x 4.0 m	385	
	Shasta	540 Sh			6.5 x 3.5 m	440	
		2160 Total			6.5 x 3.0 m	513	
					6.5 x 2.5 m	615	

The irrigation system was designed with a consistent application rate of 1.42 mm/h, regardless of tree spacing. It should be noted that in very young trees, and in mature orchards, this situation assists in meeting the water requirements of trees at all spacings. However, because young trees begin to fill their allocated space, both above and below ground, at different times due to different tree spacing, the water requirements of different spacings will vary during this period. During the orchard's establishment phase, irrigation management aimed to provide adequate irrigation for all tree spacing treatments.

Soil moisture monitoring was installed in three tree spacing treatments (2.5, 3.5 & 5 m), across two varieties (NP and Shasta), giving a total of six sensors. The installations are EnviroPro® sensors, reading at 10 cm intervals to a depth of 120 cm. These sensors are attached to the GreenBrain® Plexus® network to monitor soil water content every half an hour.

SWAN Systems® software was used to record irrigation and nutrition applications across the Almond Centre of Excellence. This system incorporated data from the GreenBrain® system, as well as drawing irrigation event data from the GoldTec® controller, and other data was entered manually (for example fertiliser applications). Table 7-2 displays nutrient applications to the trial area, using data extracted from the SWAN Systems website.

Irrigation and nutrition management was assisted by the use of Phytech® dendrometers mounted on the trunks of multiple trees across the block. Each monitoring station consisted of three adjacent trees, with one station installed on Nonpareil trees in each of the three valve units making up Trial 3 (Valves 23, 24 & 25).

Table 7-2. Nutrient application to Low (H1) – Medium (H2) Optimised Density Trial

Nutrient	NO_3-N	Other N	Total N	P	K	Ca	Mg	S
Applied (kg/ha)	66.02	75.30	141.32	41.362	172.13	17.28	2.20	37.47

Two sets of soil solution samplers were installed in Nonpareil tree rows. The samplers were installed next to trees in the 2.5 and 5 m tree spacing treatments, at depths of 30, 60 and 90 cm below the surface, adjacent to the dripline at each site. Soil solution samples were collected approximately once per week across the growing season, and more often during fertigation campaigns. Successful sample collection was determined by soil water content, and while some samplers did not produce samples very often, others produced samples almost every time. Samples were assessed for EC, pH, NO_2, NO_3 and K.

Tree size was measured manually in 2019. Subsequently other remote sensing methods were used to collect data on tree size and canopy development.

SARDI's Mobile Orchard Phenotyping Platform (MOPP) was used to assess canopy growth through the season's by measuring trunk diameter, tree height and light interception. A range of data were collected from all experimental (and buffer) trees on 11 occasions between August 2020 and July 2021. Across these 11 collection dates there were 8 sets of light interception data, 7 sets of tree height and 2 sets of trunk diameter measurements.

Leaf Area Index was measured using the Li-Cor® LAI 2200C. Measurements were taken on 11 occasions between December 2019 and July 2021 to coincide with the MOPP measurements.

Yield was measured in 2020 and 2021. In 2020 harvest was carried out by hand picking all the nuts from selected treatment trees. In 2021 harvest was accomplished using commercial scale harvest, sweeping and pickup machines.

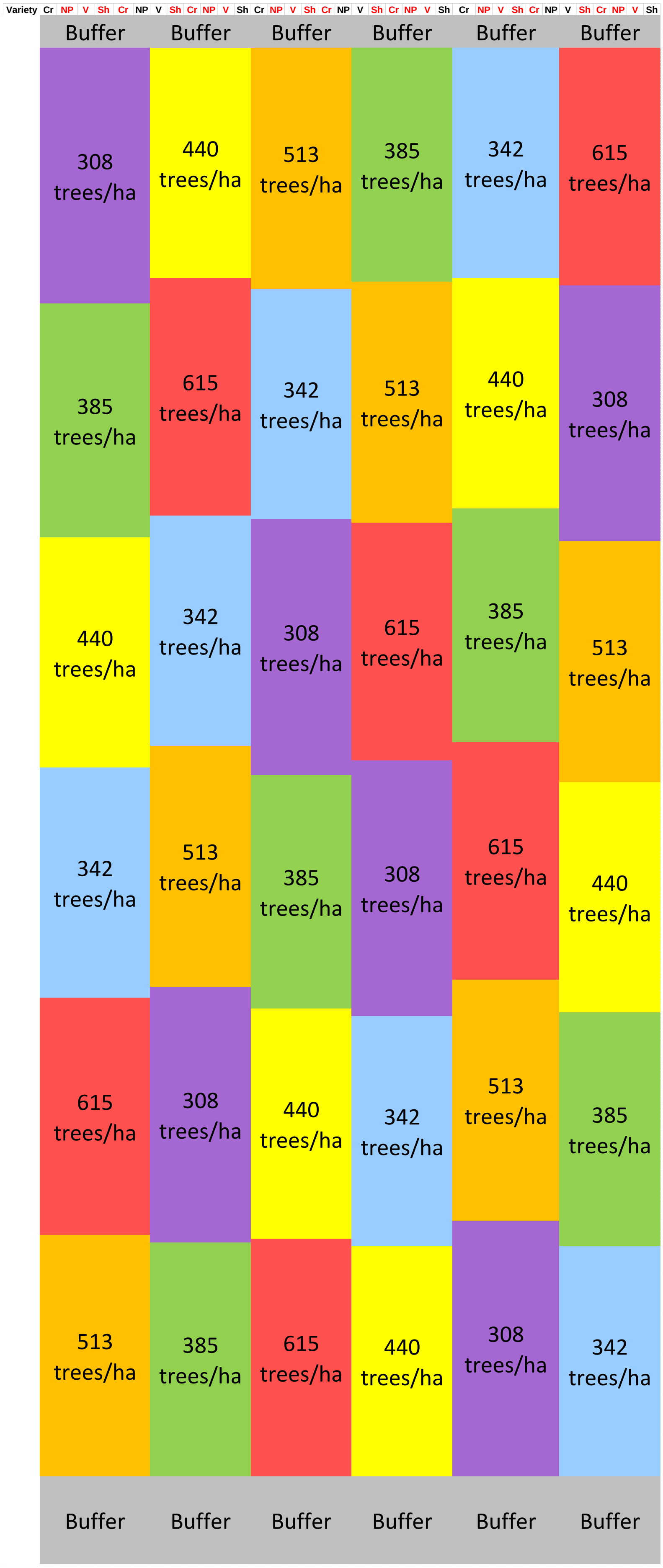


Figure 7-1. Treatment map of Low (H1) – Medium (H2) Optimised Density Trial, showing tree density treatments

Individual variety x density yields were measured using a trailer mounted weighing platform that trailed the pickup machine.

In both years a sub-sample was collected, oven dried in a fan forced oven at 40°C (to constant moisture or for 14 days). Nut samples were processed using a cracking machine (Jessee® mini almond huller and sheller; Jessee equipment manufacturing, Chico, California, USA) to separate kernels from hulls and shells. Percent crack-out and kernel weight were determined for each subsample and the plot average was calculated prior to statistical analysis

7.3 Results

Soil Water Monitoring

Soil water data for the 2020/21 season in Nonpareil trees, collected using EnviroPro® probes attached to the GreenBrain® Plexus® network, is presented in Figure 7-2. Data displayed is average soil water content (%) within the top 1 metre of soil depth. Irrigation, rainfall and reference evapotranspiration (ET_0) are also shown on the same time scale.

It is important to note that the irrigation system design is consistent throughout the property, with changes in dripper flow rate or emitter spacing along the row correlating with row width, and irrigation application rate for all plantings is close to 1.4 mm/h. As a result, individual trees in treatments with wider within-row spacings theoretically had access to more water than trees at closer within-row spacing, which had to share the available water with more closely spaced neighbouring trees.

While trees were young, with distinctly separate canopies, the extent of root development was unlikely to have greatly exceeded the spread of the canopy, meaning that all trees would be expected to have access to a similar area of rootzone, and water applied in the gaps between trees would be expected to pass through to drainage. In these young trees there would be no competition between trees for available water and sunlight. As the canopies of adjacent trees began to meet, the root areas would also be expected to meet, and competition for water from the soil as well as competition between canopies for sunlight would occur. However, assuming that overall irrigation applied was sufficient, it is surmised that all trees should have had access to as much water as they were able to transpire, and that more closely spaced trees would be no more or no less water stressed than more widely spaced trees.

The general trend at all sites was similar, with initially high water content declining from September 2020, as the canopy developed and transpiration increased in response to increased leaf area and climatic demand. Water content rose again in April 2021, likely as a result of increased irrigation applications after harvest. Water content again decreased late in the season as irrigation applications were decreased.

The pattern of peaks is also representative of the irrigation schedule, with many peaks in the middle of the season representing daily irrigation during the highest demand period, and more separated peaks at either end of the season indicating a greater delay between irrigations when demand was reduced.

Analysis of data from individual sensor depths indicates that trees at the lowest density (308 trees/ha) had adequate water availability at most depths throughout the season, although values at all depths dropped somewhat from mid-December to mid-March. At higher tree densities soil moisture dropped earlier in the season. The Phytech sensors, used to infer canopy growth and water requirements were installed in the lowest tree density treatment. Negotiations are underway to install additional monitoring stations in this trial that inform metrics in the highest densities.

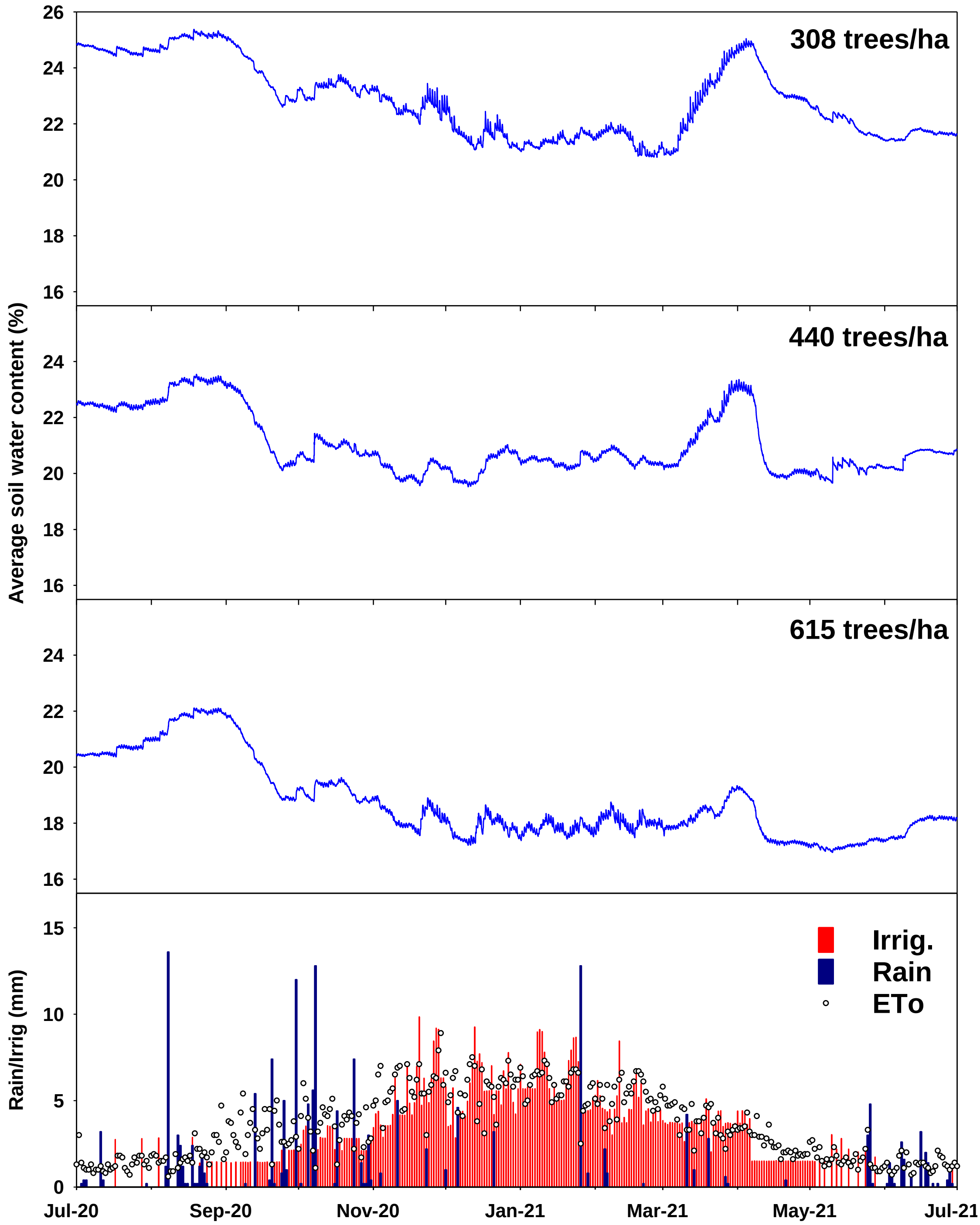


Figure 7-2. EnviroPro soil water monitoring data and irrigation, rainfall and reference evapotranspiration for 2020/21 season, Nonpareil in Low (H1) – Medium (H2) Optimised Density Trial. Soil moisture is average percent soil water content of the top 1m soil depth.

Soil Solution Sampling

Seasonal soil water samples identified a minor accumulation of salts in the deeper soils of both the high- and low-density planting treatments. Average soil water salinity at 30 cm depth was less than 2 dS/m whereas that at 90 cm depth was approximately 4 dS/m. This is consistent with concentrating of salts in the soil water as plant roots extract water and some salts (fertilisers) and excluding others (e.g., Cl^-). Soil water EC's also indicated a minor increase in rootzone salts over the course of the season (data not shown) which is consistent with trends observed in other production systems.

On three occasions, aligned with late spring fertigation events, the soil water samples registered nitrate concentrations approaching 40 mg/L at 30 cm depth. However, soil water nitrates generally remained below 5 mg/L, suggesting that the trees rapidly consumed the applied nutrients and no movement beyond the trees rootzone.

Seasonal soil water samples exhibited slightly alkaline pH, consistently hovering around pH 8. The natural buffering capacity of this soil is very high, and the application of acidic fertiliser is yet to make any appreciable difference to the pH of the soil solution.

Tree Size

Trees were planted in September 2018. At planting, Nonpareil, Vela and Carina trees were of a similar size, having been headed to a single stem at roughly 900 mm high. Shasta trees were delivered with notably thicker trunks and more developed root mass (data not shown). In April 2019 the first season's growth was assessed.

There were significant differences across all measurements when compared by variety (Figure 7-3a). Shasta trees were larger than all other varieties on all three measurements (height, width and trunk diameter). This most likely reflects the larger size of the trees at planting, and therefore the head start they had over trees of the other varieties.

Vela trees showed very similar height and width, reflecting their more weeping growth habit. Nonpareil trees presented a more narrow, upright shape. In spite of some differences between Nonpareil, Vela and Carina in height and width, trunk diameter was not significantly different between these varieties, suggesting a similar overall canopy biomass, despite the differences in canopy shape.

Canopy height and trunk diameter showed no significant response to density (Figure 7-3b). Although there were significant differences in width, there is no logical pattern between the groupings and tree density, so it is difficult to assign any cause to the differences at this early stage.

Subsequent measurements of trunk diameter were collected using the SARDI's MOPP, in October 2020 (early 3^{rd} leaf) and July 2021 (end of 3^{rd} leaf). These data are displayed, together with the 2019 trunk diameter data, in Figure 7-4.

Shasta trees had the largest trunks on every measurement date (Figure 7-4a). Vela trees had smaller trunks than Shasta but larger than Carina in the 3^{rd} leaf (October 2020 & July 2021). Nonpareil trees, however, had significantly smaller trunks than all other varieties early in the 3^{rd} leaf (October 2020), but larger than Carina trees and not different to Vela trees by the end of the 3^{rd} leaf (July 2021). This suggests that Nonpareil trees grew more slowly initially, but that their growth was less restricted by adjacent trees than that of the other varieties during the 3^{rd} leaf.

The assumption that tree growth is being restricted by adjacent trees is borne out clearly in the comparison by planting density (Figure 7-4b). There was no difference in trunk diameter in April 2019, but by October 2020 trunk diameter reduced significantly for every increase in planting density. Not only was this pattern maintained in July 2021, but the differences had increased. Between October 2020 and July 2021 trees at the lowest density (308 tress/ha) increased their trunk diameter by 24%, whilst trees at the highest density (615 trees/ha) only increased by 8% during the same period. Using trunk diameter as a proxy for overall tree size, it is clear that planting density is influencing tree growth.

Figure 7-5 displays relative trunk radius as measured by Phytech dendrometers. Each dataset is the average of three dendrometers, all installed in adjacent Nonpareil trees within each valve unit. The data was used by the Farm Manager to assist with irrigation scheduling. The clear sigmoidal curve illustrates the growth pattern of the trees, as well as the variation in absolute values between valve units.

The sensors were located in different treatments in the different valve units. In valve 23 (orange line) the sensors were installed in the 440 trees/ha treatment, valve 24 (blue line) in 342 trees/ha, and valve 25 (grey line) in 385 trees/ha. There was no obvious correlation between tree spacing and the size of the average annual trunk growth shown in Figure 7-5.

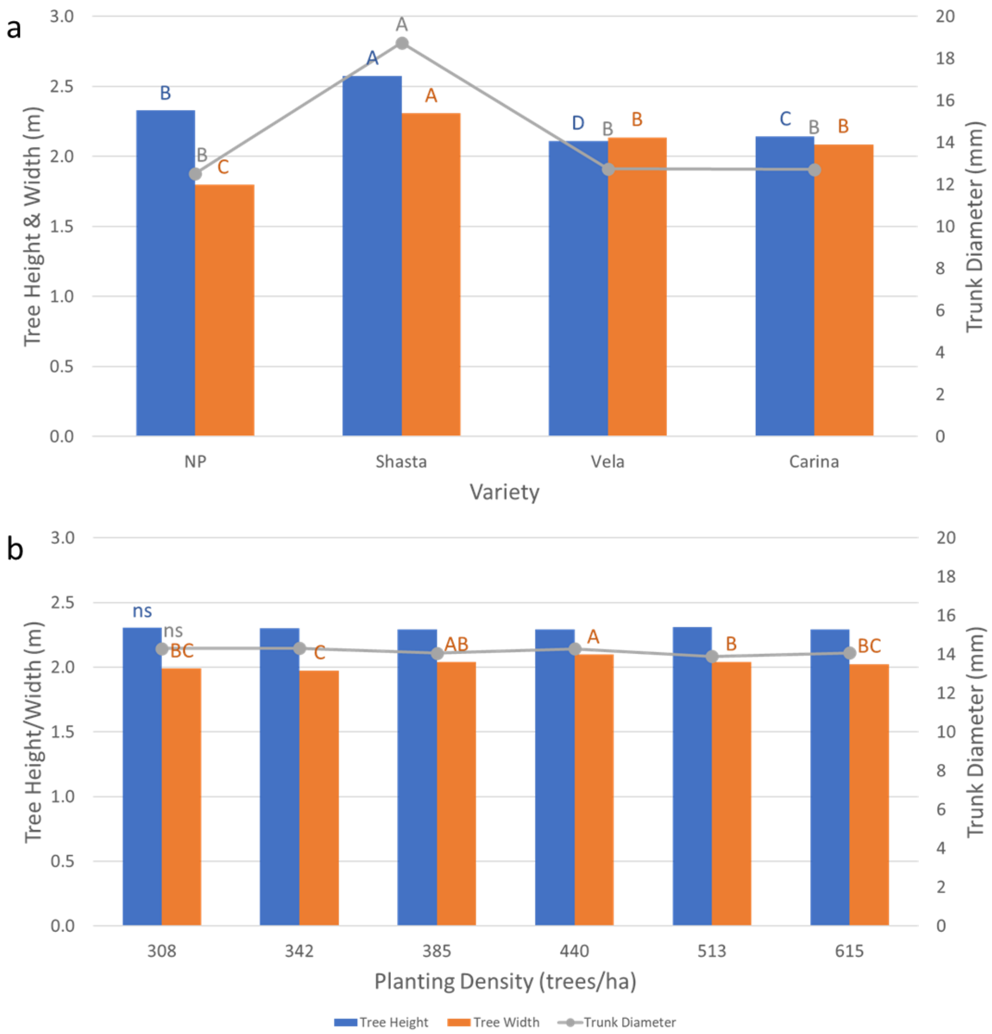


Figure 7-3. Impact of variety and planting density on canopy height and width, and trunk diameter in 1st leaf of Low (H1) – Medium (H2) Optimised Density Trial

Light Interception

Through the 2021 irrigation season, SARDI's MOPP was deployed (approximately) monthly across all trials to collect light interception metrics. Figure 7-6 is a sample of light interception data collected in December 2020 from SARDI's H1 to H2 (low to medium) density optimisation trial. The values reported for each density are averaged across four varieties (Shasta, Carina, Nonpareil and Vela) grafted to the Garnem rootstock. Light values across the row suggest greater interception close to the trunk with the greatest interception by trees planted at the highest density (615 trees/ha).

Figure 7-7 displays data for leaf area index (LAI), measured on a number of dates during the 2020/21 growing season. The chart shows the low level of leaf area index at the beginning and end of the season, as well as changes during the season. It also indicates that statistically significant differences in LAI occurred between the variety x spacing treatments on all dates apart from the beginning and end of the season.

On all dates with significant differences, the highest density Nonpareil treatment gave significantly higher LAI than the lowest density Nonpareil treatment. Also, Shasta trees appeared to be slow to develop, with LAI of both Shasta treatments in October 2020 being significantly lower than all other varieties at the highest density, and Carina at the lowest density, but this distinction was removed later in the season.

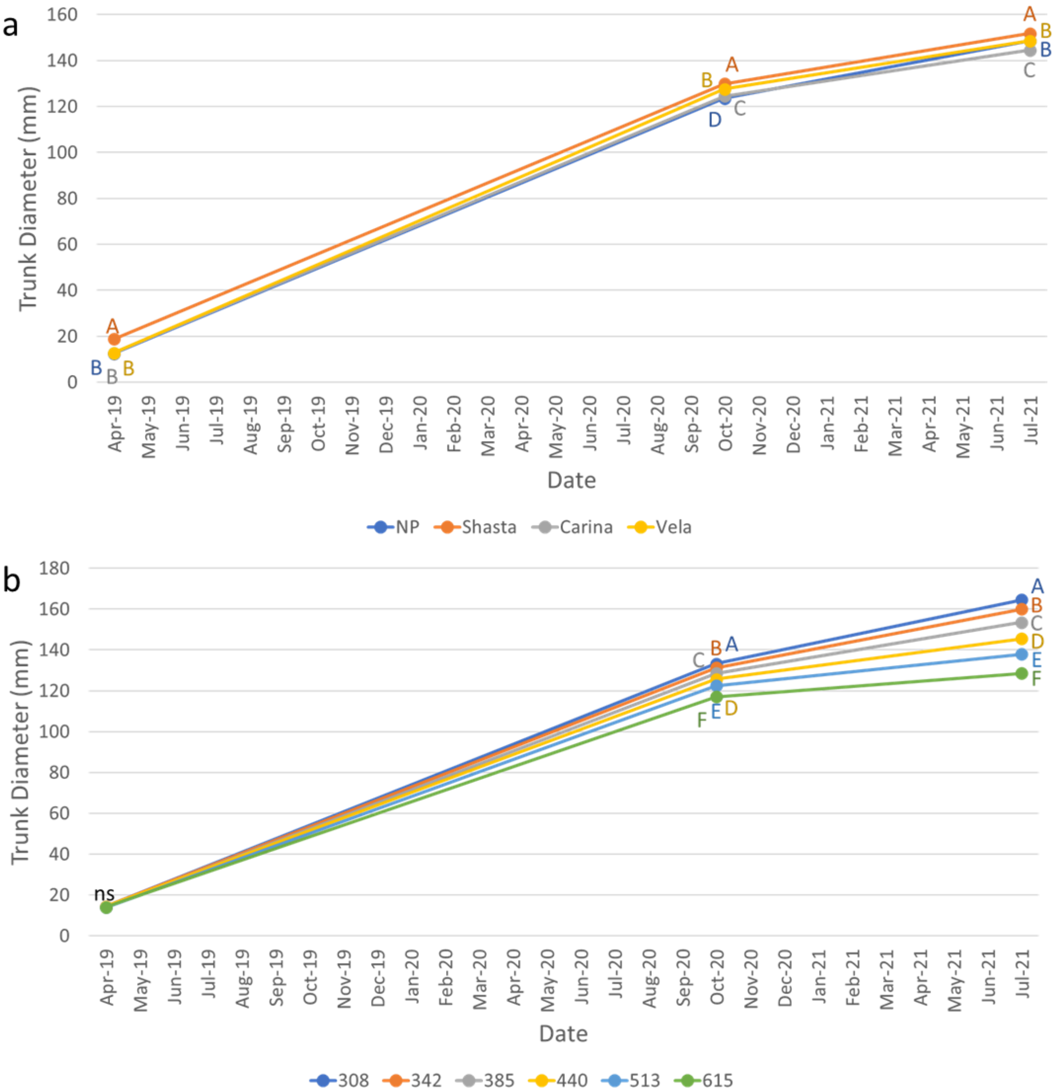


Figure 7-4. Impact of variety and planting density on trunk diameter over time in Low (H1) – Medium (H2) Optimised Density Trial

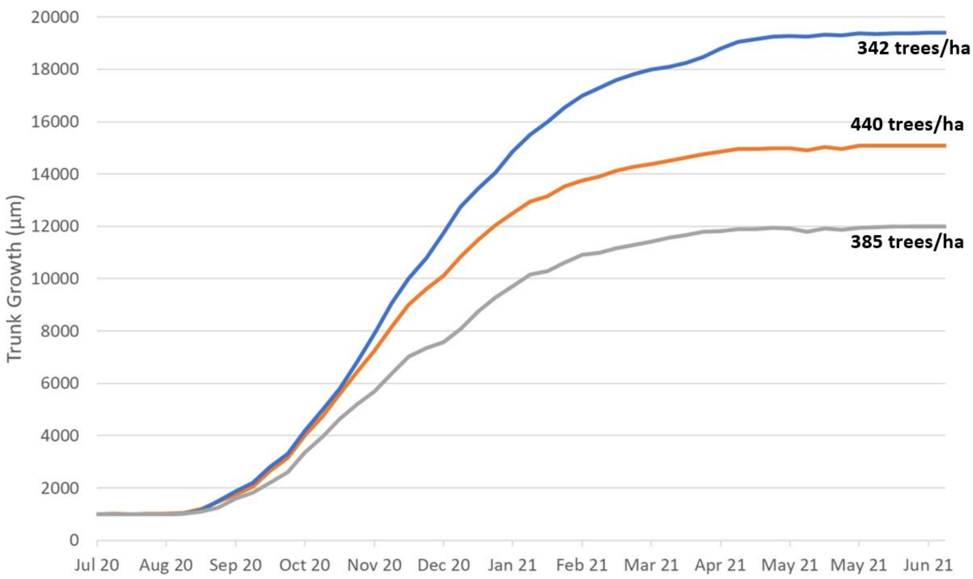


Figure 7-5. Trunk radius increase from nominal 990 µm base value, sourced from Phytech dendrometer data

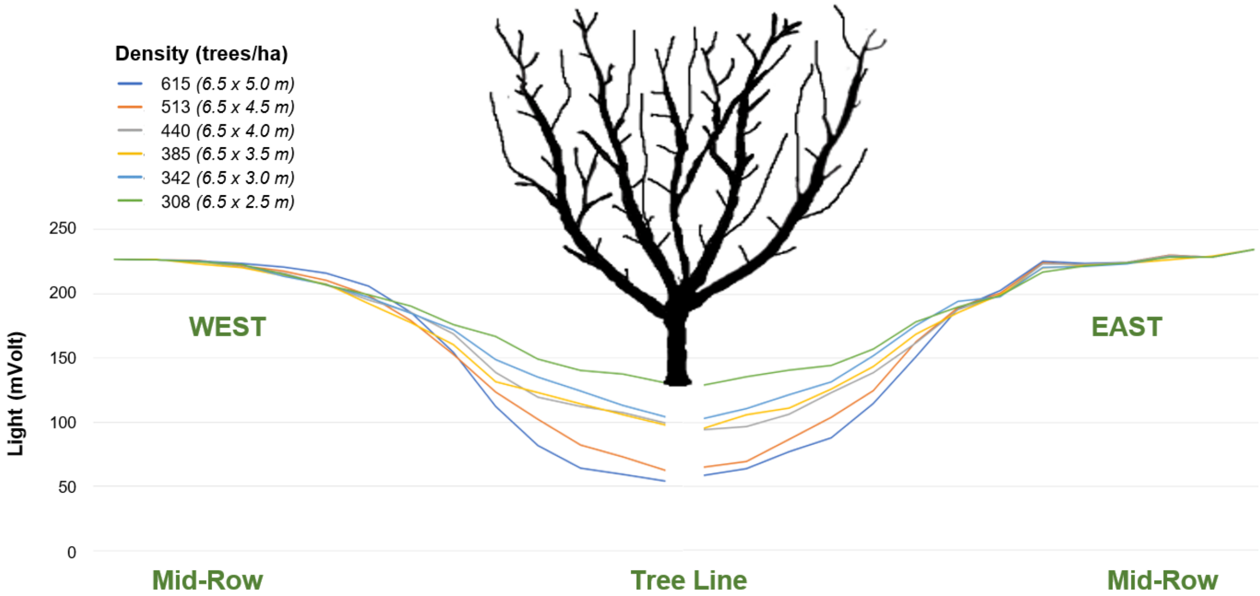


Figure 7-6. Light intensity at ground level across the tree row as measured by pyranometer array on SARDI's Mobile Orchard Phenotyping Platform in the Low (H1) – Medium (H2) Optimised Density Trial, December 2020

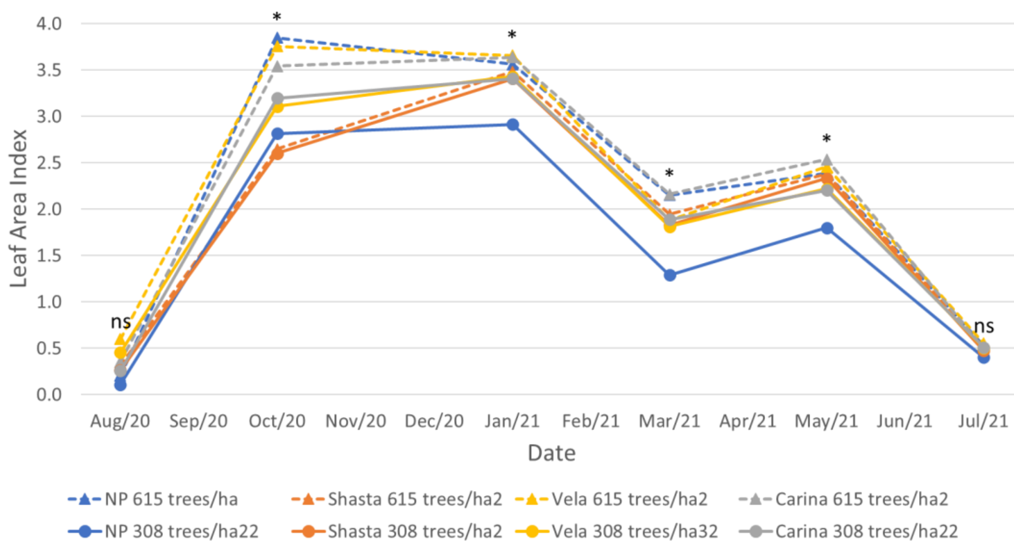


Figure 7-7. Leaf area index measured in the Low (H1) – Medium (H2) Optimised Density Trial across the 2020/21 growing season. An asterisk (*) indicates the presence of statistically significant differences (P = 0.05) between treatments on the given date, "ns" indicates no significant differences on that date.

Tree Shape/Structure

Figure 7-8 displays the trial's four varieties across a subset of the planted densities. The images were taken in winter 2021 and highlight branching structure and a tendency for smaller trees at the higher density. Nonpareil and Shasta show strong scaffold branches and an upright habit. Whilst Vela is less weeping without leaves, the photographs clearly show illustrate the much less dominant role of scaffold branches in this variety, and the more rounded shape of the trees.

Figure 7-8. Representative trees in SARDI's Low (H1) – Medium (H2) Optimised Density Trial. Four varieties (Nonpareil, Shasta, Vela and Carina) grafted to Garnem and planted to six densities ranging from 308 to 615 trees/ha (308, 440 and 615 trees/ha pictured). Two-year-old nursery trees planted in July 2018. Photos - July 21.

Carina displays a structure midway between these extremes, with clear scaffold branching, but a more spreading habit than Shasta and Nonpareil.

Figure 7-8 clearly demonstrates the decline in tree size moving from lowest to highest tree density (lowest density on the left, highest density on the right). The lowest planting density has clearly resulted in the largest trees after three growing seasons, trees at the mid-range planting density are of medium size, and the highest density has produced the smallest trees, reinforcing the results presented in Figure 7-4, Figure 7-6 and Figure 7-7 above.

Yield Components

The 2020 harvest did not produce commercially significant yields and was carried out by hand. However, the 2021 harvest was significant and required the use of modified commercial harvest equipment, allowing measurement of yield and collection of samples from each treatment plot. Harvest data from both years is displayed in Figure 7-9 and Figure 7-10, which show bulk yield (t/ha), kernel yield (t/ha) and percent crack-out, displayed by variety (Figure 7-9) and planting density (Figure 7-10).

Variety comparison (Figure 7-9) indicates that both Nonpareil and Vela yielded significantly less than Shasta and Carina in 2020 (2nd leaf) in both bulk kernel yield. In 2021 Carina outyielded all other varieties in bulk yield, but the very low crack-out resulted in kernel yield being less than Vela. Nonpareil again yielded less than most other varieties in both bulk and kernel, whilst Vela yielded the highest kernel in 2021 (3rd leaf). The increase in yield in 2021 more than compensated for the lower yield from Vela in 2020.

Comparison of data by planting density (Figure 7-10) indicates that both bulk yield and kernel yield per hectare generally increased with increasing tree density in both years. This suggests that there is still a yield advantage in having more trees per hectare in the third leaf, when averaged across varieties. Crack-out was unaffected by tree density in either year, suggesting no interaction.

There were, however, some interesting differences in responses between varieties. In Figure 7-11 to Figure 7-14 only data for 2021 (3rd leaf trees) is presented. This data is the integration of 144 individual trial plots comprising more than 1000 experimental trees. The data is presented separately for each variety in order to display and discuss the differences in response to tree density for each variety. Yield is presented as tonnes of kernel per hectare as well as kilograms of kernel per tree, and kernel size. Crack-out showed no significant differences due to tree density within any of the varieties.

Nonpareil (Figure 7-11) showed no significant response to tree density for yield per tree or kernel size, but a significant increase in yield per hectare at the higher densities. The lack of any density effect on yield per tree suggests that individual Nonpareil trees were not limited by competition from neighbouring trees at any of the densities tested.

Conversely, Shasta (Figure 7-12) and Vela (Figure 7-13) trees both showed no significant difference in yield per hectare at different tree densities, but a decrease in yield per tree, and for Shasta in kernel size, as density increased. This suggests that trees of these varieties were experiencing competition from neighbouring trees which limited yield and nut development, and that the competition was greater as the tree density increased. Note that Vela produced the largest kernels compared to the other varieties in both years (data for 2020 not shown).

Carina (Figure 7-14) showed a significant effect of tree density on both measures of yield and on kernel size, suggesting an intermediate response where there was some retardation of yield and nut growth due to competition from neighbouring trees, but not enough to completely outweigh the advantage of having more trees per hectare. Carina produced the smallest kernels in 2021, and equal smallest with Nonpareil in 2020 (data not shown).

Note that the consistent irrigation application rate across all treatments means that the relative yield per hectare between treatments is directly reflected in relative yield per megalitre, as the same amount of water (ML/ha) was applied across all spacing treatments.

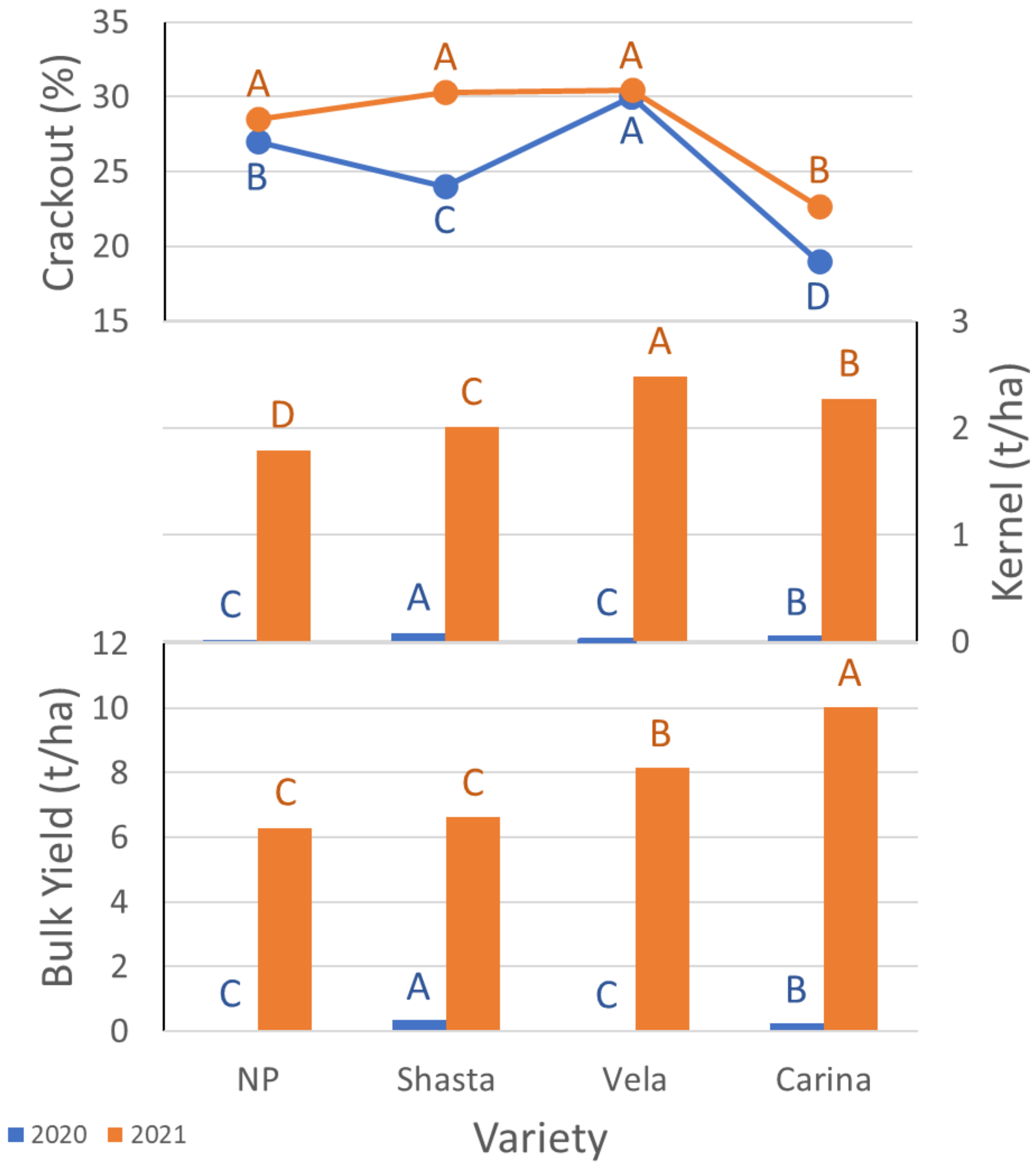


Figure 7-9. Bulk yield, kernel yield & crack-out in the Low (H1) – Medium (H2) Optimised Density Trial, for 2nd (blue symbols) & 3rd leaf trees (orange symbols) summarised by variety. Data points with the same letter are not significantly different at P = 0.05.

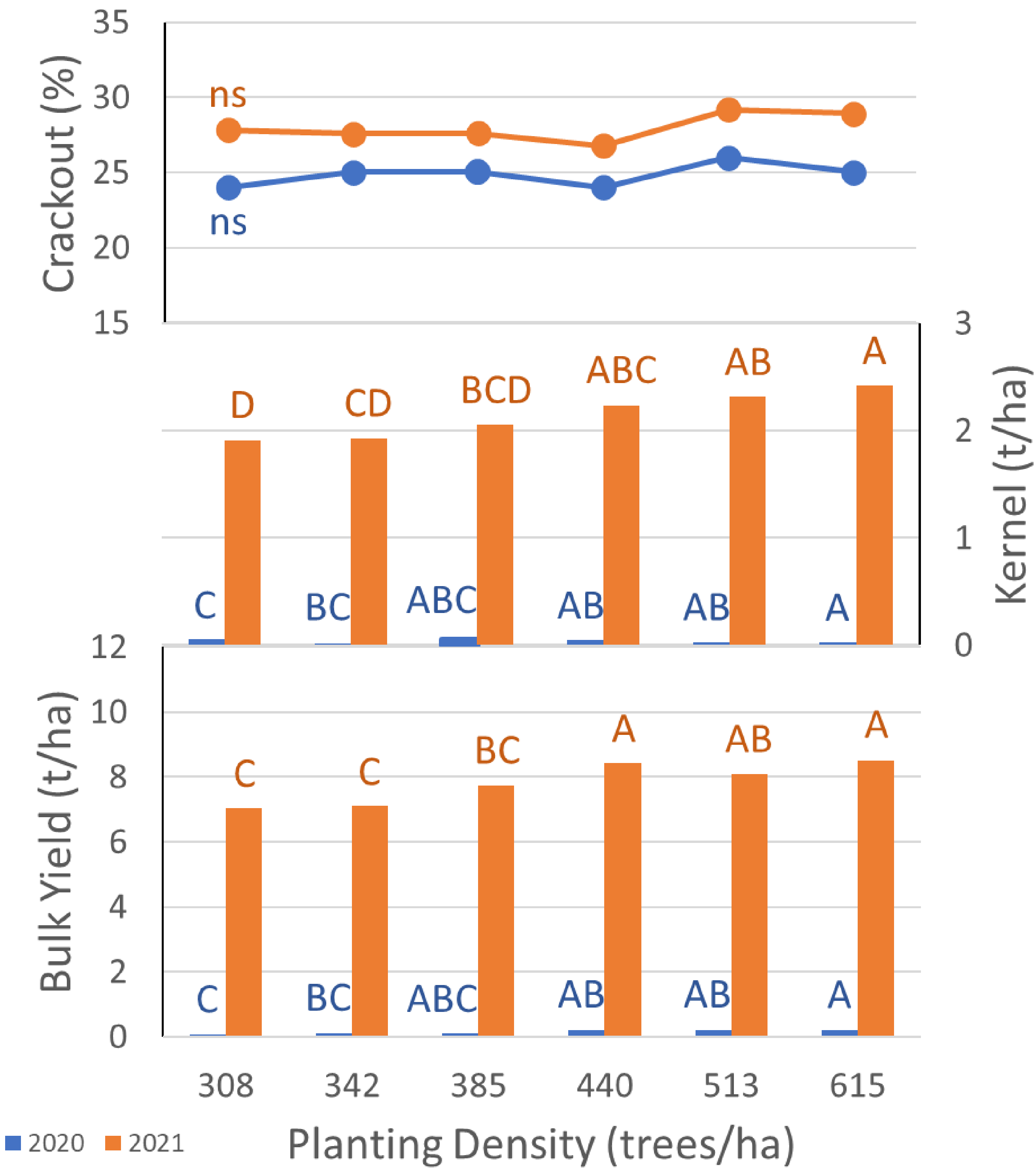


Figure 7-10. Trial 3 bulk yield, kernel yield & crack-out in the Low (H1) – Medium (H2) Optimised Density Trial, for 2nd (blue symbols) & 3rd leaf trees (orange symbols) summarised by tree density. Data points with the same letter are not significantly different at P = 0.05, "ns" indicates no significant differences in the data set.

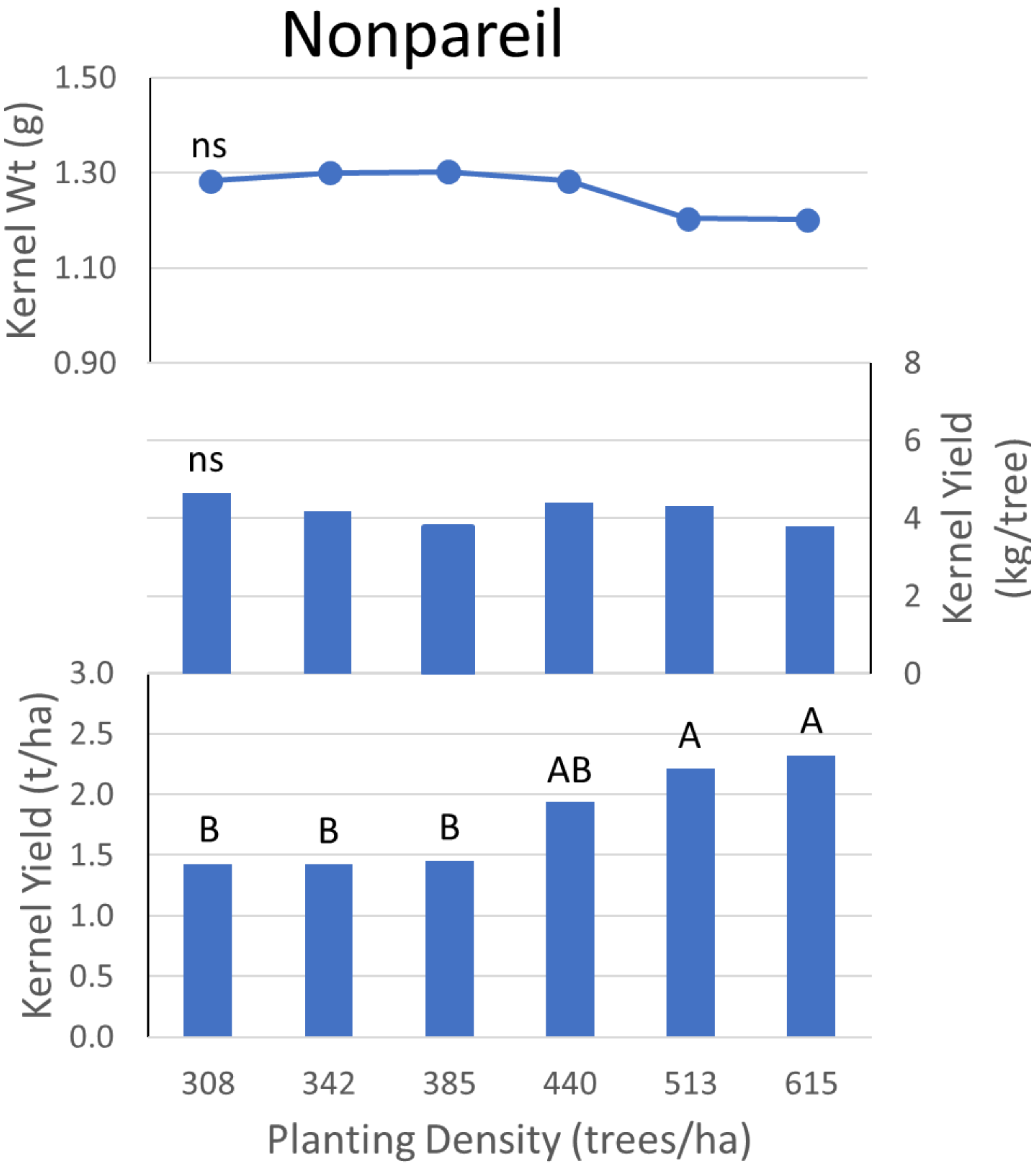


Figure 7-11. Effect of six planting densities on average kernel weight (g) and two measures of kernel yield (kg/tree & t/ha) for 3rd leaf Nonpareil almonds grafted to Garnem rootstock. Data points with the same letter are not significantly different at P = 0.05, "ns" indicates no significant differences in the data set. Note that the Y-axis scales are consistent between corresponding plots in Figure 7-11 to Figure 7-14

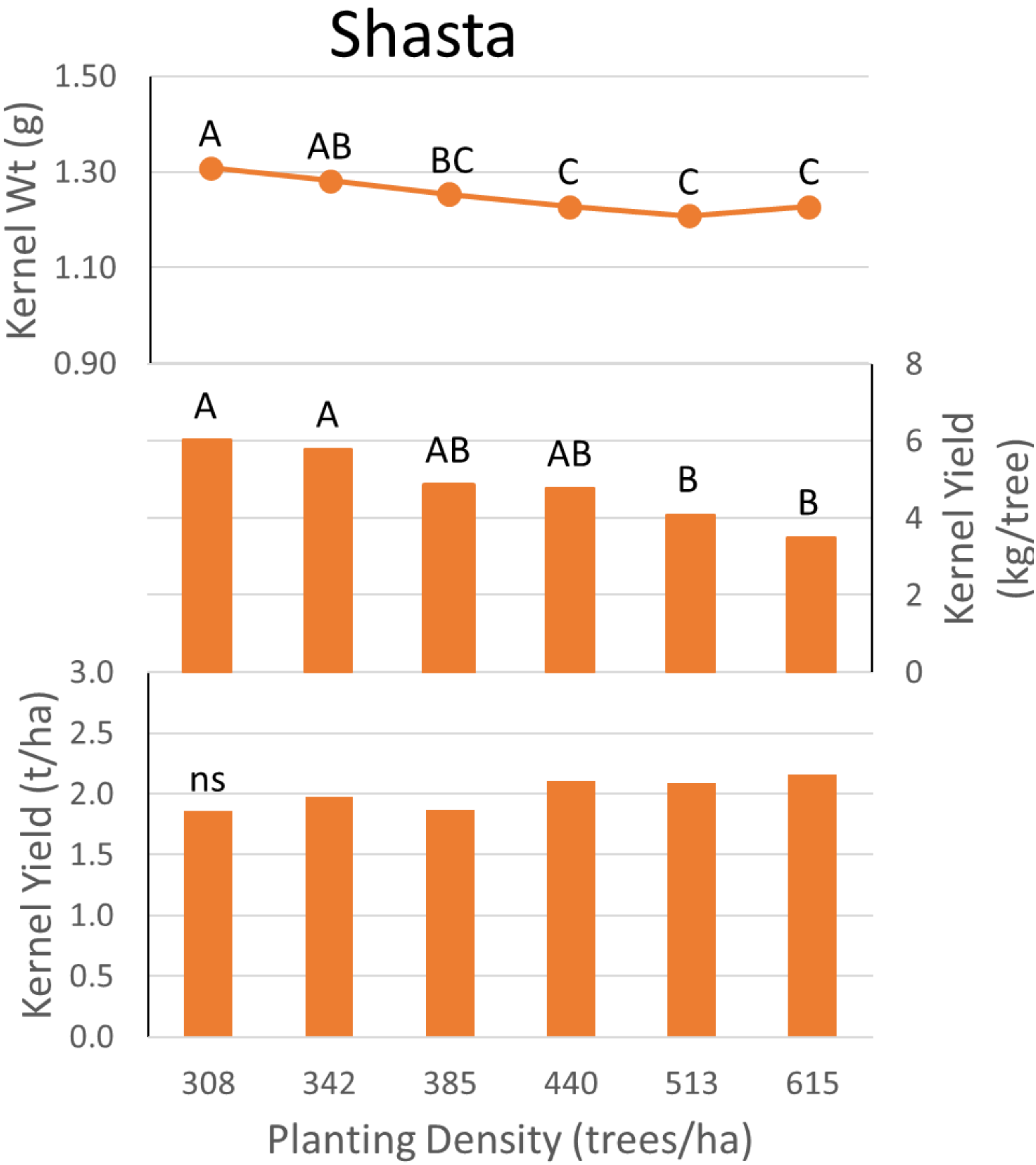


Figure 7-12. Effect of six planting densities on average kernel weight (g) and two measures of kernel yield (kg/tree & t/ha) for 3rd leaf Shasta almonds grafted to Garnem rootstock. Data points with the same letter are not significantly different at P = 0.05, "ns" indicates no significant differences in the data set. Note that the Y-axis scales are consistent between corresponding plots in Figure 7-11 to Figure 7-14

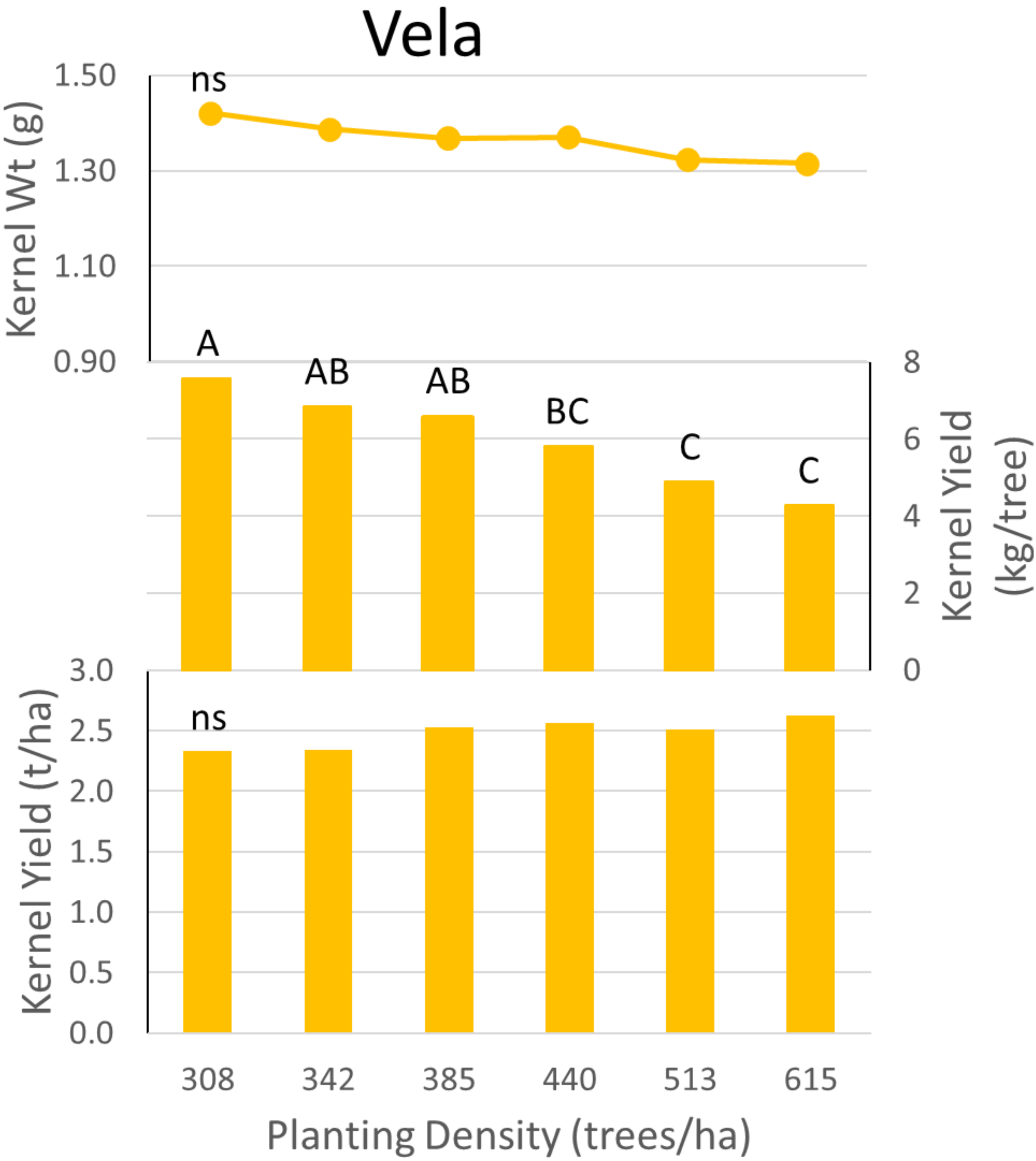


Figure 7-13. Effect of six planting densities on average kernel weight (g) and two measures of kernel yield (kg/tree & t/ha) for 3rd leaf Vela almonds grafted to Garnem rootstock. Data points with the same letter are not significantly different at P = 0.05, “ns” indicates no significant differences in the data set. Note that the Y-axis scales are consistent between corresponding plots in Figure 7-11 to Figure 7-14

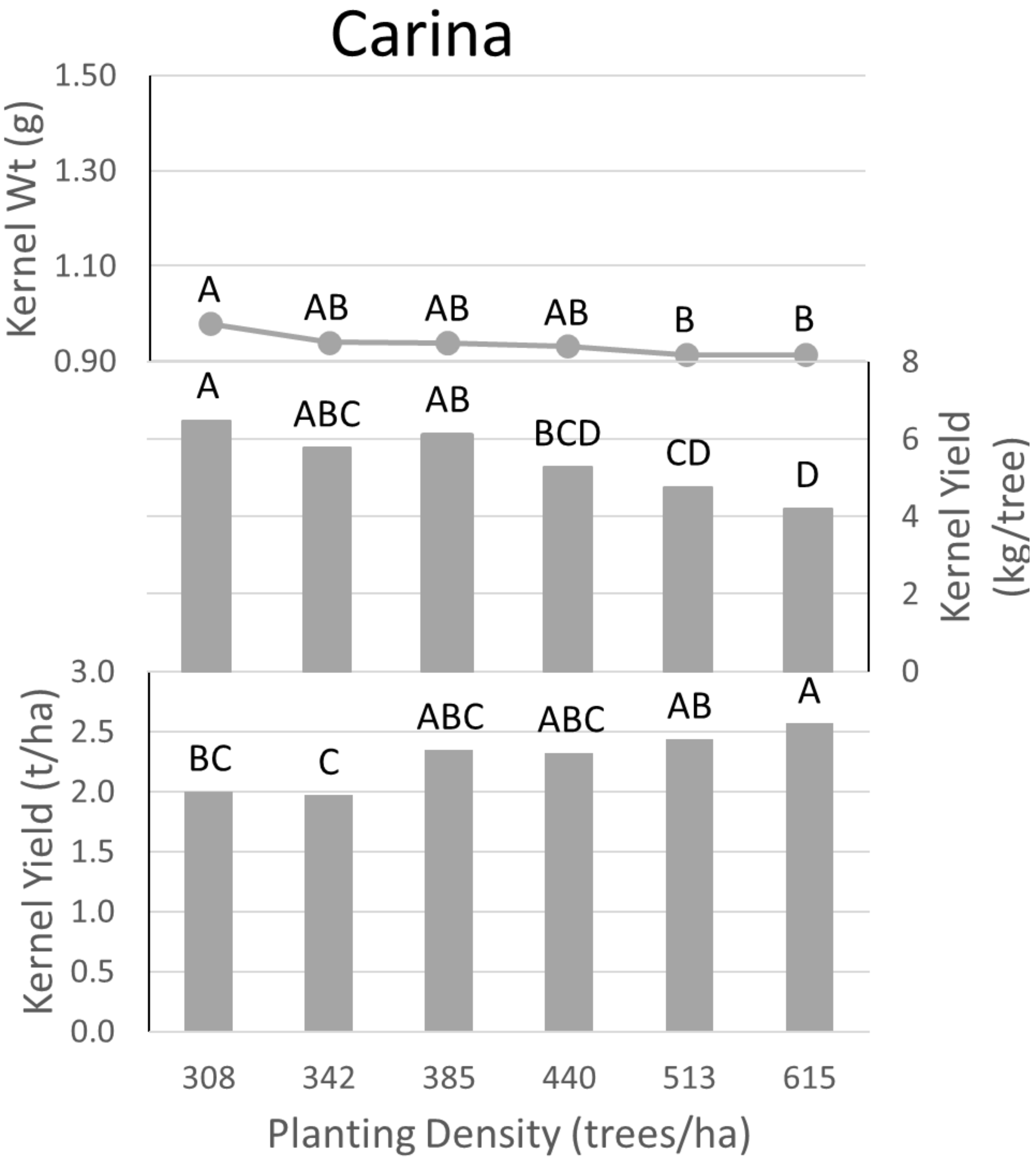


Figure 7-14. Effect of six planting densities on average kernel weight (g) and two measures of kernel yield (kg/tree & t/ha) for 3rd leaf Carina almonds grafted to Garnem rootstock. Data points with the same letter are not significantly different at P = 0.05, "ns" indicates no significant differences in the data set. Note that the Y-axis scales are consistent between corresponding plots in Figure 7-11 to Figure 7-14

7.4 Issues and opportunities

Economics

A full exploration of the economics of different planting densities was beyond the scope of the orchard establishment phase of this work. Economic analysis relies on analysing the costs associated with planting extra trees and calculating the payback period required to re-coup those additional costs. Given that only two years of yield data have been collected from this trial so far, and that the first of those years produced a very small crop, there is a need for further data collection and analysis before this question can be addressed.

As a starting point for further analysis, Table 7-3 displays the cost per hectare of purchasing trees at the range of tree densities trialled in the Low (H1) – Medium (H2) Optimised Density Trial, as compared to the industry standard Horizon 1 spacing of 4.5 m between trees and 7.0 m between rows, or 317 trees/ha. At the highest density in this trial the cost of trees is estimated to be $4,605/ha higher than the standard planting. This additional establishment cost, plus the additional costs associated with planting and maintaining these extra trees, would need to be recouped from higher yields over the early years of the orchard's life in order for the higher density to be financially viable.

Table 7-3. Estimated cost of additional trees for higher density plantings compared to Horizon 1 density of 308 trees/ha

Tree spacing	Density (trees/ha)	Cost of trees ($/ha)*	Additional cost of trees ($/ha)
4.5 x 7.0 m	317	4,755	-
5.0 x 6.5 m	308	4,620	-
4.5 x 6.5 m	342	5,130	510
4.0 x 6.5 m	385	5,775	1,155
3.5 x 6.5 m	440	6,600	1,980
3.0 x 6.5 m	513	7,695	3,075
2.5 x 6.5m	615	9,225	4,605

* Cost of trees estimated at $15/tree, based on 2021 costings

Water use

In the first three seasons of this trial the planting received a total of 5.6 ML/ha (2018/19), 7.5 ML/ha (2019/20) and 10.2 ML/ha (2020/21) of irrigation water. As outlined above, the irrigation system installed at the Almond Centre of Excellence applied water at a consistent application rate across the property, rather than varying with planting density. This reflected the expectation that water use will be similar across densities in mature trees, given that transpiration is driven by canopy area, not the number of trunks in the ground.

However, until the tree canopy's fill their allotted space and merge into a hedgerow, there are differences in water use between the different planting densities within trials. As a result, some trees will likely receive too much or not enough water when other trees are irrigated adequately.

Following concerns that inadequate irrigation may have been a brake on tree growth and development, greater focus will be given to the higher water use treatments, ensuring that all trees receive at least adequate water to fulfill their needs. Whilst this will not facilitate estimation of the real water needs of the different planting densities, it will ensure that each density treatment grows and yields to its potential.

Trials incorporating detailed irrigation scheduling for individual treatment plots at different planting densities are being undertaken by Agriculture Victoria at Irymple. This work will provide supplementary information to complement the work being undertaken in this trial.

Remote Data Acquisition

SARDI is hosting an AgTech demonstration hub at Loxton Research Centre, which includes a number of companies offering remote monitoring of orchards. As well as collecting demonstration data from the Loxton Research Centre, some of these companies are monitoring the Almond

Centre of Excellence as well. One such company is CERES, who use fixed wing aircraft to assess crop health and water status. This monitoring has the potential to add valuable supplementary data, enhancing the ground and aerial remote sensing platforms that SARDI are currently developing at ACE.

Canopy Structure

The varieties planted in this trial were selected to cover a range of tree architecture. Nonpareil was included as the current industry standard, against which the other varieties will be compared. Vela has a weeping habit, whilst Shasta is much more upright, and Carina lies somewhere in between. Ongoing monitoring will assess how well these different growth habits adapt the trees to medium density planting. Results to date demonstrate clear differences in tree size and shape (Figure 7-3, Figure 7-7 & Figure 7-8), as well as early differences in yield (Figure 7-9) and yield response to spacing (Figure 7-11, Figure 7-12, Figure 7-13 & Figure 7-14). Ongoing monitoring is needed to assess the long-term productivity of the different tree architectures in this trial.

Further tree architecture observations are ongoing in the Scion/Rootstock Compatibility and New Scion/Rootstock Compatibility trials, SECTION 6, where a much larger number of rootstock and scion genotypes are being compared in a range of combinations.

SECTION 8. Optimised planting density; Medium (Horizon 2) to High (Horizon 3)

Key points

- SARDI's Medium to High Density Optimisation Trial contains two varieties, both new potential Nonpareil replacements, budded to three new size controlling rootstocks. The trees are planted in 4.5 m rows, with between tree spacing ranging from 3.5 down to 1.5 m, giving three tree density treatments ranging from 635 to 1481 trees/ha. All treatments are replicated four times.
- The trial was planted in 2019 as a proof-of-concept trial testing the function and practicalities of trellising almond trees.
- Tree size has been monitored over the life of the planting, but no yield data has been collected yet. Other measurements collected from the trial include soil water content (from four plots), soil solution constituents (from two plots), Leaf Area Index (LAI) and light interception (across all plots), and tree shape and architecture.
- Results indicate that variety, rootstock and tree density all had a significant impact on tree size, Leaf Area Index and light interception.
- One key factor in the performance of the different rootstocks was poor health of trees budded to Controller-7 in many of the plots. The evidence suggests that trees on this rootstock suffered from chlorosis due to the high pH of the soil across parts of the trial site. Hence a key finding that Controller-7 rootstock is not suitable for Riverland soils.
- There are current plans to replace the worst affected replicates of Controller-7 trees in the trial, and replace them with trees on two other rootstocks, in order to maximise the data gathering and demonstration opportunities of this trial.

8.1 Background and aims

This trial builds upon the H1 to H2 optimised density planting and extends the densities assessed into the super high density, H3, range (HortInnovation, 2017). The planting uses self-fertile almond cultivars, Shasta and Vela, grafted to each of three size controlling rootstocks, Rootpac-40, Controller-6 and Controller-7, at three planting densities, 635, 889 & 1481 trees/ha.

The low to medium density trial discussed in SECTION 7 decreased the distance between trees while retaining current industry tree training practices. However, there is a growing understanding that simply intensifying traditional growing methods is not the most efficient method to improve almond production, and consequently an increasing interest in alternate tree architecture under intensified planting systems (Thorp et al. (2021); Tustin et al. (2018)).

Key to this research is an understanding of the impact of different rootstocks and planting density combinations on tree size and agronomic factors, including yield efficiency (Lordan et al., 2019, Palmer et al., 2002). Factors of interest in this research are the specific influences of size controlling rootstocks on tree architecture (Seleznyova et al., 2003, Seleznyova et al., 2008), and the impacts of orchard architecture on light interception, and consequently yield (Scofield et al., 2020, Breen et al., 2020).

Progression of the Almond industry toward H3 orchard design brings the potential for a major redesign of all orchard operations. The key orchard operation impacted by super-high density is harvesting, with the potential for shake-and-catch harvesting of smaller, more densely planted trees. A single pass harvest operation would represent significant labour, machinery and fuel savings. Shake-and-catch harvesting would also remove the need for nuts to touch the ground, greatly reducing the potential for nut contamination and quality downgrades associated with aflatoxins and water staining, which are especially prevalent in years when the harvest period is wet.

Without the requirement for a clean orchard floor associated with current harvest practices, shake-and-catch harvesting will provide growers with greater flexibility in orchard floor management. These may include increased use of cover-crops that will assist in improving soil health. Cover crops will also facilitate the maintenance of beneficial insects, promoting the uptake of integrated pest management (IPM) strategies across the Almond industry, and reducing reliance on pesticides to manage major pests.

Further tree growth and yield metrics will be reported through to 2025 via the Hort Frontiers AS18000 Orchard Intensification program which is partially funding SARDI to continue orchard maintenance and yield assessment activities of this experimental orchard.

8.2 Orchard establishment and methods

Trees were planted in 2019. Three tree densities were applied to each of the six scion x rootstock combinations. Tree rows were planted 4.5 m apart, with between tree spacings of 3.5 m (635 trees/ha), 2.5 m (889 trees/ha) & 1.5 m (1481 trees/ha). Full details of the planting are outlined in Table 8-1.

Each treatment plot comprised four rows of 21 to 24.5 m in length, between 7 & 14 trees per row, depending on the density treatment (Figure 8-1). The spacing treatments were overlaid by two rootstock combinations, and the resulting six treatments were replicated four times across each variety in a Randomised Complete Block design (Figure 8-1).

Table 8-1. Summary of Medium (H2) – High (H3) Optimised Density Trial planting

Rootstocks	Scions	# Trees	Valve	Rows	Spacings	Density (trees/ha)	Area
Controller-6 Controller-7 Rootpac-40	Vela Shasta	240 Ve/C6 240 Ve/C7 240 Ve/R40 240 Sh/C6 240 Sh/C7 240 Sh/R40 **1520 Total**	38	385 – 400	4.5 x 3.5 m 4.5 x 2.5 m 4.5 x 1.5 m	635 889 1481	1.54 Ha 16 rows

The rootstocks selected for this trial are all size controlling, in that they reduce the size of the scion budded onto them without reducing fruit size. The following is published information about their impact on tree size relative to normally vigorous rootstocks such as Nemaguard and Garnem:

- Controller-6 – trees reach 60-75% of unrestricted size, patented as HBOK 27 (Bliss et al., 2013)
- Controller-7 – trees reach 80-85% of unrestricted size, patented as HBOK 32, (Bliss et al., 2012)
- Rootpac-40 – trees reach 70-75% of unrestricted size, patented as Nanopac, (Pinochet, 2010)

Figure 8-2 shows an aerial view of the trial soon after planting. The different density treatments are visible in the spacing of the white tree guards. Replacement trees were propagated by SARDI using planting material provided by the nursery, and fill-in trees and replacements for dead trees were planted later in the 2019/20 growing season.

An Eco-Trellis® semi-permanent support structure was installed in July 2020. The trellis consisted of metal posts and strainers, supporting two wires at 700 and 1700 mm above the ground. At each tree a 3 m long bamboo pole was affixed to the wires so that it extended from 0.5 m to 3.5 m above the ground (Figure 8-3). Trees continued to be trained to this pole targeting a dominant single leader from which laterals could develop to ultimately fill a hedge row.

Soil moisture monitoring was installed in two tree spacing treatments (1.5 & 3.5 m), across both varieties (Shasta and Vela) within adjacent Rootpac-40 treatment plots, giving a total of four sensor arrays. The installations are EnviroSCAN® sensor arrays, with individual soil water sensors at 10, 20, 30, 40, 60, 80, 100 and 150 cm soil depths. These sensors are attached to a standalone logger to monitor soil water content every hour.

SWAN Systems® software was used to manage irrigation and nutrition across the Almond Centre of Excellence. This system incorporated irrigation event data from the GoldTec® controller, and other data was entered manually (for example fertiliser applications). Nutrient applications to the trial area are summarised in Table 8-2, using data extracted from the SWAN Systems website.

Irrigation and nutrition management was assisted by the use of Phytech® dendrometers mounted on the trunks of trees. Each monitoring station consisted of three adjacent trees, and there was one station installed on Shasta trees in the Trial 4 valve unit (Valve 38).

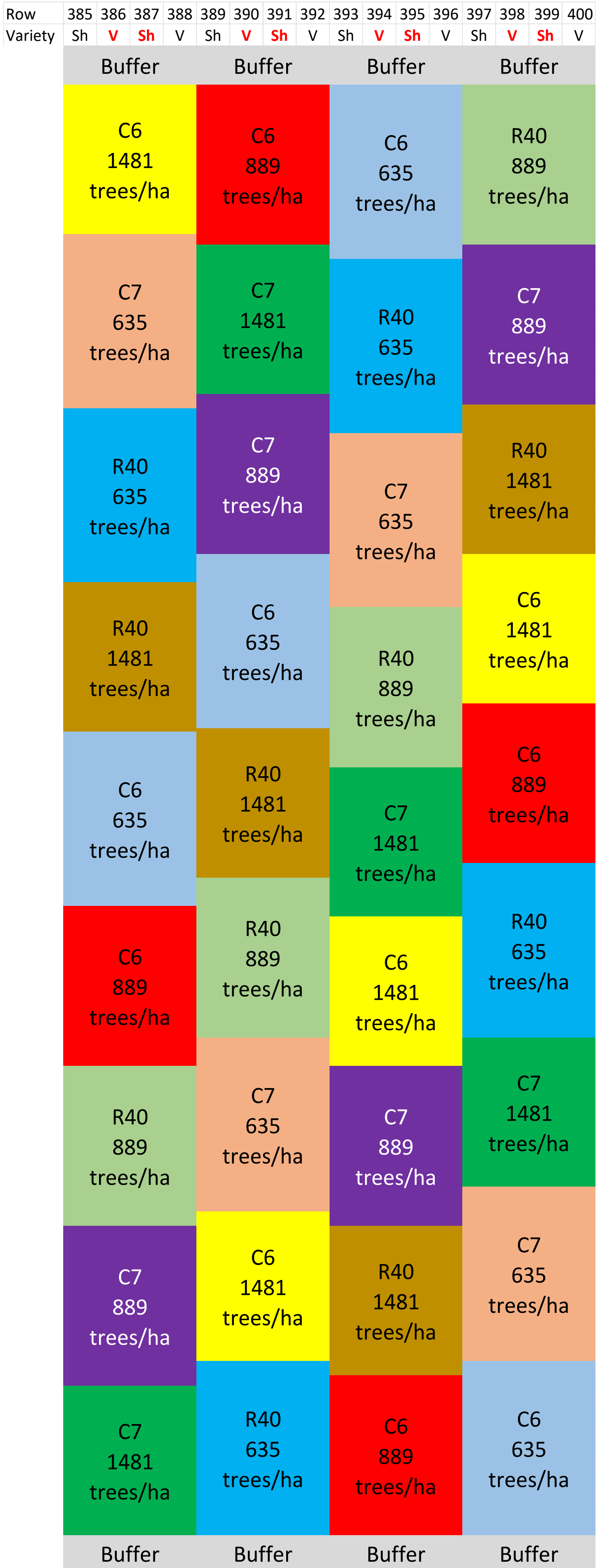


Figure 8-1. Treatment map of Medium (H2) – High (H3) Optimised Density Trial, showing rootstock and tree density treatments (C6 = Controller-6, C7 = Controller-7, R40 = Rootpac-40)

Figure 8-2. Medium (H2) – High (H3) Optimised Density Trial, taken shortly after planting in May 2019

Figure 8-3. Medium (H2) – High (H3) Optimised Density Trial, showing trees trained to bamboo stakes tied to horizontal wires strung between steel posts

Table 8-2. Nutrient application to Medium (H2) – High (H3) Optimised Density Trial

Nutrient	NO_3-N	Other N	Total N	P	K	Ca	Mg	S
Applied (kg/ha)	46.08	55.6	101.68	32.88	131.18	13.32	1.42	31.99

Two sets of soil solution samplers were installed in this trial at 1.5 and 3.5 m tree spacing in Shasta x R40 plots. The samplers co-located with EnviroSCAN soil water sensors. Samplers were installed at depths of 30, 60 and 90 cm at each site. Soil solution samples were collected approximately once per week across the growing season, and more often during fertigation campaigns. Successful sample collection was determined by soil water content, and while some samplers did not produce samples very often, others produced samples almost every time. Samples were measured for EC, pH, NO_2, NO_3 and K content.

Tree size was measured manually in May 2020. Other remote sensing methods were also used to collect data on tree size and canopy development.

SARDI's Mobile Orchard Phenotyping Platform (MOPP) was used to assess canopy growth through the season's by measuring trunk diameter, tree height and light interception. Light interception data were collected on 6 occasions between May 2020 and July 2021. Leaf Area Index was measured using the Li-Cor LAI 2000®. Measurements were taken on 9 occasions between March 2019 and May 2021.

Figure 8-4. Targeted removal of poorly directed laterals followed by light hedging in Dec. 2020, Medium (H2) – High (H3) Optimised Density Trial. Before (a) and after (b)

Most trees carried zero crop in 2021 (2nd leaf) meaning yield assessments were not conducted in the life of this project.

Throughout season 2021 (second leaf), trees received (approximately) monthly tipping to increase branching, reduce branch calliper and encourage growth along the row. Tipping should be performed in the first two seasons, and again in seasons 3-4 if the scion variety or scion/rootstock combination produces a very upright tree. The most significant training input during season 2021 was the removal of thick, poorly directed laterals in early summer followed by a light hedging operation, Figure 8-4.

8.3 Results

Soil Water Monitoring

Total soil water content of the top 40 cm of soil during the 2020/21 season, as measured by EnviroSCAN® sensors, is shown in Figure 8-5 for the Shasta row, and Figure 8-6 for the Vela row. The top graphs show data for 3.5 m tree spacing (635 trees/ha), and the lower graphs show data for the 1.5 m tree spacing (1480 trees/ha). Irrigation, rainfall and reference evapotranspiration (ET_0) are also displayed.

Technical issues with some of the sensors at site 4 (Shasta 635 trees/ha) led to random data peaks during the period from late December to early March. In addition, there was a failure of the logger in mid-June, resulting in a gap in the data from that time. This has since been rectified.

Detailed analysis of the traces from sensors at various depths in the profile (detail not shown) provides some understanding of irrigation adequacy throughout the season. This analysis indicates that the Shasta trees planted at 635 trees/ha were well irrigated throughout the majority of the season, only drying out in Autumn when irrigation was cut back after harvest and as the trees began to lose their leaves.

It is pertinent to note that this treatment was also where the Phytech sensors were installed, whose data supported irrigation scheduling decisions.

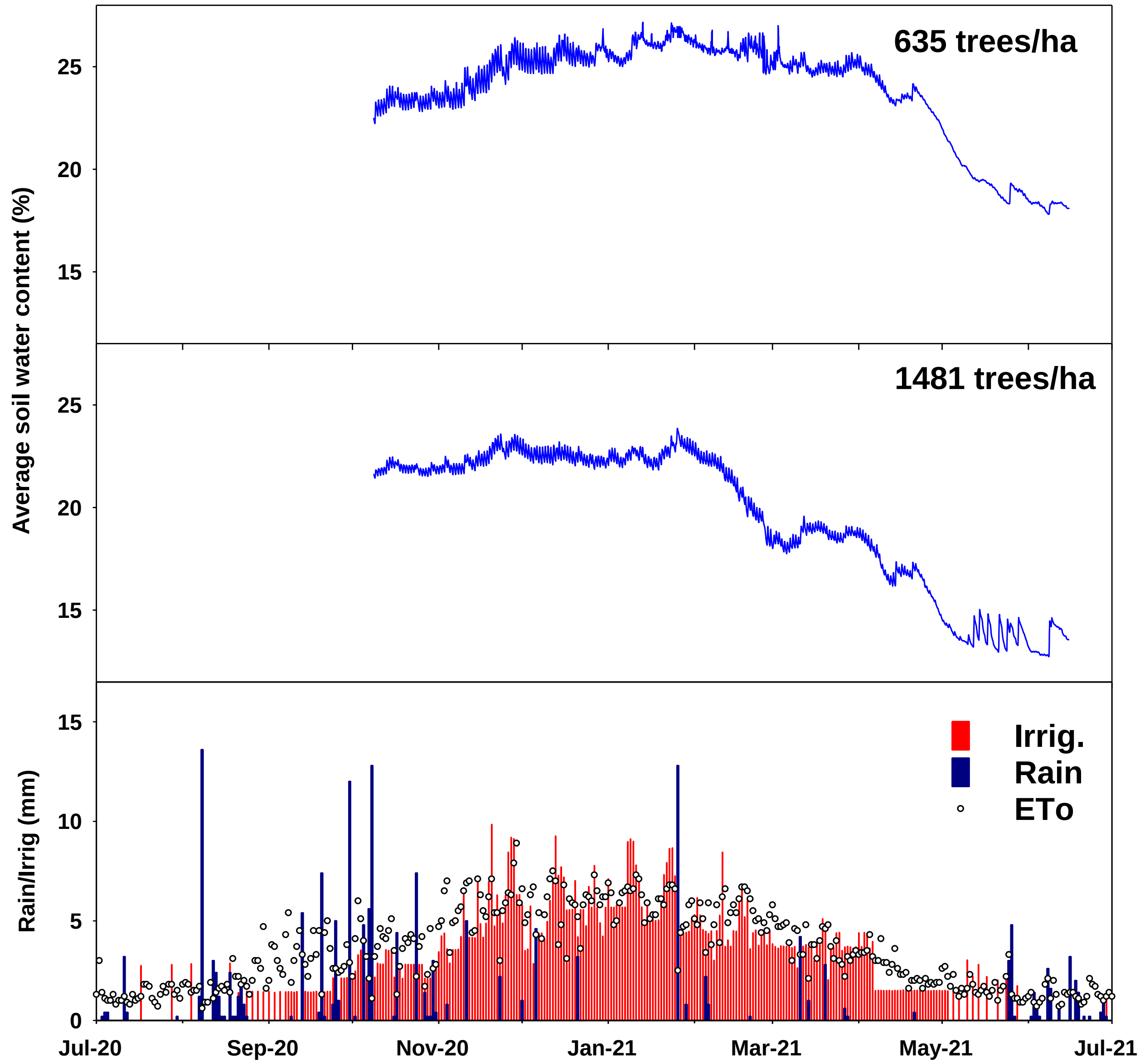


Figure 8-5. EnviroPro soil water monitoring data and irrigation, rainfall and reference evapotranspiration for 2020/21 season, Medium (H2) – High (H3) Optimised Density Trial, for Shasta trees planted at two tree densities, on Rootpac-40 rootstock. Soil moisture is average percent soil water content of the top 1m soil depth.

All other variety and density combinations showed some level of inadequate irrigation through the season. Suggesting that the irrigation applied was just enough for the Shasta 635 trees/ha treatment, but that the higher density treatments used more water, as did Vela trees.

Modifications have been made to monitoring and irrigation scheduling in this trial, to ensure that all treatments have non-limiting water availability.

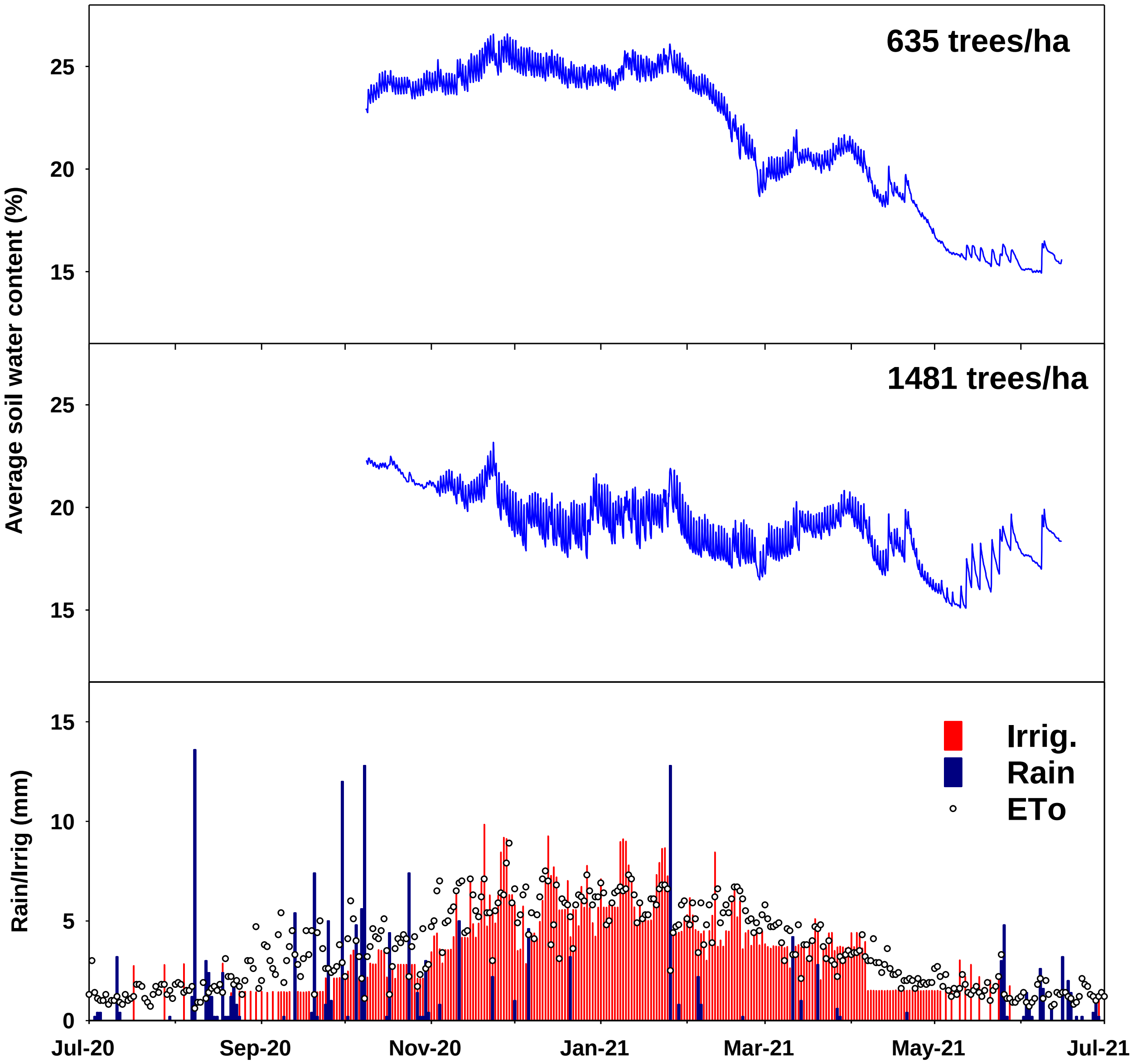


Figure 8-6. EnviroPro soil water monitoring data and irrigation, rainfall and reference evapotranspiration for 2020/21 season, Medium (H2) – High (H3) Optimised Density Trial, for Vela trees planted at two tree densities, on Rootpac-40 rootstock. Soil moisture is average percent soil water content of the top 1m soil depth.

Soil Solution Sampling

Figure 8-7 and Figure 8-8 display the results of analysis of nitrate concentration (a), pH (b) and electrical conductivity (c) of soil solution samples collected from three soil depths in the lowest (635 trees/ha) and highest (1481 trees/ha) density treatments of this trial. Note that as the season progressed the shallow depths (30 & 60 cm) in the highest density treatment failed to produce soil solution samples (Figure 8-8). This suggests that in this high density treatment the trees were rapidly taking up the applied irrigation water.

In both treatments the concentration of nitrate in the soil water (Figure 8-7a & Figure 8-8a) was quite variable and included some quite high values through the middle of the season (as high as ~250 mg/L). This suggests that nitrate applications to this trial were in excess of the requirements of these small trees. It is pertinent to note here that there are two rows of Maxima trees on the edge of this trial, and served by the same irrigation valve, which are 12 months older than the trees in this trial, and thus the nitrate applications were a compromise between the differing requirements of these trees within the same valve unit.

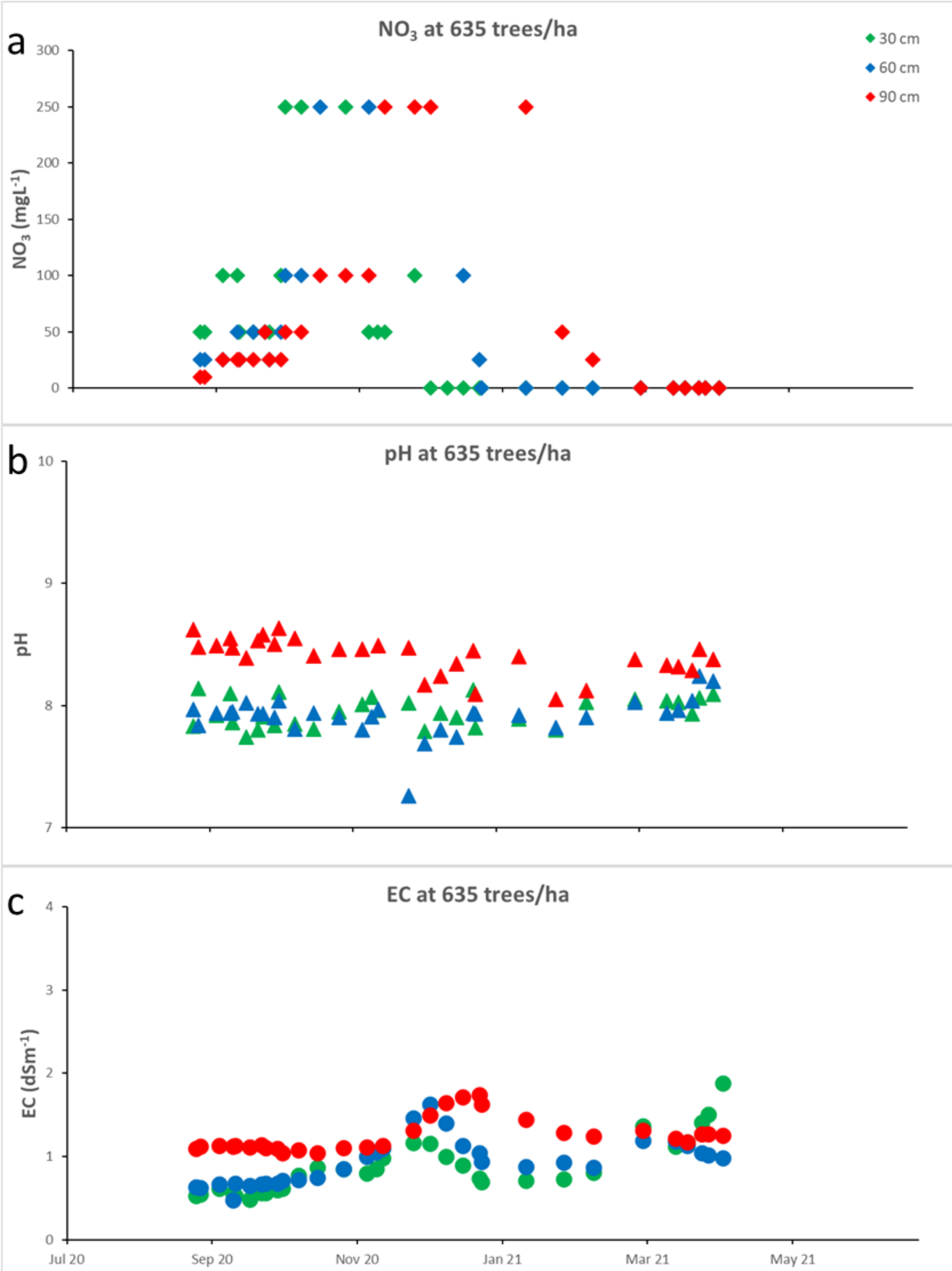


Figure 8-7. Soil solute measurements from 30, 60 & 90 cm soil depths in lowest planting density (635 trees/ha) of Medium (H2) – High (H3) Optimised Density Trial

The pH of the soil solution was uniformly alkaline but varied generally between 7.5 and 9.0 (Figure 8-7b & Figure 8-8b). The lower values were generally found in the lower tree density treatment, and at shallower soil depth. This suggests that the application of acidic fertiliser had a transitory impact on soil solution pH, despite the very high buffering capacity of this calcareous soil.

Electrical conductivity (Figure 8-7c & Figure 8-8c) was generally higher at greater soil depth, reflecting the concentration of salts in the soil water as plant roots extract water.

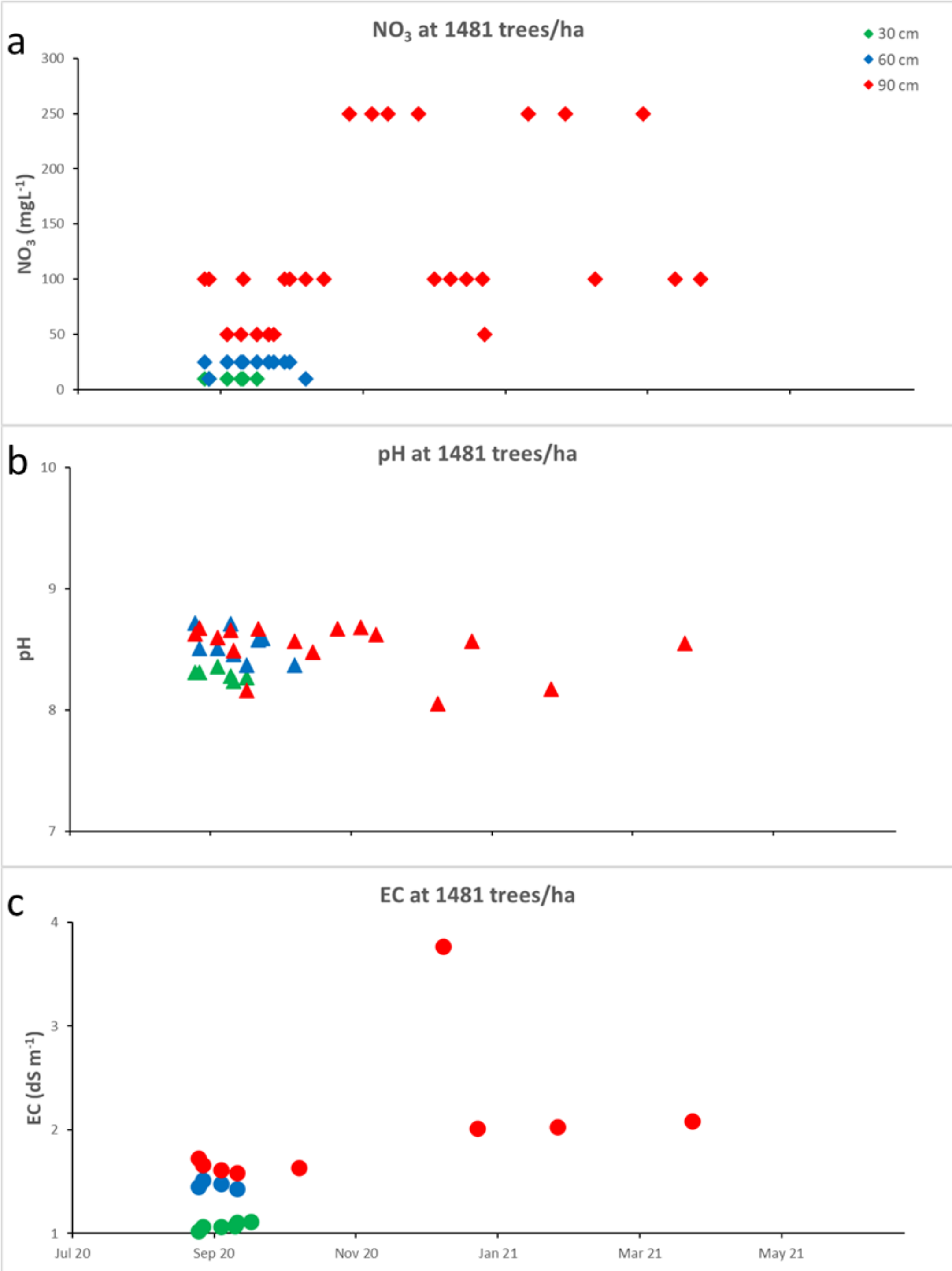


Figure 8-8. Soil solute measurements from 30, 60 & 90 cm soil depths in highest planting density (1481 trees/ha) of Medium (H2) – High (H3) Optimised Density Trial

Data from the lowest tree density (Figure 8-8c) also indicate a pattern of rising and falling salinity across the season, with the shallow depths responding first and the 90 cm depth lagging behind.

Tree Size

The full suite of tree size measurements was carried out in May 2020, near the end of the first season of in-field growth. Tree height and width, and trunk diameter data are displayed in Figure 8-9, with data compared by rootstock, variety and planting density.

Comparison by variety (Figure 8-9a) indicates that Vela trees were wider than Shasta and had larger trunk diameter. Height was not affected by scion variety. The natural habit of Vela is weeping, whilst Shasta is a more upright tree, hence the difference in tree width.

The trees in this trial were trained regularly, with a central leader being selected and tied to a vertical bamboo as described above. Without this training it is expected that the Vela trees would not have been as tall as Shasta trees, but the vertical training resulted in Vela trees matching Shasta for height.

Trunk diameter data suggests that Vela trees were more vigorous than Shasta trees, producing a larger overall tree, irrespective of the physical structure of the canopy. This increased vigour could possibly be associated with the training regime, which significantly altered the form of Vela trees but did not alter Shasta tree shape.

Comparison by rootstock (Figure 8-9b) indicates significant effects on all three tree size parameters. Trees on Rootpac-40 and Controller-6 were taller than trees on Controller-7, whilst Rootpac-40 produced the widest trees and the largest trunk diameters, followed by trees on Controller-6, with trees on Controller-7 being smallest for all parameters.

The smaller size of trees grafted to Controller-7 is not purely as a result of genetic dwarfing by this rootstock. Tree size is very variable in these trees, as is tree health, and is believed to be related to soil pH (see below Section 8.4).

Planting density had no significant impact on any of the tree size parameters measured in May 2020. This appears to be due to the fact that the trees were still filling their allotted spacing at all densities, and to that date there was minimal competition between adjacent trees even at the highest planting density (1481 trees/ha).

In September 2021 trunk diameter was measured in these trees, at the beginning of their 3rd leaf. Figure 8-10 presents the data for three dates, planting in May 2019 (set to a nominal value of 5 mm diameter), the end of the first leaf in May 2020, and the beginning of the third leaf in September 2021.

The larger trunk diameter of Vela trees as compared to Shasta trees was maintained from 2020 into 2021. Trunk diameter can be used as a proxy for overall tree biomass, and these results suggest that the Vela trees continued to be larger than Shasta trees overall, supported by LAI data.

Whilst there was a significant difference in trunk diameter between trees on Rootpac-40 compared to those on Controller-6 in May 2020, this difference was smaller and not statistically significant in September 2021. The reason for this is not clear.

What is clear, however, is that the poor health of trees on Controller-7, in reaction to moderately high soil pH, continued to retard the growth of these trees. The gap between these trees and those on the other two rootstocks widened considerably during the 2020/21 growing season (2nd leaf).

There was no impact of tree density on trunk diameter in May 2020, but separation between treatments was evident by September 2021. Trees planted at 1481 trees/ha (4.5 x 1.5 m spacing) had significantly smaller trunk diameters than those planted at the wider spacings. This indicates that trees at this highest density were beginning to fill their allotted space, and competition between adjoining trees was restricting the rate of growth. However, there was still no significant difference between trees planted at 889 (4.5 x 2.5 m) and 635 trees/ha (4.5 x 3.5 m).

Figure 8-11 displays relative trunk radius as measured by Phytech dendrometers. The data is the average of three dendrometers, all installed in adjacent Shasta trees within the lowest planting density (635 trees/ha). The data was used by the Farm Manager to assist with irrigation scheduling. The clear sigmoidal curve illustrates the growth pattern of the trees across the growing season.

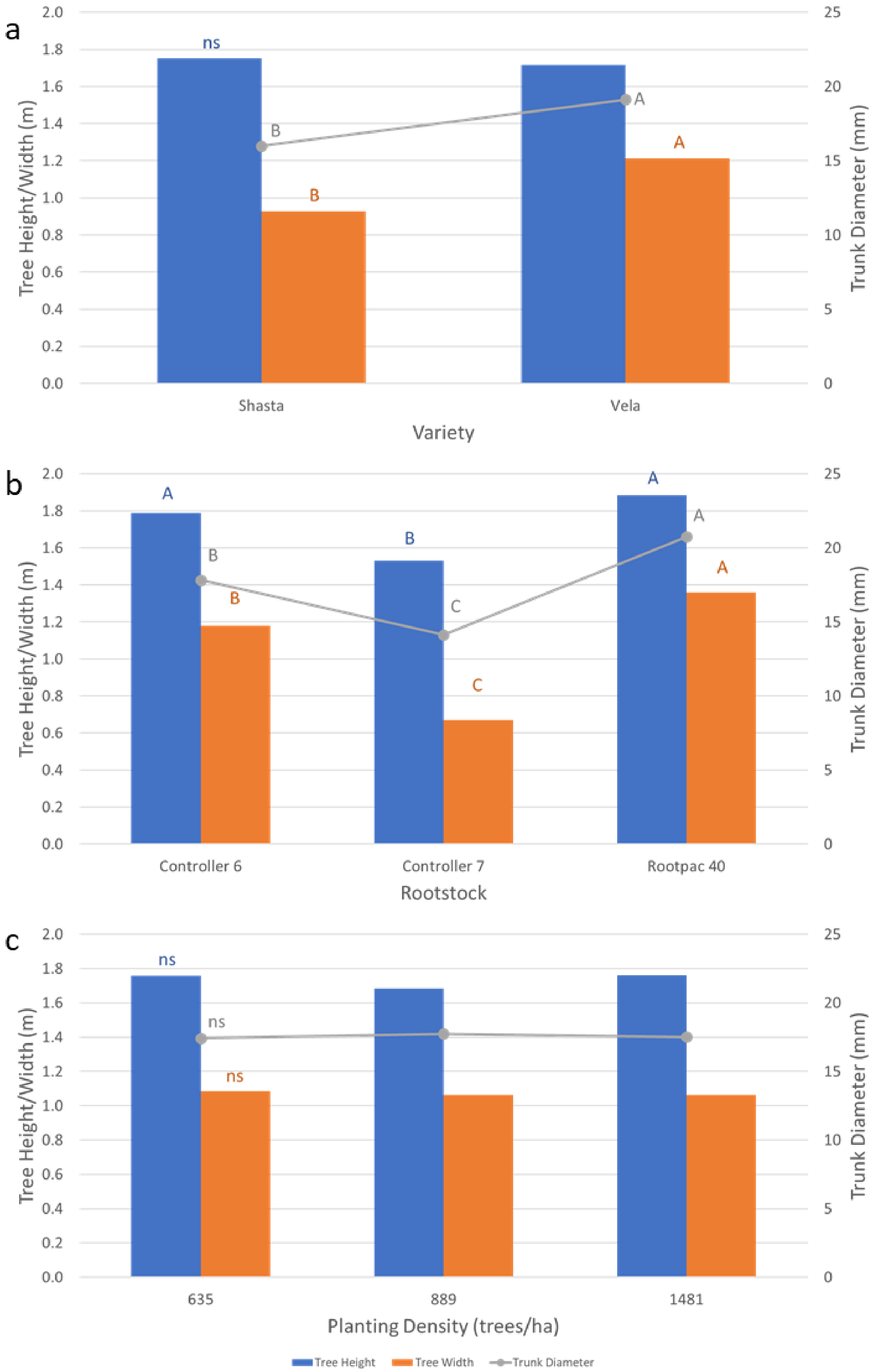


Figure 8-9. Tree size in Medium (H2) – High (H3) Optimised Density Trial, measured in May 2020, as affected by rootstock and variety genotype and planting density. Data points with the same letter are not significantly different at P = 0.05, "ns" indicates no significant differences in the data set.

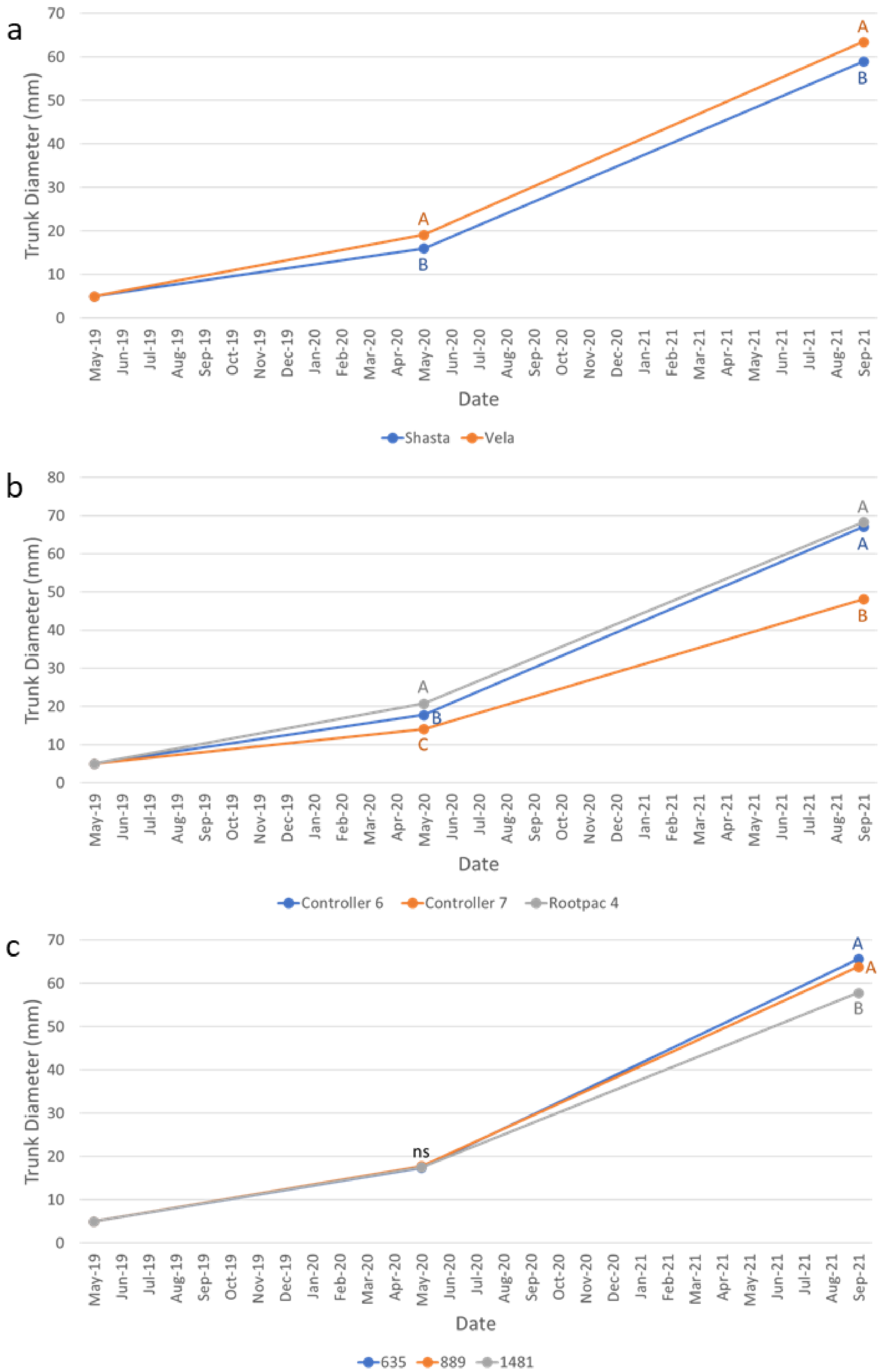


Figure 8-10. Trunk diameter over time in Medium (H2) – High (H3) Optimised Density Trial, as affected by rootstock and variety genotype and planting density (nominal 5 mm at planting in May 2019). Data points with the same letter are not significantly different at P = 0.05, "ns" indicates no significant differences in the data set.

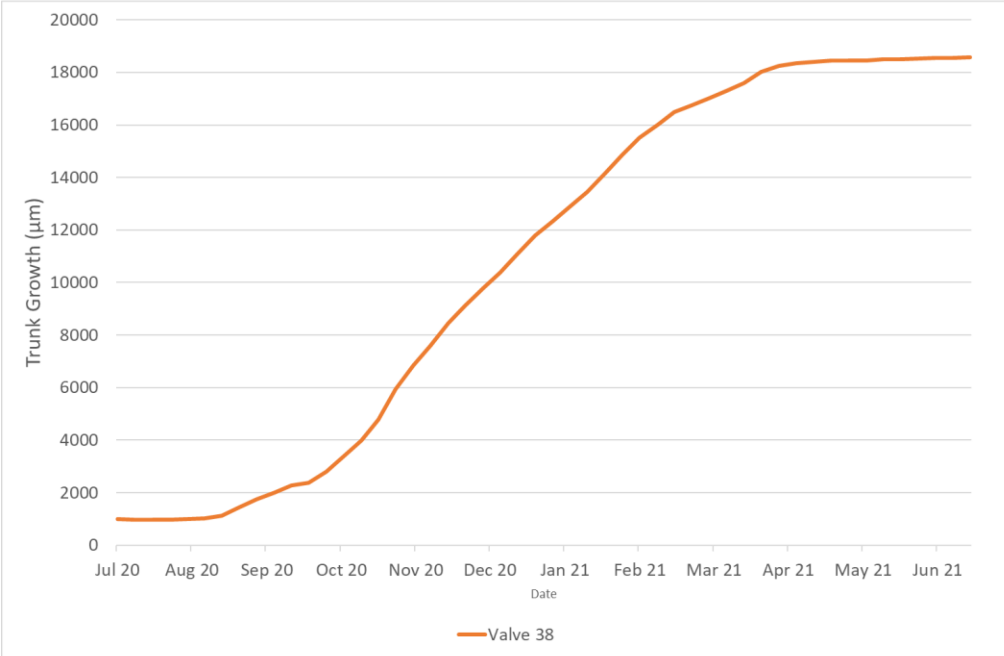


Figure 8-11. Trunk radius increase from nominal 990 µm base value, sourced from Phytech dendrometer data

Light Interception

Through the 2021 irrigation season, SARDI's MOPP was deployed (approximately) monthly across all trials to collect light interception metrics. Figure 8-12 displays light interception data collected in December 2020 from SARDI's H2 to H3 (medium to high) density optimisation trial. The values reported for each density are averaged across two varieties (Shasta and Vela) grafted to three rootstocks (Rootpac-40, Controller-6 and Controller-7). Light values across the row suggest greater interception close to the trunk, with the greatest interception by trees planted at the highest density (1481 trees/ha).

There is also higher interception on the east side of the tree than on the west side. This correlates with greater canopy development on the east side, apparently due to the prevailing winds coming from the west, and therefore encouraging growth on the east side and discouraging growth on the west side of trees.

Leaf area index (LAI) results are shown in Figure 8-13, for both varieties and the highest and lowest tree densities. The annual pattern of low LAI during senescence and high LAI during the growing season is shown, with a clear reduction in LAI in January 2021. This coincided with a summer pruning to train the trees and maintain a narrow canopy to facilitate access between the rows, and to provide flexibility in harvesting method in later years, when over-the-row harvesting may be trialled.

Although most dates showed no statistically significant differences in LAI between treatments, the highest density of Vela trees showed significantly higher LAI than the lowest density of Shasta trees in January and March 2021.

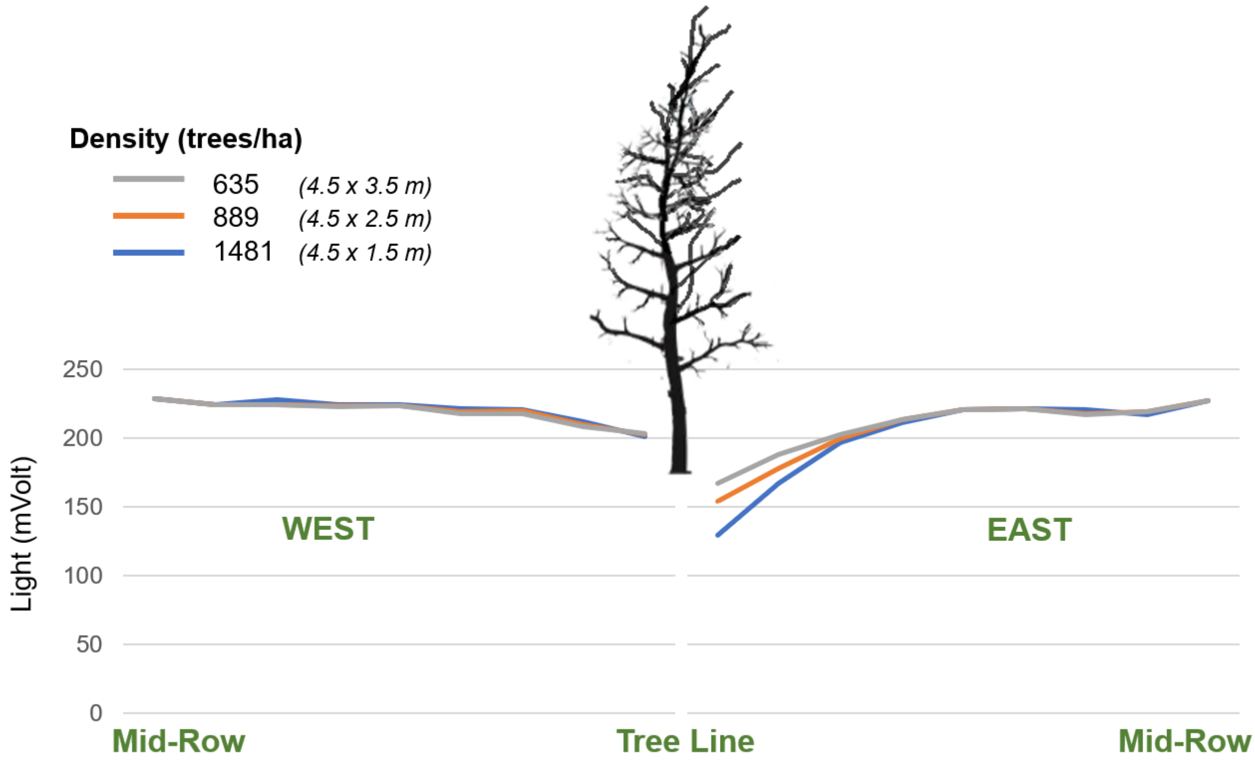


Figure 8-12. Light intensity at ground level across the tree row as measured by pyranometer array on SARDI's Mobile Orchard Phenotyping Platform in the Medium (H2) – High (H3) Optimised Density Trial, December 2020

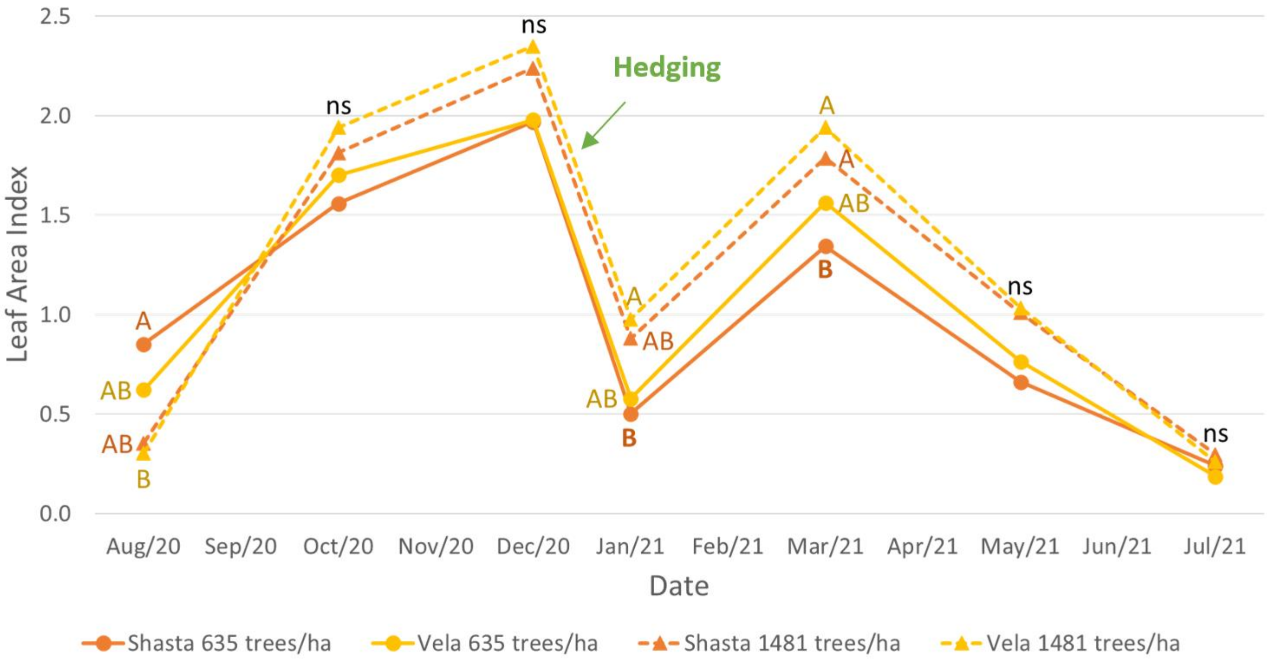


Figure 8-13. Leaf area index measured in the Medium (H2) – High (H3) Optimised Density Trial across the 2020/21 growing season. Data points with the same letter are not significantly different at P = 0.05, "ns" indicates no significant differences in the data set.

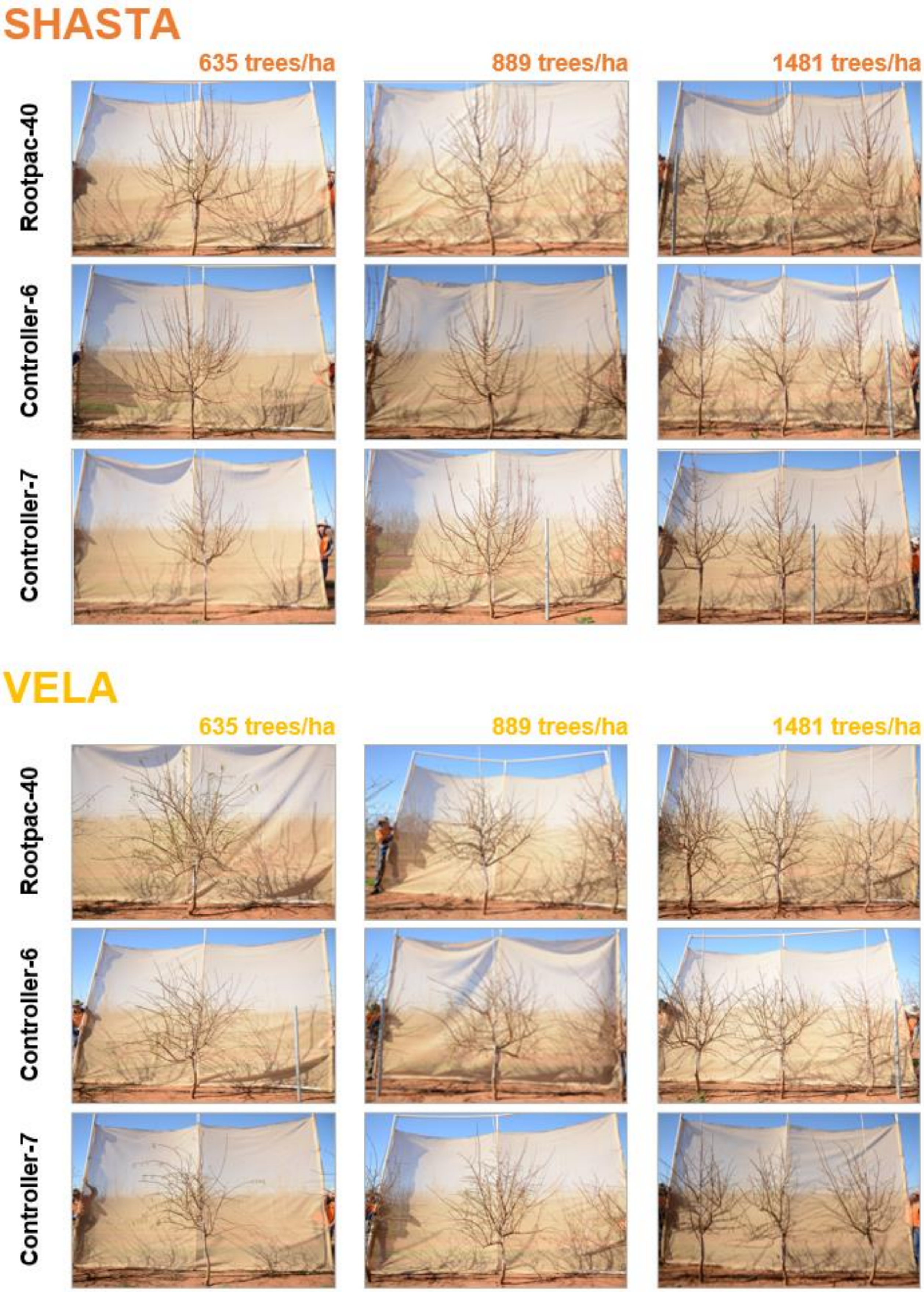


Figure 8-14. Representative trees in SARDI's Medium (H2) – High (H3) Optimised Density Trial. Two scions (Shasta and Vela) grafted to three rootstocks (R-40, C-6 and C-7) planted to three densities (635, 889 and 1481 trees/ha). Agromillora 'Smart Trees' planted in May 2019. Photos taken in July 2021.

Tree Shape/Structure

Figure 8-14 displays trees planted in this trial, representing both varieties, all three rootstocks and the three planting densities. The images were taken in July 2021 (when dormant) allowing a clear view of the branching structure.

The figure clearly demonstrates the difference in structure between Shasta and Vela. Shasta shows strong scaffold branches and a strong vertical growth pattern, whilst Vela branches are much less vertically oriented and naturally flatter than those of Shasta. Shasta's upright growth habit will place further emphasis on tipping into the third and fourth seasons to encourage lateral canopy development.

Comparison of rootstocks within each variety demonstrates differences in tree vigour. Trees on Rootpac-40 tend to be the largest, followed by trees on Controller-6, whilst those on Controller-7 are more variable. Other evidence suggests that the effect of Controller-7 rootstock on tree size is moderated by the pH of the soil at the location. These photographs were taken in some of the better soil within the trial, and do not show the full impact of the chlorosis symptoms on tree growth. An example of a severely affected tree is shown in Section 8.4.

Figure 8-15. Photograph of developing nuts on third leaf Vela tree on Controller-6 rootstock in Medium (H2) – High (H3) Optimised Density Trial, photographed on 30/9/2021.

Figure 8-14 demonstrates the impact of tree density on tree size to date. At this early stage, there is no consistent difference between the lowest two densities (635 trees/ha on the left, and 889 trees/ha in the centre), but the highest density trees (1481 trees/ha on the right) appear to be the smallest, which is consistent with the results displayed in Figure 8-10c above.

Close-up views of branching and developing nuts are also shown in Figure 8-15 (Vela) and Figure 8-16 (Shasta), which further illustrate the horizontal positioning of branches on Vela trees, and the more vertical branch position on Shasta trees.

Figure 8-16. Photograph of developing nuts on third leaf Shasta tree on Controller-6 rootstock in Medium (H2) – High (H3) Optimised Density Trial, photographed on 30/9/2021.

8.4 Issues and opportunities

Economics of Orchard Establishment

The economics of this system will be more closely assessed through SARDI's contributions to AS18000. However, a preliminary assessment follows. The highest tree density in this trial (1481 trees/ha) requires roughly 4.7 times as many trees as the Horizon 1 Resource Block (317 trees/ha). Table 8-3 displays the estimated cost of the additional trees required for the densities planted in the Medium (H2) – High (H3) Optimised Density Trial, incorporating the higher unit cost of trees budded to size controlling rootstocks. The additional costs are substantial, close to $40,000/ha at the highest density.

In addition to the higher cost of the trees themselves, the greater number of trees has a direct impact on a whole range of operations associated with planting and establishing an orchard, and consequently the cost of these operations, for example planting, staking and tree training.

Table 8-3. Estimated cost of additional trees for higher density plantings compared to Horizon 1 density of 308 trees/ha, and incorporating additional cost for size controlling rootstocks

Tree spacing	Density (trees/ha)	Cost of trees ($/ha)*	Additional cost of trees ($/ha)
4.5 x 7.0 m	317	4,755	-
3.5 x 4.5 m	635	19,050	14,295
2.5 x 4.5 m	889	26,670	21,915
1.5 x 4.5m	1481	44,430	39,675

* Cost of standard trees estimated at $15/tree, cost of trees on size controlling rootstocks estimated at $30/tree, based on 2021 costings

There were a range of other operations associated with this trial planting which were in addition to the usual operations associated with orchard establishment:

- Trellis post purchase and installation
- Installation of two trellis wires at 700 and 1700-mm height using metal clips
- Plugging of un-used holes in the posts using plastic plugs (to minimise the noise created by the wind)
- Tying bamboo stakes to the wires using rubber ties
- Tying trees to the bamboo stakes using rubber ties
- Selective pruning
- Trimming using hedge trimmer

All of these operations would dramatically increase the cost of setting up an orchard, and as a result there needs to be a similarly dramatic increase in yield and/or production efficiency, especially in the early years of production, to offset these additional costs.

A full exploration of the economics of different planting densities is beyond the scope of this work. Given that no yield data has been collected from this trial so far, there is a need for ongoing data collection and analysis in order to address this question.

Controller-7 Chlorosis Issue

The small size of trees on Controller-7 (Figure 8-9) relates to a decline in tree health that first became apparent in early 2020 when trees grafted to Controller-7 rootstock began to exhibit leaf yellowing, leaf burn and stunted growth (see Figure 8-17 for an example of a severely affected tree). While the physical symptoms suggested iron, zinc or manganese deficiency, leaf nutrient analysis was inconclusive. Soil pH tests indicated a correlation between chlorotic foliage and higher pH soils, Figure 8-18. This hypothesis was strengthened following consultation with UC Davis researchers Patrick Brown and Ted DeJong who both relayed their experiences with the challenges of higher pH soils. Irrigation rates were adjusted in early February, and with the milder conditions following the summer period, many trees recovered to put on fresh growth late in the growing season. Trees on Controller-7 remained smaller than those grafted to other rootstock genotypes.

Figure 8-17. Photograph of a tree on Controller-7 rootstock severely affected by chlorotic response to high pH soil.

Potential management strategies were discussed with the ABA's ACE management committee in June 2020.   It was decided that the Controller-7 trees should be kept within the trial and an attempt made to recover their health through the application of elemental sulphur. This remedial treatment was applied to the Controller-7 plots within Trial 4 in August 2020. Sulphur was buried in a shallow trench adjacent to the tree row at 100g per linear metre (equivalent to 10t/ha). It was anticipated that biological activity would slowly convert the sulphur into sulphuric acid and lower soil pH in the vicinity of the trench. Tree roots within the zone of lower pH should then be better able to access the previously unavailable micronutrients.

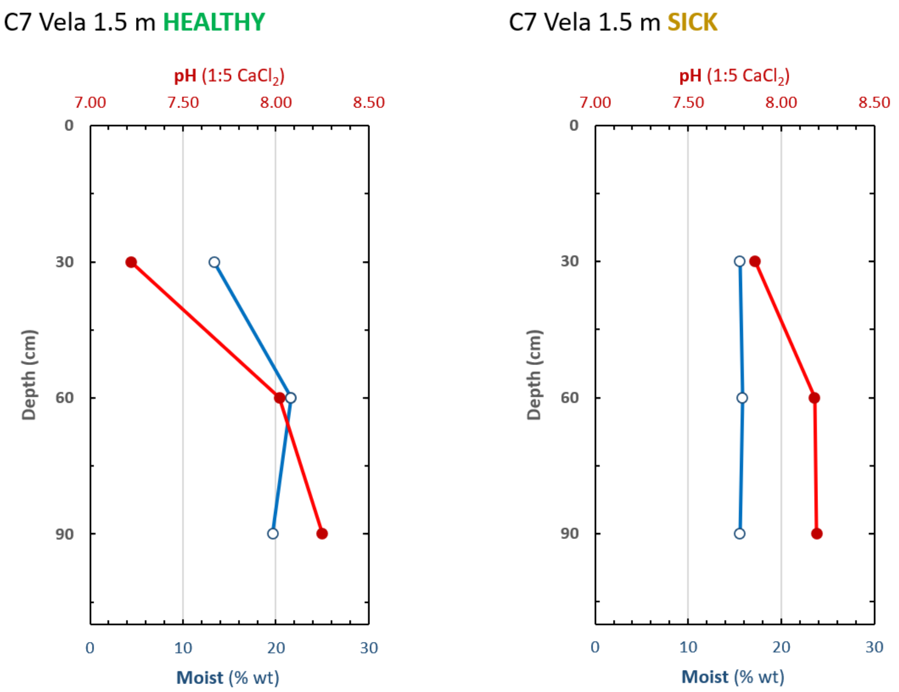


Figure 8-18. Comparison of soil pH and moisture content in soils producing healthy versus chlorotic/necrotic trees grafted to Controller-7

Early in season 2021, these trees appeared to be recovering from the issue, with new growth presenting as healthy shoots. However, in February 2021, following a period of hotter weather, trees grafted to Controller-7 again started to yellow. In some cases, this yellowing developed into necrotic tissue. Whilst one of the Controller-7 plots, on deeper less alkaline soil, remains healthy, three of the replicated plots are still in decline.

The integrity of the overarching trial remains intact with multiple replicates testing two varieties, two rootstocks and three densities. However, those trees grafted to Controller-7 have proven to be uneconomic for soils such as those at the Almond Centre of Excellence.

Although this issue was unexpected at the time when this trial was designed, it does highlight the need for such trials to test new planting material under local conditions. Tree performance to date is evidence for avoiding the use of Controller-7 rootstock in the Southern Murray Darling Basin region, where the vast majority of the Australian almond industry is based.

Further information about the performance of Controller-7 at the ACE site is contained in SECTION 6.

Replacing Controller 7 trees

SARDI are currently exploring options for making better use of the Controller-7 plots, clear in the knowledge that they will not contribute further industry learnings. The option of replanting the unhealthy Controller-7 plots with trees on an alternative rootstock is being explored. Although these replant trees would no longer be statistically comparable to the balance of the trial area (itself remaining as a valid RCBD design), they would enable a secondary demonstration opportunity to investigate other rootstock genotypes, densities and pruning strategies.

To date, SARDI investigations of Horizon 2 orchards have focused on using dwarfing stocks to help manage tree size to mitigate space and sustainability issues with the system. However, these stocks are size controlling for a reason, and often bring with them a host of potential issues such as incompatibilities, physiochemical challenges, smaller or less functional root and vascular systems, low vigour, constant need for nitrogen inputs, suckering, small fruit and graft union overgrowth.

Recent personal communications with Jose Maria Lianez of Agrolainez (Spain), and John Slaughter, Wawona-Prima (California), suggest that super high-density systems planted on shallow or less hospitable soils, may be successful using high vigour rootstocks. Vigour can be controlled through planting in poor, shallow soils, well controlled sparing irrigation during phase 2 fruit growth stage, and appropriate orchard management practices.

With this in mind, consideration is being given to replanting two of the worst affected Controller 7 replicates in the Medium (H2) – High (H3) Optimised Density Trial with trees on more vigorous rootstocks, better able to accommodate the shallow calcareous soil in the southern end of the trial area. Rootstocks would be selected based on learnings from the ACE compatibility trial and offsite experience and target genotypes with the capacity for early canopy fill and cropping.

Water use

In the first two seasons of this trial the planting received a total of 3.6 ML/ha (2019/20) and 7.6 ML/ha (2020/21) of irrigation water. As outlined above, the irrigation system installed at the Almond Centre of Excellence applies water at a consistent application rate across the property, rather than varying with planting density. This reflects the expectation that water use will be similar across densities in mature trees, given that transpiration is driven by canopy area, not the number of trunks in the ground.

However, until the tree canopies fill their allotted space and merge into a hedgerow, there are differences in water use between the different planting densities within trials. As a result, some trees will likely receive too much or not enough water when other trees are irrigated adequately.

Following concerns that inadequate irrigation may have been a brake on tree growth and development, irrigation will now be scheduled according to the highest water use treatments, ensuring that all trees receive at least adequate water to fulfill their needs. Whilst this will not facilitate estimation of the real water needs of the different planting densities, it will ensure that each density treatment grows and yields to its potential.

Trials incorporating detailed irrigation scheduling for individual treatment plots at different planting densities are being undertaken by Agriculture Victoria at Irymple. This work will provide supplementary information to complement the work being undertaken in this trial.

Canopy structure

The two varieties planted in the Medium (H2) – High (H3) Optimised Density Trial were chosen for their very different growth habits. Vela is a weeping tree, whilst Shasta is very upright (Figure 8-14). This choice was intentional, as it offered the opportunity to assess the adaptability of these two different growth habits to a very high planting density.

Results to date indicate that Vela requires constant re-tying of the central leader as it grows but adapts well to this regime. Shasta requires much less attention, as it naturally grows in this fashion, and just needs periodic tying up to ensure it grows straight.

With regard to establishing the hedgerow planting being targeted, the varieties responded differently. Vela filled the space between trees more effectively than Shasta, as even when trained to a central leader, the side branches weep out from the central trunk, while Shasta branches tended to grow vertically, and the tree remained narrow. However, as a result of its spreading habit, Vela was more prone to invade the mid-row, and required more pruning to maintain access, whilst Shasta required less management in the mid-row.

As the trees grew over their first two seasons it became clear that the widest in-row tree spacing (3.5 m) was too wide, especially for Shasta. After 2 seasons there was still a large amount of empty space between Shasta trees along the row, and some empty space between Vela trees at this spacing. The time taken for Shasta trees to fill this space was lost productivity in the early years of the orchard, a critical period for obtaining the rapid payback required for high density orchards to prove economical.

Going forward a key focus of the research will be on how the different tree architecture impacts yield. It is likely that the height of trees will need to be managed by pruning, especially if over-the-row harvesting is practiced. This raises the question of where trees of each variety will bear fruit in later seasons, and whether the upright habit of Shasta may lead to the removal of significant amounts of new fruiting wood each time the trees are pruned, limiting the long term viability of this variety.

Further tree architecture observations are ongoing SARDI's Scion/Rootstock compatibility screens, SECTION 6, where a greater number of rootstock and scion genotype combinations are being compared.

Timing of trellis removal

One issue to address in regard to the Medium (H2) – High (H3) Optimised Density Trial is when to remove the 'temporary' trellising. The trellising had been invaluable in supporting the trees through the initial seasons of growth and training, but the trellis is not designed as a permanent structure. In addition, the presence of the trellis may prove an obstacle to efficient shake-and-catch harvesting of the orchard. As a result, it is planned that the trellising will be removed at some point through the 21/22 or 22/23 season.

The 2021/22 season will be the first in which these trees have yielded a significant crop. In order to harvest this crop modifications to the current structure may be required, and thus it may be appropriate to remove the structure altogether. However, this decision will be made later in the season, and will depend on how well the trees are able to support their own weight, including the weight of the crop, without the aid of the trellis structure.

Timing of pruning ops

Some pruning was carried out on the trial during the 2020/21 season, to reduce growth into the inter-row space, and encourage growth along the tree rows. There is a need for ongoing canopy management in this planting, given the very narrow inter-row space (4.5 m). However, the timing of canopy management operations is problematic now that the trees have commenced fruiting. In addition, there is potential for the weight of the crop to bend branches down into the inter-row area, restricting access.

Pruning while almonds are on the tree threatens to remove crop and impact yield measurements. Conversely, dormant pruning may remove fruiting buds for the new season's crop, and also may promote excessive vegetative growth at bud burst. The ongoing management of this planting will need to consider these issues, and further learnings will be available as the development of the experimental orchard progresses.

SECTION 9. Salinity tolerance of *prunus* rootstocks grafted to almond

Key points

- A glasshouse-based salt tolerance investigation was established to characterise the suitability of traditional and new rootstock genotypes for more saline production conditions.
- The study included eight replicates of six *Prunus* rootstocks and four saline irrigation treatments ranging from Control (nutrient salts only) through to High, >5 dS/m (nutrients plus mixed chlorides).
- The six rootstocks were assessed in separate trials, either as ungrafted trees or grafted with Nonpareil and Shasta as scions.
- Cornerstone was identified as being the most tolerant of the rootstock genotypes assessed. It showed good salt exclusion properties and maintained growth under saline growing conditions.
- Cornerstone's favourable performance extended to the Nonpareil and Shasta scion genotypes when grafted to it.
- Garnem and Barrier-1 also managed some levels of salt stress but were less consistent performers than Cornerstone.
- Agriculture Victoria Research incorporated SARDI samples in the development of a spectral model to allow proximal sensing of leaf ionic composition.

9.1 Background and aims

Almond is a salt sensitive crop. For most of the Australian almond industry, the risk of soil salinity is linked to the quality and availability of water in the Murray River. While groundwater systems close to the Murray hold vast quantities of saline water, the risk of saline flows has significantly reduced since the late 1980's when investment into salt interception (SI) schemes allowed diversion of saline groundwater and drainage water away from the river. Whilst SI schemes have lessened the threat of salinity for River Murray irrigation districts, there are scenarios where almond production remains susceptible to salt related decline.

Despite the downward trend in salinity following the installation of SI infrastructure, the river's occasional susceptibility to salt spikes during both drought and flood events remain as irrigation induced salinity risks, Figure 9-1. The spike between 2007 and 2010 occurred during the Millennium Drought when evaporation was high and surface water inflows were too low to dilute the saline groundwater inflows.

The spikes following 2012 relate to higher river flows and periods of widespread flooding, when the recession of flood waters from saline flood plains transported dissolved salts through the river before draining to the sea. Elevated river salinities, particularly during periods of reduced water availability/affordability, increase the risk of salt accumulation in the rootzone.

Some Australian almond growers contend with a more constant presence of salt in their irrigation water. These orchards include those using groundwater and/or recycled wastewater for their irrigation, both of which can have salt concentrations that exceed levels previously shown to cause vigour and production decline.

One of the strategies available to growers who want to protect against the threat of salinity is the use of salt excluding or salt tolerant rootstocks.

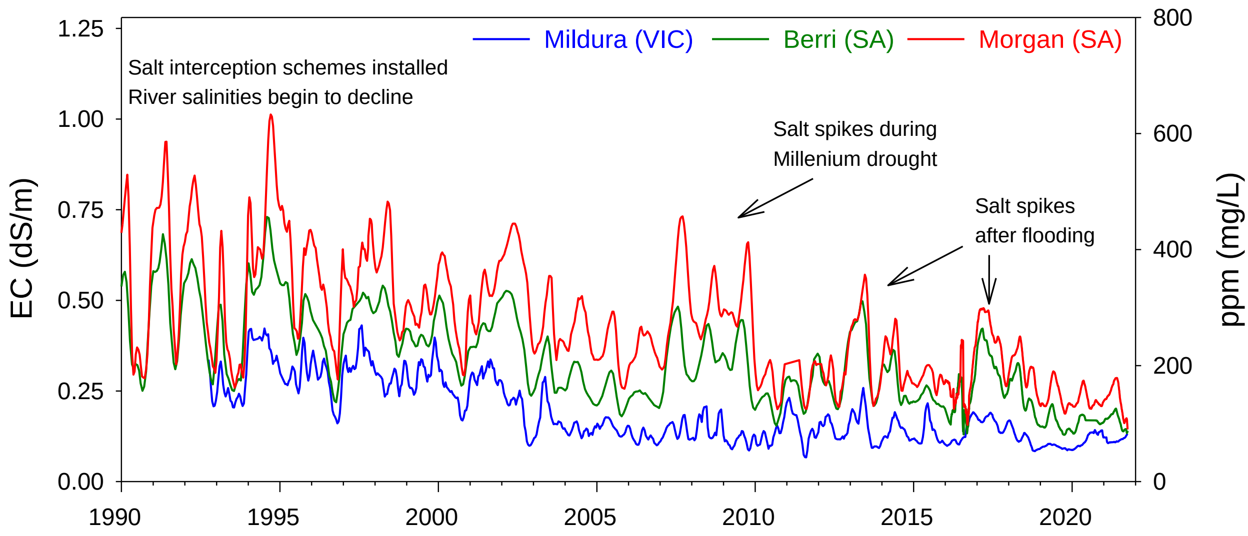


Figure 9-1. River Murray salinity (Electrical Conductivity and Parts Per Million) at each of three sampling points (Mildura, Berri and Morgan). 1990-2021. Note occasional spikes despite downward trend

This trial aimed to screen a suite of new and emerging prunus rootstocks for their tolerance to increasing concentrations of saline irrigation. The screen assessed six genotypes of rootstocks as ungrafted and grafted (to two scion genotypes) using eight replicates of four saline irrigation treatments ranging from 1.2 dS/m (nutrient salts only) through to 5.1 dS/m (nutrient plus mixed chlorides). Rootstock response was tested through plant growth metrics, ionic composition of leaf tissue, plant water relations and photosynthetic rates

9.2 Glasshouse trial methods

Trial design and statistical methods

Two trials were established to test the effect of increasing irrigation salinities on the performance of prunus rootstocks. Trial 1 (Ungrafted trial) comprised six ungrafted rootstock genotypes subjected to four irrigation salinities. Trial 2 (Grafted trial) tested the same six rootstocks but grafted to one of two almond varieties. Experimental plots were laid out in a randomised complete block design with four irrigation treatments replicated eight times as shown in Figure 9-2.

Plots were bordered by potted barrier trees of equivalent age and size to the experimental trees and non-bordered edge effects were accounted for in the analysis.

Statistical analysis was undertaken using Genstat® for Windows 21st Edition (VSN International, Hemel Hempstead, UK). Data were analysed as two-way factorials, Irrigation treatment by rootstock (and scion where appropriate). The four treatments represented different levels of salinity, so it was possible to partition the treatment effects into a linear component and characterise any deviations from linear. Comparisons were based on least significant difference (LSD) at P = 0.01 with comparisons also calculated for LSD at P = 0.05 and reported as indicative of a trend for differentiation.

Plants and glasshouse conditions

The trial was established in a glasshouse located in Urrbrae, South Australia (-34.97, 138.64). Glasshouse temperatures ranged from 23-33°C in the day and 15-23°C at night. Glasshouse cladding allowed more than 80% of total solar transmission with light supplemented by halide lamps, early in the season, to ensure a minimum 13 hours of daylength during the peak growing period. In September 2017, 150 plants of each of six prunus rootstocks were received as rooted cuttings or seedlings and planted in 5 L plastic pots containing coarse washed river sand. Plant genotypes are listed in Table 9-1. Plants were grown through to February 2018 when 50 of each rootstock genotype were grafted to Nonpareil and 50 to Shasta scion materials, the balance continuing to grow as ungrafted rootstocks.

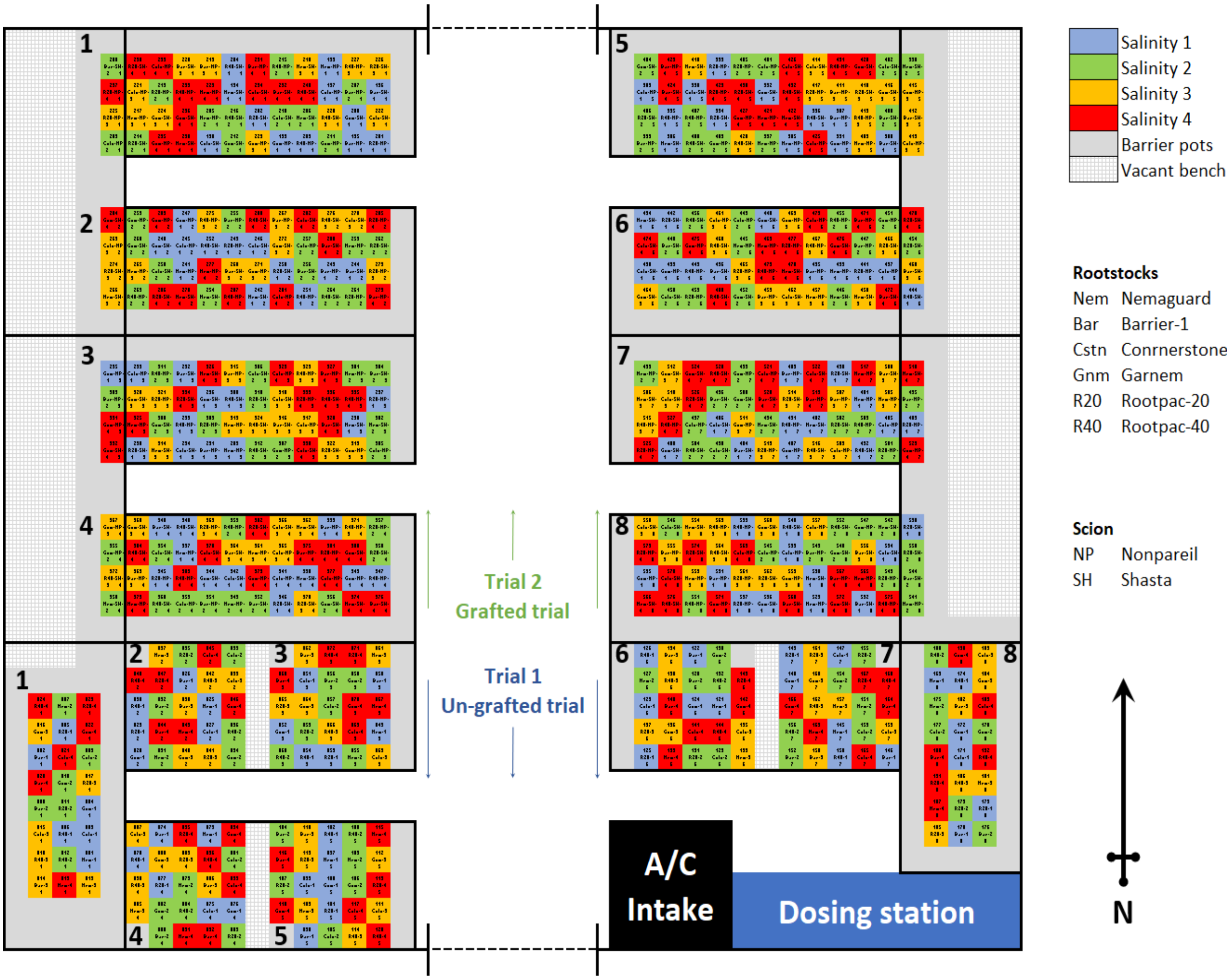


Figure 9-2. Map of experimental treatments in glasshouse salinity tolerance trials. Trial 1 – six ungrafted rootstock genotypes. Trial 2 – six rootstock genotypes grafted to two scion genotypes. Each trial comprised eight replicates of four salinity treatments with genotypes and treatments distributed randomly within each replicate.

During the pre-trial tree production phase, Rootpac-40 was noted for its low vigour and poor graft strike rate relative to that of the other rootstock genotypes. While the quality of planting material was questioned, Rootpac-40 trees were retained for the salt tolerance studies, and their response to saline growing conditions reported herein. It should be noted that the response of the Rootpac-40 plants available to this study may not truly reflect the genotype's potential to contend with a salt stress. Plant quality may have been the more dominant factor in the genotype's performance.

Extension growth was trained along bamboo stakes to produce single leaders. Between May and September 2018 plants overwintered outdoors. Experimental measures commenced on one-year-old trees on 22 November 2018, following all stems being pruned back to five viable buds (approximately 15 cm trunk length). On 18 February 2019, plants were pruned back to approximately 40 cm, leaving at least ten buds, and the harvested extension growth of leaders and laterals measured for length and dry weight. These measures were repeated at the end of the trial period, 21 May 2019.

Table 9-1. Rootstock and scion genotypes included in salinity tolerance investigations

Rootstock name	Parentage	Salt tolerance
Nemaguard	*P. persica*	Sensitive ††
Rootpac-20	*P. besseyi x P. cerasifera*	Moderately tolerant †
Rootpac-40	*P. dulcis x P. persica*	Moderately tolerant †
Barrier-1 (Empyrean 1)	*P. persica x P. davidiana*	Tolerant *
Garnem	*P. dulcis x P. persica (Nemared)*	Excluder **
Cornerstone	*P. dulcis x P. persica (Nemared)*	Excluder ‡ **

Scion name	Parentage
Nonpareil	Unknown seedling (1879)
Shasta	Tuono' X B1.005' (2001)

†† (Doll et al., 2014); † (Agromillora, 2021); * (Shao et al., 2021); ** (Zrig et al., 2016); ‡ (Burchell's, 2018)

Irrigation treatments

Experimental plots were irrigated with potable mains water, average Electrical Conductivity (EC) less than 0.6 dS/m, pH 7.3, Sodium (Na^+) 2 mM and Chloride (Cl^-) 2.2 mM. Nutrient and salt brines were injected by high pressure Acromet pumps (S2500 metering pumps, Acromet, VIC Aust.) at sequential dosing points separated by non-return valves and dampening loops of at least 2 m, Figure 9-3a. All treatments received the same fertiliser rate injected as a modified half strength Hoagland's mix (Hoagland and Arnon, 1950). A mixed chloride brine comprising NaCl and $CaCl_2$, at a ratio of 2.6:1, was injected into separate irrigation lines at rates targeting salinity treatments of:

Control (1.2 dS/m)	(potable water salts + Nutrient salts)
Low salinity (2.4 dS/m)	(potable water salts + Nutrient salts + mixed chloride salts)
Medium salinity (3.4 dS/m)	(potable water salts + Nutrient salts + mixed chloride salts)
High salinity (5.1 dS/m)	(potable water salts + Nutrient salts + mixed chloride salts)

All pots were irrigated with individual Netafim button drippers (2 L/hr @ 100 kPa), Figure 9-3d. Daily irrigations were scheduled to maintain sufficient drainage and avoid excessive salt accumulation in the pots. Irrigation volumes increased from 200 to 450 mL/pot through the experimental period and were monitored by in-line flow meters. Irrigation water samples were collected weekly by continuously bleeding the supply lines through micro-capillary tubes into 5 L sub-sampling drums Figure 9-3b. Continuous drainage samples were also collected from multiple replicates of Nemaguard rootstock (Ungrafted trial) and Nonpareil x Nemaguard trees (Grafted trial), Figure 9-3c. Both irrigation and drainage samples were measured for EC on a weekly basis with temperature compensated conductivity meter (model CON510, Eutech, Singapore). After measurement the remaining sample was frozen at –18°C prior to be being assessed for ionic composition, data not shown.

Quarter strength saline irrigation treatments commenced on 14 December 2018, 22 days after trees were pruned back to five bud leaders. Salt concentrations were incrementally increased to full strength by 27 December 2018, 36 days after pruning. 27 December 2018 was then considered day zero in the timeline of saline irrigation treatments.

Plant growth measures

Trees were non-destructively measured for the length of their extension growth, leader plus laterals, at approximately ten-day intervals, before and after the application of saline irrigation treatments. At day 54, extension growth was harvested leaving approximately 15 cm of trunk with at least ten viable buds. All harvested stems and leaves were dried at 70°C for at least 72 hours and their dry weight recorded. Plants continued to grow through until day 144 at which point the length of extension regrowth was measured and the whole plant harvested for dry weight. The relative growth rate (RGR) of each genotype grown under different salt treatments was estimated as the slope of the linear regression of the natural logarithm of plant extension growth on time. RGR was calculated before and after the imposition of saline irrigation treatments in a modification of methods suggested by Almeida-Cortez et al. (1999) and Negrao et al. (2017). RGR units were reported as micrometres of new extension growth per millimetre of pre-existing length per day (µm $mm^{-1}day^{-1}$).

Ionic composition of leaf tissue analysis

Twenty leaves were collected from plants at both the 54- and 144-day destructive sampling timesteps and prepared for determination of Na^+ and Cl^- concentrations. Leaves were sampled from midway along the extension growth. Samples were weighed before and after drying at 70°C for at least 72 hours in an Essa DO2 drying oven (FLSmidth, Copenhagen, Denmark).

Dried leaf samples were ground using a Micro Hammer-Cutter Mill (Culatti AG, Zurich, Switzerland) to pass through a 0.5 mm mesh. Cl^- concentration was measured by silver nitrate titration using a Metrohm 855 Robotic Titrosampler (Metrohm AG, Herisau, Switzerland). Na^+ concentrations were measured by Perkin Elmer Optima 7300 ICP-OES (Spectro Analytical Instruments, Kleve, Germany). Leaf sample extracts were prepared for Na^+ analysis using 100-300 mg of dried, ground sample in a nitric acid and hydrogen peroxide digestion. Samples were diluted to 25 mL and cold digested overnight. Following this, the temperature of samples was increased over a 2.5-hour time period to a maximum not exceeding 125°C.

Figure 9-3. Acromet nutrient and salt brine dosing station (a), irrigation sampling (b), drainage sampling (c), individual button drippers per pot (d) and experimental plants at commencement of trial (e).

Measuring leaf sodium and chloride with spectroradiometer

Agriculture Victoria Research (AVR) collaborated with SARDI to develop a model to relate leaf ionic compositions with spectral signatures. At both the 54- and 144-day sampling times, a 10-leaf subset was randomly selected prior to drying and scanned using a Spectral Evolution SM-3500 portable spectroradiometer (Spectral Evolution, Haverhill, MA, USA). Ratio-based reflectance scans were collected across the ultraviolet-near-infrared (350-2500 nm) part of the spectrum. Once scanned, leaves were returned to the bulk sample for drying.

Leaf water content was calculated from the ratio between the fresh and dry masses and used to convert leaf % Na^+ and Cl^- reported on a dry mass basis (Na^+_{DM} and Cl^-_{DM}) by the analytical service, back to % Na^+ and Cl^- on a fresh mass basis (Na^+_{FM} and Cl^-_{FM}).

Spectral data were evaluated using the multivariate statistical analysis program Unscrambler X (Camo Analytics, Oslo, Norway).

Photosynthesis and plant water relations

Stem water potentials and gas exchange were measured on all replicates between days 139 and 144 (May 2019). Fully formed leaves were enclosed in aluminised plastic bags for at least one hour prior before being excised and measurements collected with a Scholander Pressure Bomb (Scholander et al. 1965, Turner and Long 1980). Leaf gas exchange were measured on fully expanded and exposed leaves using a Ciras-3 Portable Photosynthesis System (PP Systems, Amesbury MA, USA).

9.3 Response of potted trees to salt stress

Saline irrigation

All experimental plots were irrigated with mains reticulated water (~0.6 dS/m) for the first 22 days after pruning back to five buds. At day 22, saline irrigation treatments commenced at quarter strength and gradually increased to full strength over the subsequent two weeks. Saline irrigation treatments then remained at full strength for the duration of the trial period, Figure 9-4. While treatment pots had a high drainage rate, the average concentration of salts in the leachate was approximately 20 % higher than that in the irrigation water. Saline irrigation treatments ranging from 1.2 – 5.1 dS/m resulted in average soil water salinities ranging from 1.2 – 6 dS/m.

Treatment response

Ungrafted Nemaguard and Rootpac-40 trees averaged 83% mortality at the highest salt exposures. Nonpareil and Shasta trees grafted to Rootpac-40 suffered the same effect with over 40% mortality at the highest salt concentrations. All other genotypes survived through to the end of the trial and were available for assessment. The significance of effect upon metrics assessed in the grafted and ungrafted rootstock trials are summarised in Table 9-2.

Plant gas exchange and water relations

Saline irrigation treatments significantly impacted photosynthetic rate (A), stomatal conductance (G_S) and stem water potential (ψ_{stem}) with plants exposed to the higher salt loads reporting reduced gas exchange and more negative ψ_{stem} relative to the control. Ungrafted Cornerstone rootstocks were least affected with A values ranging from 15.6 to 14.1 µmol $CO_2/m^2/s$ across the treatment range while Barrier-1 and Rootpac-20 were strongly affected with A values halved across the same treatment range (18 to <9 µmol $CO_2/m^2/s$). After 144 days of saline treatment, the ungrafted Nemaguard and Rootpac-40 trees had either died or had too few viable leaves for measurement at the higher treatment end. While there were strong treatment and rootstock effects in the ungrafted trial, there was no interaction between the two, Table 9-3.

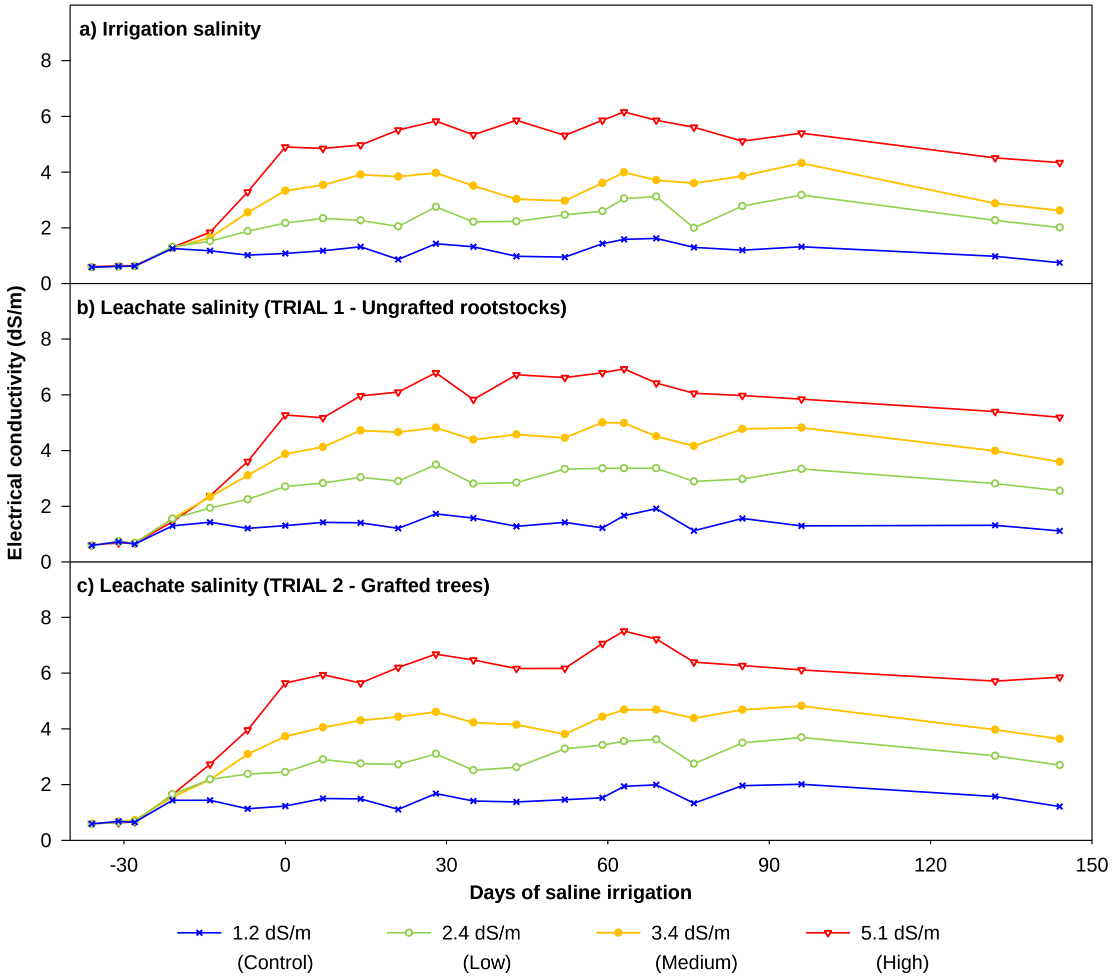


Figure 9-4. Average irrigation salinity across the trial period for four saline irrigation treatments (a) and the effect of treatments on the salinity of leachates collected from ungrafted Trial 1 Nemaguard trees (b) and grafted Trial 2 Nonpareil x Nemaguard trees (c).

Table 9-2. Significance of saline irrigation treatment, rootstock and scion genotype on photosynthetic rate, stomatal conductance, stem water potential, leaf Na^+ and Cl^- and plant relative growth rate.

	A	G_S	Ψ_{stem}	Leaf Na^+	Leaf Cl^-	RGR
Ungrafted rootstocks						
Treatment	**<0.001**	**<0.01**	**<0.001**	**<0.001**	**<0.01**	**<0.001**
Rootstock	**<0.05**	**<0.01**	**<0.05**	ns	**<0.001**	**<0.001**
Trt x RtStck	ns	ns	ns	ns	**<0.05**	**<0.001**
Grafted rootstocks						
Treatment	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Rootstock	ns	**<0.001**	**<0.05**	**<0.05**	**<0.001**	**<0.001**
Scion	ns	**<0.01**	**<0.01**	ns	ns	ns
Trt x RtStck	ns	ns	ns	**<0.05**	**<0.001**	**<0.05**
Trt x Scion	ns	ns	ns	**<0.01**	ns	ns
RtStck x Scion	ns	ns	ns	ns	Ns	ns
Trt x RtStck x Scion	ns	ns	ns	ns	Ns	ns

Similar trends were observed in the grafted trial with gas exchange decreasing with increased salt exposure, but effects tended to be more aligned with the highest salt treatments and the rootstock effect was less pronounced. Trees grafted to Barrier-1, Cornerstone, Garnem and Rootpac-20 were equivalent in their photosynthetic performance while those grafted to Roopac-40 and Nemaguard tended to be more adversely affected by the salt treatment. Of particular note was the

G_S of leaves on trees grafted to Rootpac-40, which were significantly lower than those of trees grafted to other rootstocks. Nemaguard leaves trended lower, but this response was not significant.

Table 9-3. The effect of irrigation treatment and rootstock genotype on photosynthetic rate (A – µmol $CO_2/m^2/s$), stomatal conductance (GS – mol $H_2O/m^2/s$) and stem water potential (ψ_{stem} – MPa) of ungrafted *prunus* rootstocks.

	A	G_S	ψ_{stem}
Irrigation Salinity			
Control	18.0	0.507	-0.96
Low	18.4	0.486	-0.92
Medium	15.9	0.368	-1.14
High	11.7	0.373	-1.36
LSD	2.0	0.094	-0.16
P value	<0.001	<0.01	<0.001
Ungrafted Rootstock			
Barrier 1	15.8	0.396	-1.11
Cornerstone	16.4	0.534	-1.10
Garnem	18.6	0.499	-0.91
Nemaguard	18.1	0.405	-0.95
Rootpac-20	16.3	0.405	-1.06
Rootpac-40	16.3	0.427	-1.11
LSD	2.4	0.114	-0.19
P value	<0.05	<0.01	<0.05

Table 9-4. The effect of irrigation treatment, rootstock and scion genotype on photosynthetic rate (A – µmol $CO_2/m^2/s$), stomatal conductance (GS – mol $H_2O/m^2/s$) and stem water potential (ψ_{stem} – MPa) of grafted *prunus* rootstocks.

	A	G_S	ψ_{stem}
Irrigation Salinity			
Control	20.2	0.631	-0.75
Low	19.7	0.652	-0.82
Medium	18.7	0.577	-0.93
High	16.9	0.468	-1.01
LSD	0.84	0.045	-0.05
P value	<0.001	<0.001	<0.001
Grafted Rootstock			
Barrier 1	19.0	0.593	-0.85
Cornerstone	18.8	0.605	-0.91
Garnem	19.3	0.638	-0.85
Nemaguard	18.5	0.560	-0.87
Rootpac-20	19.4	0.614	-0.87
Rootpac-40	18.9	0.505	-0.81
LSD	1.0	0.055	-0.06
P value	ns	<0.001	<0.05
Scion			
Nonpareil	19.2	0.569	-0.90
Shasta	18.8	0.611	-0.84
LSD	0.6	0.032	-0.04
P value	ns	<0.001	<0.05

Both ungrafted and grafted plants expressed decreasing ψ_{stem} at the highest salt exposure. While rootstock and scion genotype impacted these measures, there was no interaction with the salinity treatment. Cornerstone rootstocks showed the least ψ_{stem} response to the saline irrigation and ranged from -0.94 to -1.3 MPa across the range of salt treatments.

In general, trees grafted to Shasta had lower A and more negative ψ_{stem} than those grafted to Nonpareil, Table 9-3 and Table 9-4.

Measures of sodium and chloride in the leaf tissue

Leaf ionic composition was assessed at both 54- and 144- days after commencement of saline irrigations. At the 54-day timestep, trees were pruned back to a single leader and the harvested extension growth assessed for ionic composition (data not shown). Leaf samples were again harvested on day 144. The data that follows relates to the second timestep.

Saline irrigation treatments affected the expression of leaf Na^+ and Cl^- concentrations in both the ungrafted and grafted rootstock trials and there was a significant interaction between rootstock and irrigation for leaf Cl^- concentration of the ungrafted trees and for both the concentrations of leaf Na+ and Cl^- in the grafted trees.

Na^+ concentrations in ungrafted leaf tissue remained well below levels normally associated with tree decline, 0.25 % (Robinson et al., 1997), Figure 9-5a. Grafted trees expressed almost double that in the higher salinity treatments, Figure 9-5b, with these higher values being driven by individual samples with some particularly high values.

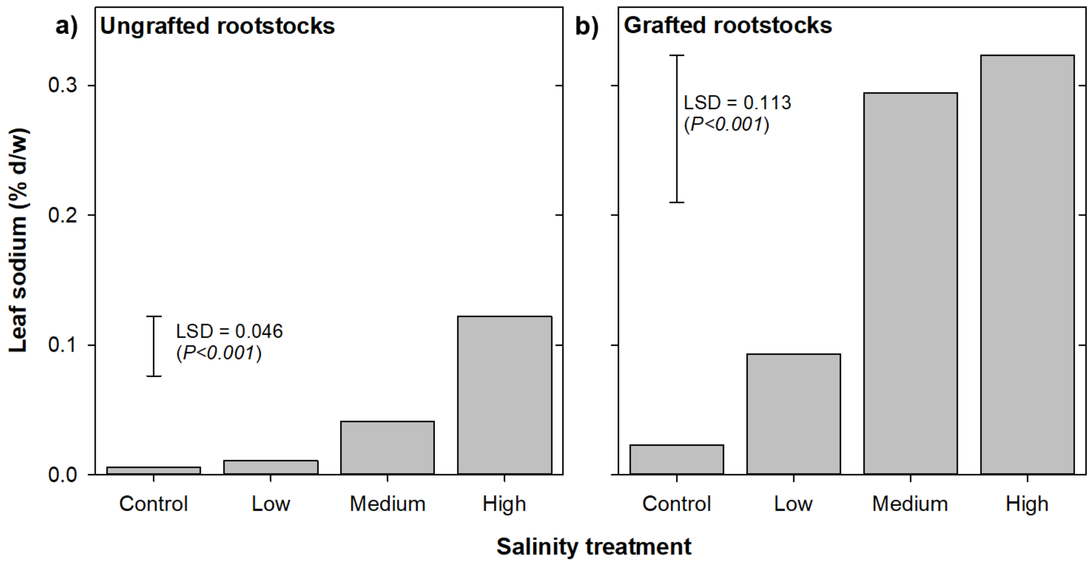


Figure 9-5. Effect of irrigation salinity treatment on the mean concentration of sodium (% d/w) in leaves from ungrafted (a) and grafted rootstocks (b). Leaves sampled at 144 days after commencement of saline irrigations.

In general, the effect of rootstock on leaf Na^+ concentration was less pronounced than that of treatment, although plants grafted to Barrier-1 and Cornerstone presented significantly lower concentrations than those on Garnem in the high salt treatment, Table 9-5. The low values reported for Rootpac-40 do not reflect the significantly high mortality rates for this genotype at the higher salt levels.

Trees grafted to Barrier-1 showed promising leaf Na^+ concentrations at the low- and high-end salt treatments, but some high value samples in the mid salinity treatment (in both Nonpareil and Shasta) skewed this result and the reported 0.67 % Na^+ casts doubt on the rootstock's performance, Table 9-5. Rootpac-40 trees either defoliated or died at the high salt level and Nemaguard grafted trees measured Na^+ concentrations in excess of 0.4 % in this and the second highest salt treatment.

Other rootstock combinations survived and presented suppressed Na^+ concentrations, relative to Nemaguard, in all but the highest salt treatment, where they then exceeded 0.4 % Na^+. The exception being trees grafted to Cornerstone which remained below 0.3 % Na^+ even at the highest salt pressure, Table 9-5.

Table 9-5. The effect of irrigation treatment and rootstock genotype on the mean Na^+ (%) concentration of leaves sampled from prunus rootstocks grafted to Nonpareil and Shasta almond varieties.

	Mean Leaf Sodium Concentration (%)						
	Bar-1	**Cstn**	**Nem**	**Gnm**	**R-20**	**R-40**	**LSD (P<0.05)**
Irrigation salinity							
Control	0.050	0.015	0.024	0.017	0.015	0.014	0.038
Low	0.110	0.166	0.107	0.084	0.058	0.032	0.138
Medium	0.671	0.245	0.525	0.202	0.054	0.110	0.364
High	0.204	0.294	0.434	0.477	0.381	0.176	0.522

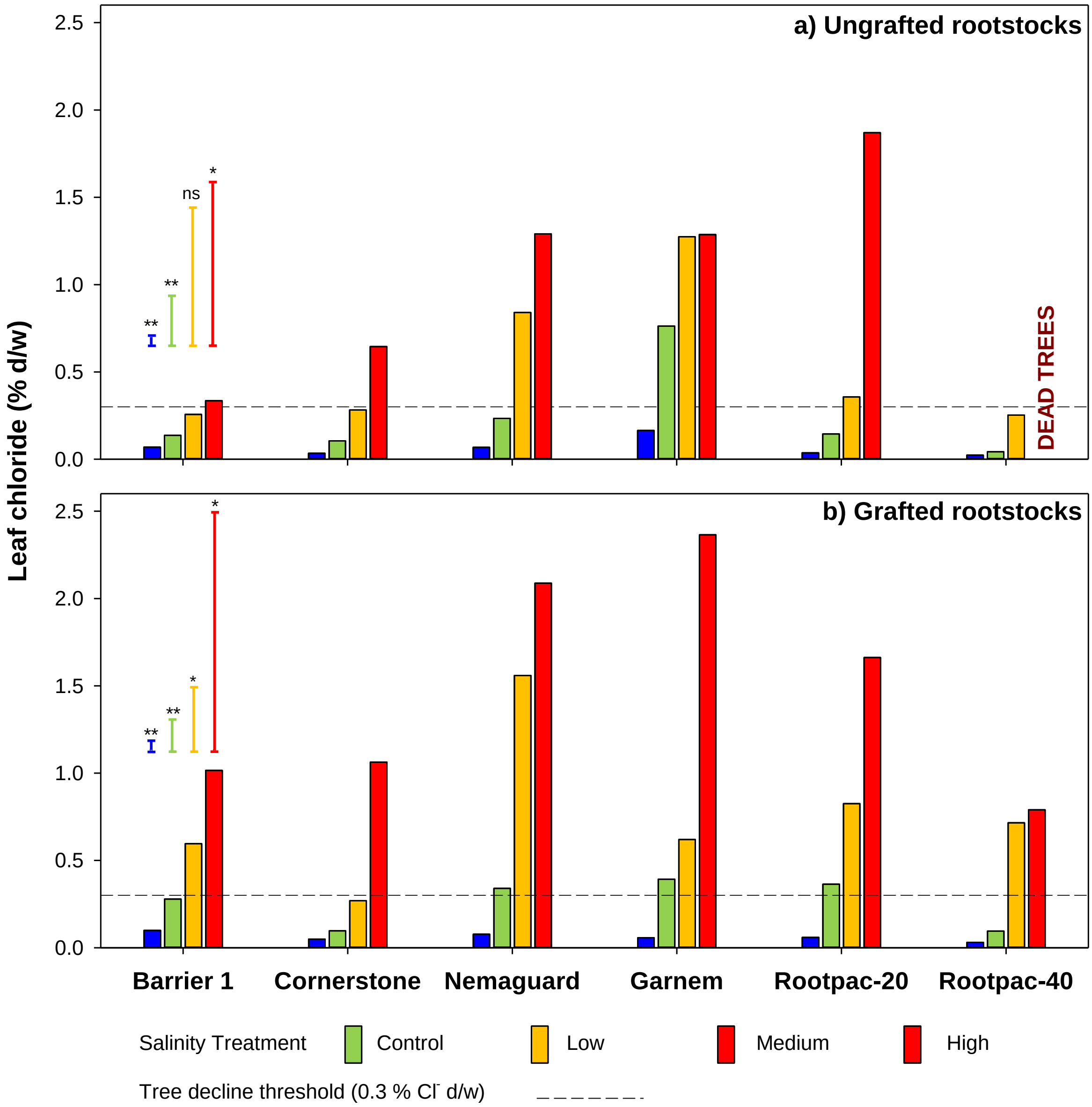


Figure 9-6. Effect of irrigation salinity and rootstock genotype on the concentration of chloride (% d/w) in leaves from ungrafted rootstocks (a) and the mean of Nonpareil and Shasta grafted rootstocks (b). Sampled at 144 days after commencement of saline irrigations. Bars represent Treatment LSD at *P*<0.01 (*) and *P*<0.001 (**)

The concentrations of leaf Cl^- in ungrafted rootstocks were affected by both rootstock genotype ($P<0.001$) and the saline irrigation treatment. The interaction was significant ($P<0.05$), Figure 9-6a.

Both Barrier-1 and Cornerstone rootstocks showed significantly lower Cl^- concentrations than Nemaguard and Garnem at the third salinity level and were lower than Garnem and Rootpac-20 at the highest salinity level. Data for ungrafted Nemaguard leaf Cl^- concentrations at the highest salinity level mask the fact that many of these trees were defoliating or had died after 144 days of the high salt treatment. There can be no such confusion for the ungrafted Rootpac-40 trees who suffered 100 % mortality after 144 days of high salt.

Scion genotype did not affect the leaf Cl^- concentration of grafted trees. However, leaf Cl^- concentration was affected by both salinity treatment and rootstock genotype and the interaction between these was significant. Trees grafted to Nemaguard showed average leaf Cl^- of more than 2 % with frequent defoliation and significant mortality in the high salt treatment by day 144. Rootpac-40 also suffered significant mortality although the few leaves available for assessment measured significantly lower Cl^- content than Nemaguard grafted trees at the low and high salt treatments. Trees grafted to Garnem also produced high Cl^- concentrations but without the necrotic leaf symptoms typical of salt stress. These trees continued to grow despite their high Cl^- values. Trees grafted to Cornerstone and Barrier-1 showed lower leaf Cl^- than trees grafted to Nemaguard and those grafted to Cornerstone were notable for maintaining concentrations below production thresholds until being exposed to the highest salt pressure, Figure 9-6.

Correlating leaf spectral signature with ionic composition

One of the complexities of hyperspectral spectroscopic data is that differences in sample composition, size and density can cause variability in molar absorptivity and pathlength resulting in both additive and multiplicative scattering effects. As such, various standard pre-processing techniques were trialled to prepare the data for analysis.

Partial least squares regression (PLS) was performed using 80% of the raw and pre-processed data as the training set and both the total Na and Cl concentration on fresh and dry mass bases as independent variables. A random assignment of data divided into 20 segments was used as a variation on the "leave-one-out" cross validation method to estimate the predictive value of each of the multivariate models. The remaining 20% of data was presented to the resultant model(s) as a test set to determine the predictive error.

The partial least square (PLS) model using leaf spectral data to predict Na^+ or Cl^- resulted in a greater R^2, lower root mean squared error of calibration (RMSEC) and cross validation (RMSECV) to that of the raw dataset, Table 9-6. Cl^- concentrations showed a stronger correlation to leaf spectra with R^2 values from the model higher than those obtained when Na^+ was the independent variable. A direct comparison cannot be made between the error associated with the Na^+ or Cl^- models as the RMSE of calibration and cross validation are dependent on the original scale of the dependent variable.

Table 9-6. R^2 and error associated with PLS regression models generated with raw and averaged spectral data and determined chloride (Cl^-) and sodium (Na^+) concentrations on a dry (DM) and fresh mass (FM) basis.

PLSR model			Optimal number of factors	R^2 cal	RMSEC	R^2 val	RMSECV
raw	Na^+	DM	11	0.44	0.35	0.42	0.36
		FM	13	0.45	0.09	0.44	0.09
	Cl^-	DM	14	0.74	0.62	0.71	0.65
		FM	14	0.71	0.18	0.69	0.19
averaged	Na^+	DM	7	0.52	0.33	0.45	0.35
		FM	7	0.51	0.09	0.46	0.09
	Cl^-	DM	14	0.92	0.34	0.88	0.41
		FM	15	0.92	0.09	0.87	0.12

Although models based on Cl^-_{DM} and Cl^-_{FM} had the same R^2, Cl^-_{DM} was chosen as the predictor for all further analyses as it resulted in a model with slightly fewer factors. It is furthermore the standard measure currently used by industry to gauge potential salt stress and so benchmarks for expected tree performance are available.

To reduce the variability attributable to both additive and multiplicative effects common to hyperspectral data, a number of pre-processing steps were trialled. A multiplicative scatter correction resulted in a model with the best combination of R^2, RMSE of calibration and cross validation with the lowest optimal number of factors; 13, Figure 9-7a. The predictive power of the model was tested using the 20% sample subset that had been excluded from the original training set. The standard error of prediction (SEP) was found to be 0.36 with an R^2 of 0.91, Figure 9-7b.

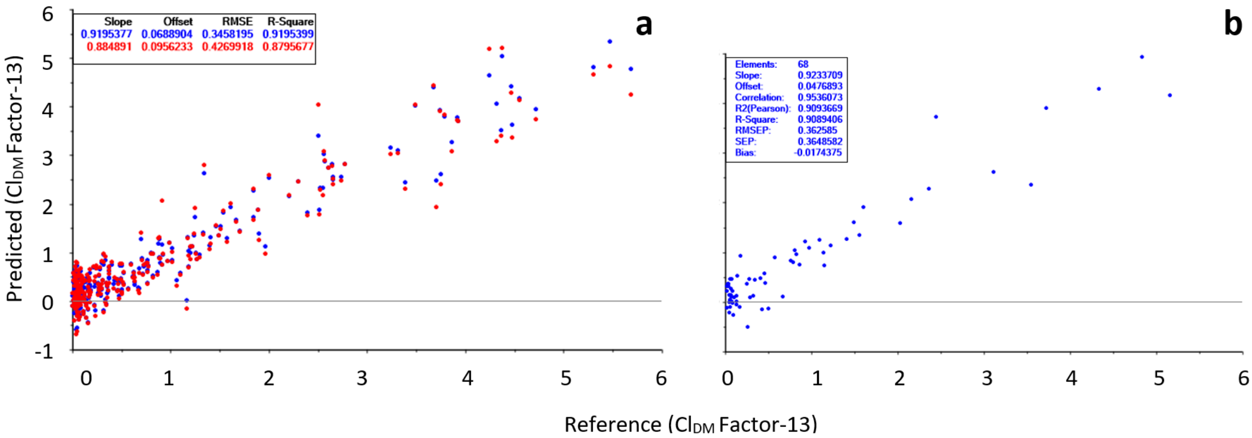


Figure 9-7. Predicted versus reference plot for calibration (blue) and internal validation (red) of the PLS model for the prediction of Cl-dm obtained with averaged pre-processed UV-Vis NIR (a). Predicted versus reference plot for Cl-dm values of test set data determined using PLS model (b).

To determine whether variability within the data was related to grafting, the data were visualised using principal component analysis (PCA). A clear separation was seen in the PCA plot between spectra collected from leaves of the rootstocks and grafted scions (data not shown) and the data were therefore separated into two datasets to eliminate this source of variability.

The PLS model based on the ungrafted data set showed large RMSE errors associated with calibration and cross validation and a low R^2. This was likely due to decrease in size of the data set and the amount of variation between the six different rootstocks included in the experiment.

The grafted data resulted in a PLS model with similar predictive ability seen for the entire data set but with a slight increase in the RMSEP; again, likely a result of fewer samples available to train the model. The optimal number of factors for the model was also reduced to 11. The grafted dataset was further refined into a subset containing only spectra collected from Nonpareil leaves (scion 1). This improved both the RMSE and R^2 of calibration, cross validation and prediction. However, clustering in the ordinate direction at the lower end of the Cl^-_{DM} concentration range was evident; the PLS was re-run but limiting inclusion to Cl^-_{DM} to 0.1% and greater, Figure 9-8a. Prediction of the test set resulted in a slight increase in the RMSE of prediction, Figure 9-8b.

Feature selection using the Boruta wrapper algorithm package identified 31 wavelengths of importance in four bands (699-720, 1390-1393, 1420-1421, 2444-2445) for the data set containing only Nonpareil spectra. The R^2 of calibration showed a correlation between the selected wavelengths and the determined Cl^-_{DM} concentration however, the RMSE associated with the calibration model increased more than two-fold.

While this small study has identified encouraging correlations between laboratory measures of Cl^- and the spectral signatures, there is an obvious need to account for genotype. Similarly, the strength of the model relies on high sample number, which was compromised when isolating analysis to genotype.

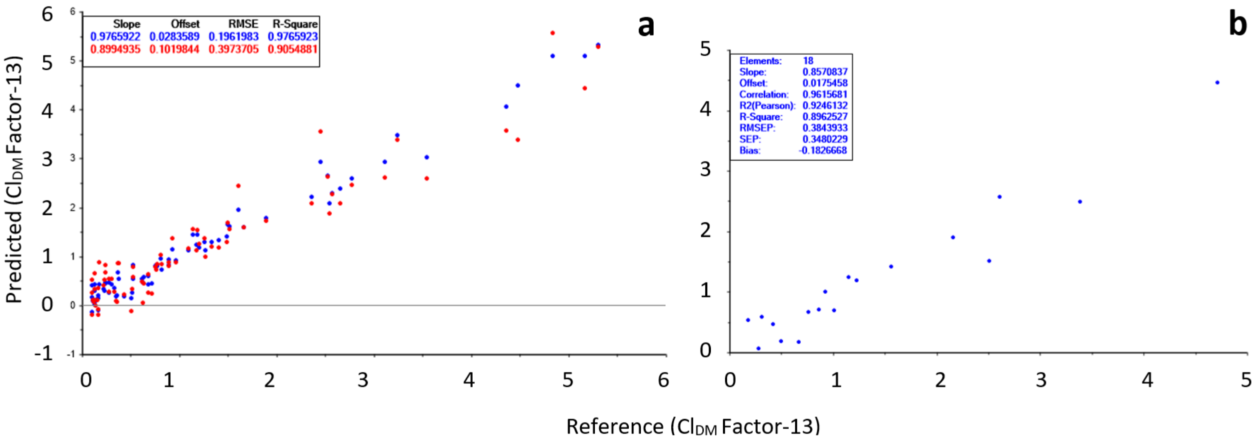


Figure 9-8. Predicted versus reference plots for calibration (blue) and internal validation (red) of the PLS model for the prediction of Cl^{-}_{DM} obtained with averaged pre-processed UV-Vis NIR Nonpareil data only and limiting inclusion to Cl^{-}_{DM} to greater than or equal to 0.1% (a). Predicted versus reference plot for Cl^{-}_{DM} values of test set data determined using PLS model (b).

Model development would benefit from additional samples from each subset of the target scion genotypes and at a wider range of concentrations, the inclusion of samples from trees grown under a wider range of conditions (especially outdoors) would also improve confidence in the models produced. The correlation would particularly benefit from more samples at the higher end. Should the opportunity present, SARDI have retained a suite of dried and dried/ground samples that could be further explored and contribute to model development.

Growth assessments

Measures of total shoot growth (mm of leader plus lateral length) were normalised to account for plant size prior to the imposition of saline irrigation treatments. This relative growth rate (RGR) was calculated as the slope of the linear regression of the natural logarithm of plant extension growth against time. Analysis of RGR showed that the rate of shoot extension was modified by irrigation treatment and that rootstock genotype was a significant source of variation, Table 9-7. RGR results were supported by a five-replicate subset of biomass measures, Figure 9-9, and aligned with the full eight replicates of growth curve data. An example of this is shown in Figure 9-10.

Table 9-7. The interaction between saline irrigation treatment and genotype on average relative growth rates (RGR) of ungrafted rootstocks (a) and grafted rootstocks (b).

a

Relative Growth Rate – Ungrafted (µm mm^{-1} day^{-1})						
Salinity	**Bar-1**	**Cnstn**	**Gnm**	**Nem**	**R20**	**R40**
Control	12.4	12.7	10.5	11.3	12.1	13.5
Low	13.2	11.5	10.3	11.3	10.9	9.4
Medium	14.4	10.6	9.9	9.9	10.8	1.5
High	7.6	6.9	8.3	9.3 *	8.8	-

LSD = 3.3 (*P*<0.001)

* Significant tree death for ungrafted Nemaguard exposed to high salt treatment

b

Relative Growth Rate – Grafted (µm mm^{-1} day^{-1})						
Salinity	**Bar-1**	**Cnstn**	**Gnm**	**Nem**	**R20**	**R40**
Control	12.4	10.6	11.8	11.3	11.4	12.4
Low	11.9	11.9	11.2	9.8	10.6	10.7
Medium	10.3	10.4	11.2	8.5	9.8	8.7
High	7.6	8.2	8.8	6.4	8.1	4.5

LSD = 2.05 (*P*<0.05)

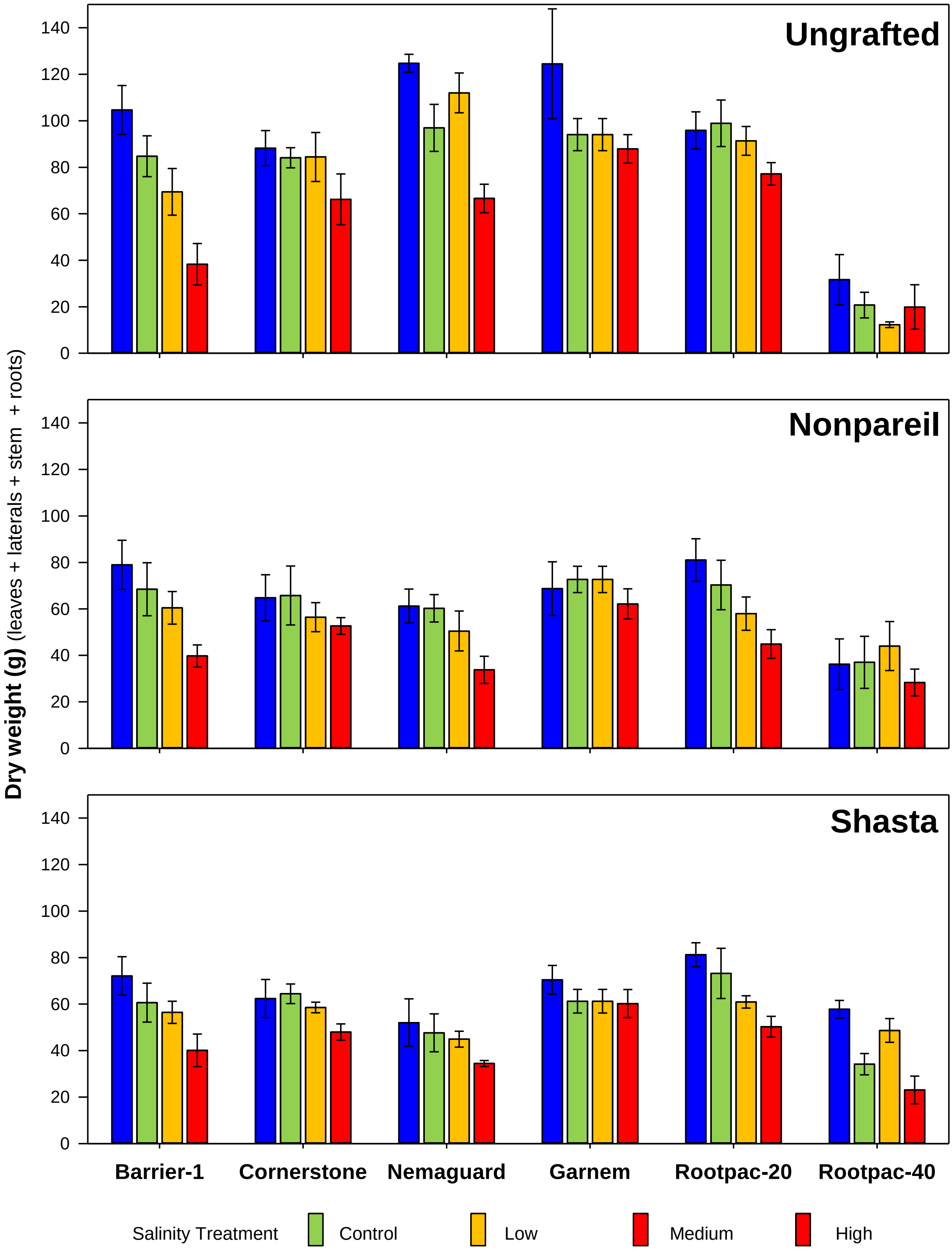


Figure 9-9. Effect of saline irrigation treatment on the total dry mass of plant material from five replicates of grafted and ungrafted rootstocks. Bars equate to SEM.

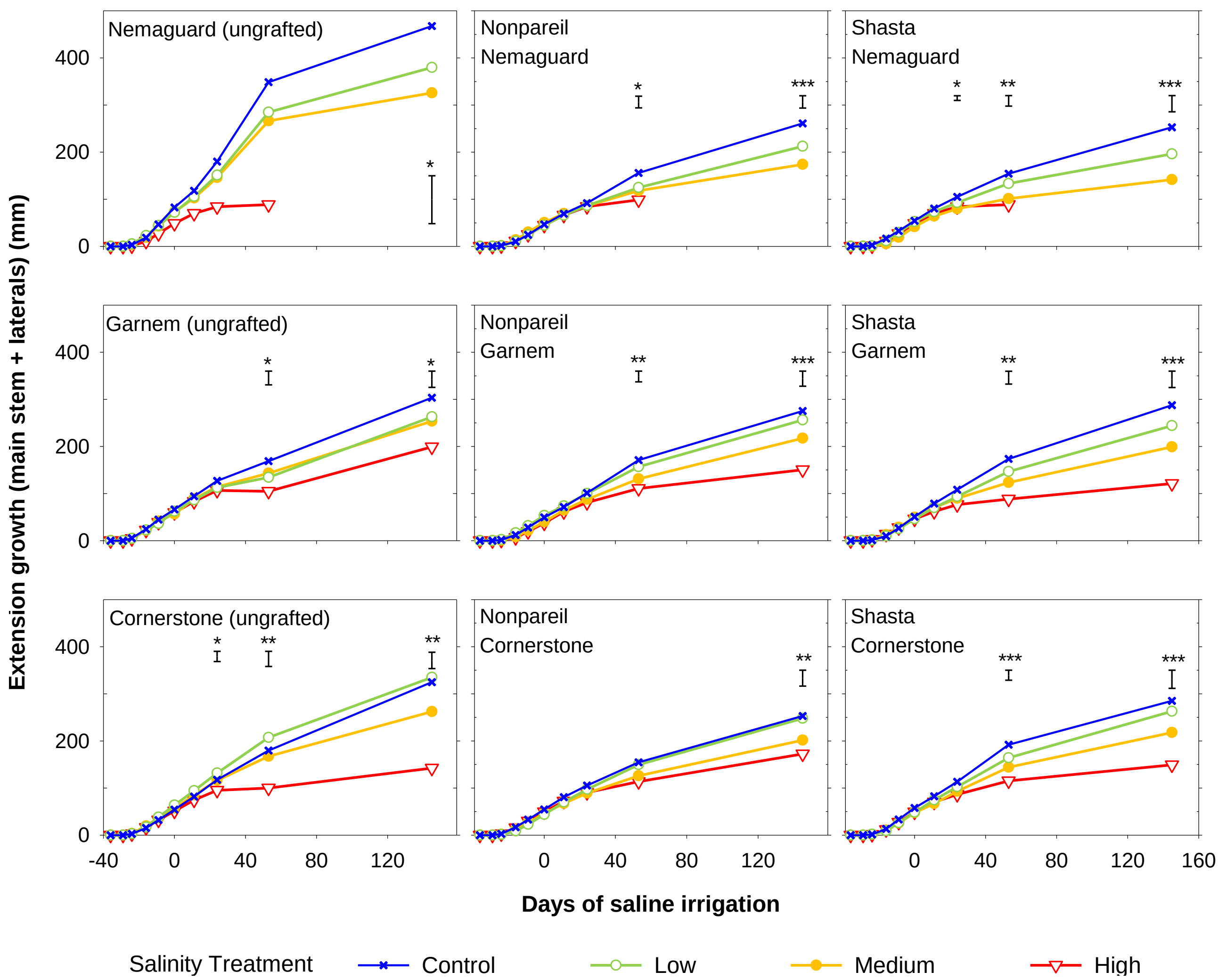


Figure 9-10. Effect of saline irrigation treatments on the growth curves of ungrafted and grafted Nemaguard, Garnem and Cornerstone rootstocks. Bars represent LSD at *P*<0.05 (*), *P*<0.01 (**) and *P*<0.001

Relative to the ungrafted Nemaguard rootstock, the rate of shoot length extension for the remaining five rootstocks was equivalent under the non-saline irrigation conditions. Ungrafted Garnem rootstocks were least affected by the increasing salt treatments, as measured by length RGR, and continued to have steady growth even at the highest salinity. Ungrafted Barrier-1 and Cornerstone trees also performed well but declined at the highest salt load. Ungrafted Nemaguard RGR suggested a level of tolerance to the increasing salinity, Table 9-7, but this result masked the occurrence of dead trees at the higher salt end, which was clearly depicted by previously described mortality results and the biomass and growth curve data in Figure 9-9 and Figure 9-10. Ungrafted Roopac-40 trees did not perform well in any of the irrigation treatments.

There were large effects of both irrigation treatment and rootstock upon the RGR of grafted trees, and there was an interaction between the two. Nonpareil and Shasta trees grafted to Rootpac-40 and Nemaguard performed poorly and were significantly impacted by salt treatments. Those grafted to Cornerstone and Garnem performed the best of the grafted trees and continued their extension growth through all salt levels, Table 9-7b.

There was a minor interaction between scion and rootstock with Nonpareil grafted to Garnem having higher RGR than Nonpareil on Nemaguard, Rootpac-20 and Rootpac-40. Similarly, Shasta grafted to Barrier-1, Cornerstone and Garnem all outgrew Shasta on Nemaguard.

9.4 Conclusions

Saline irrigation treatments assessed in this glasshouse trial were significantly more saline than those normally associated with the Australian Almond industry's principal irrigation sources. However, there are irrigators, both local and overseas, who make use of more saline water sources and/or face scenarios where rootzone salts rapidly accumulate during periods of water scarcity. For these growers, there is value in better understanding the performance of rootstocks with the potential to tolerate more saline growing conditions. SARDI's salinity glasshouse study was able to build upon the field-based production investigations at the ACE experimental orchard by selecting some promising rootstocks and assessing their salt tolerance characteristics.

This investigation showed that increasing saline irrigation treatments impacted plant growth, gas exchange and water relations as well as the concentrations of sodium and chloride in the leaf tissue. These measures were affected by both irrigation treatments, ranging up to 5.1 dS/m of nutrient salts plus mixed chlorides, and the genotypes studied.

Nemaguard did not perform well at the higher salinities assessed. Similarly, Rootpac-40 performed poorly, although this performance may be more related to the quality of the trees available for the study. Rootpac-40 was identified as having low vigour and poor graft strike rate through the pre-trial plant production and visual screening phase. It is possible that the performance of this genotype was modified by the quality of planting material rather than the imposed saline irrigation treatments. Rootpac-40 warrants inclusion in future assessments to confirm its capabilities.

Large differences in leaf concentrations of Na^+ and Cl^- did not translate into differences in growth. This was most clearly demonstrated by the Garnem rootstock genotype that expressed high leaf Na^+ and Cl^- but was able to maintain strong shoot extension and biomass accumulation.

Overall, it was the Cornerstone rootstock genotype that was found to be most consistently tolerant of the saline irrigations tested. Garnem and Barrier-1 were also favourable, but less consistent, performers. Cornerstone's photosynthetic metrics and stem water potentials were less restricted by the higher end salts, it expressed significantly lower concentrations of leaf Na^+ and Cl^- and it was amongst the better performers in terms of growth. These traits extended into the Nonpareil and Shasta scion genotypes when grafted to it.

In parallel with SARDI's salt tolerance investigations, the Agriculture Victoria Research team incorporated SARDI samples into their development of spectral models correlating traditional laboratory measures of leaf ionic composition with remotely sensed spectral signatures. This small study identified encouraging correlations but also highlighted the need to account for genotype and to incorporate samples composed of a wider range of ionic concentrations. SARDI have retained a collection of dried and dried/ground samples that could be exploited for this purpose if the opportunity presents.

SECTION 10. Modelling the impact of drip and sprinkler irrigation on rootzone water, salinity and nutrient dynamics

Key points

- A numerical model (HYDRUS-2D) was calibrated and validated for water balance, salinity distribution and applied N dynamics for two seasons (2019/20 and 2020/21) in soils under low density (H1) drip and sprinkler irrigated almond plantings.
- Model simulated transpiration in drip irrigated almond (H1 plantings) accounted for 56 - 70% of water applied compared to 40 - 53% in sprinkler irrigation system.
- Evaporation losses were 21 - 22% higher under sprinkler than drip
- Simulated drainage losses were 22 and 18% respectively for sprinkler and drip irrigation.
- Simulated N balance showed that almond trees in H1 plantings took up 68 - 71% of applied N, 9 - 10% was leached, and 22- 24% remained in the soil.
- Water productivity (WP) for irrigation (WPI) of sprinkler (0.08 kg/m3) was almost half that of drip (0.15 kg/m3) as more water was applied in the former. WP for transpiration (WPT) was also 22% higher under drip indicating a more efficient system.
- Nitrogen use efficiency (NUE) in terms of kernel yield was 20% higher under drip as compared to sprinkler. However, NUE in terms of N uptake against added N was similar (68-71%) under both irrigation systems.
- Well calibrated numerical models are a useful tool for predicting the response of production systems to scenarios such as climate change, water scarcity, poor water quality and alternate irrigation and nutrient programs.

10.1 Abstract

Developing efficient water and nutrient use under an advanced production system requires a precise evaluation of water and nutrient use by the crop over multiple growing seasons. In this study, a numerical model (HYDRUS-2D) was used to assess the almond production system for water balance, salinity dynamics and nutrient (nitrogen) transport in the soil over two seasons for drip and sprinkler irrigation systems.

Numerical models (HYDRUS-2D) were constructed, calibrated, and validated against measured data that was collected during the 2019-20 and 2020-21 seasons in the Soil Amendment Trial at the ACE (SECTION 5). Model simulated values of water and N balance were used to estimate water productivity and N use efficiency in the young almond orchard. Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), Mean Error (ME) and Percent Bias (PBIAS) were used to evaluate the performance of the model against measured values of soil water distribution, salinity dynamics and nitrate dynamics.

Soil water distribution performance of the model was generally good, as was the ability of the simulations to model salinity dynamics. Model calibration for nitrate dynamics was hampered by a scarcity of measured soil solution data, but the model was successful in matching the limited amount of measured data available.

Water balance results suggest that almond root water uptake (RWU), or actual transpiration (Ta), accounted for 56 - 70% of water applied under drip, while it was only 40 - 53% under sprinkler irrigation. Evaporation losses were 21 - 22% higher under sprinkler than drip, indicating unproductive water loss in the former system. Drainage losses of 22% and 18% respectively for drip and sprinkler were similar in percentage terms but higher in absolute values (412 mm) for sprinkler during the 2019-20 season.

In general, predicted salinity dynamics remained below the crop threshold (ECsw = 3 dS/m) during both seasons. Model simulations showed that nitrification of NH_4^+ was very rapid and most of the NH_4^+-N converted to NO_3^- before reaching a depth of 20 cm. Simulated seasonal NO_3^--N concentrations in the model domain varied from 0.0 - 200 mg/L, and an appreciable amount of NO_3-N was detected at 90 cm depth under both irrigation systems. The simulated plant NH_4^+-N uptake was only 0.4 - 1.5 kg ha^{-1}, while average NO_3-N uptake (69 - 72% of applied nitrogen) was similar under both irrigation systems. Nitrate leaching accounted for only around 10% of the applied nitrogen, although almost a quarter of N application remained in the soil profile at the end of the simulation in both systems and remained susceptible to leaching in the ensuing winter.

Estimated water productivity (WP) for irrigation (WPI) under sprinkler (0.08 kg/m^3) was almost half that of drip (0.15 kg/m^3) as more water was applied in the former. Similarly, WP for transpiration (WPT) was also higher under drip indicating more efficient system. Estimated N use efficiency (NUE) in terms of kernel yield was 20% higher under drip as compared to sprinkler. However, NUE in terms of N uptake against added N was similar (68 - 71%) under both irrigation systems.

Some of the differences in performance of irrigation systems is related to the young age and limited root distribution of the trees in this planting and is expected to change as the orchard matures. In addition, the data can be further improved by strengthening the model calibration through robust and intensive field measurements of soil salinity and N dynamics in the soil at multiple locations.

10.2 Background and aims

Water requirements of a crop depend on numerous factors such as climate, water holding capacity of soil and type of crop grown. Estimating an adequate irrigation schedule requires close correspondence with crop requirements over the entire season to enhance water use efficiency and help reduce water losses from the soil.

The development of an efficient production system for almond requires precise application of water and nutritional inputs to achieve profitable production potential. Apart from irrigation requirements, soil salinity is an important issue for almond production because almonds are highly sensitive to osmotic stress, and exposure to a unit increase in the ECe over the threshold (ECe of 1.5 dS/m, (Mass, 1990) can reduce the potential yield of almond by 19%. Hence, an increased exposure to salts and prolonged salinity stress can not only reduce nut yields but can severely impact tree growth and the sustainability of the orchard.

Providing optimum nutrition to the growing plants is essential to develop an efficient production system. This makes fertiliser an important source of essential nutrients to almond orchards for better growth and profitable nut production. However, there are numerous challenges in the estimation of fertiliser requirement of a crop, such as fertiliser amount, type of fertiliser and time of application. Excess application of fertilisers such as nitrogen could end up leaching deeper in the soil and may degrade the groundwater and associated environment.

Irrigated horticulture has been identified as the major source of nitrogen in drainage waters in the Murray Darling Basin (Harrison, 1994). A high nitrate level has been reported in drainage water (60 mg L^{-1}) and soil solution (100 mg L^{-1}) under grapevines (Correll, 2010) in the Murray Darling Basin. These values are much higher than the Australian environmental trigger value for nitrate (0.5 mg L^{-1} for lowland rivers) (ANZECC, 2000).

Assessment of the entire production system involving soil, water, crop, and climate conditions is needed to develop better guidelines for irrigation and fertiliser application to almond orchards. This study targeted:

1) calibrating and validating a numerical model (HYDRUS-2D) for water content, soil solution salinity (ECsw) and added nitrogen (N) dynamics in the soil under drip and sprinkler irrigation over two seasons (2019-20 and 2020-21);
2) assessing the seasonal water balance and N balance components in the soil for drip and sprinkler irrigated almonds; and
3) estimating water and N use efficiencies of almond by utilizing the model simulated root water uptake (RWU) and crop evapotranspiration (ET) components.

10.3 Materials and methods

Modelling was carried out for different irrigation methods (drip and sprinkler) in the Soil Amendment Trial at ACE. Experimental details and orchard management practices followed are described in SECTION 5 of this report.

For the purpose of this modelling exercise, HYDRUS-2D (Simunek et al., 2016) was calibrated and validated for water content dynamics, salinity build up and nitrate dynamics in the soil. The model simulated Nonpareil almonds planted at a spacing of 4.5 m in rows 7.0 m apart.

Estimating input parameters for HYDRUS-2D

Modelling water movement processes in the soil requires site-specific reliable values of soil hydraulic parameters (SHP) for different soil texture layers at the experimental site. These parameters are usually estimated from the water content (θ)-pressure head (h) relationship and saturated hydraulic conductivity (Ks) measurements for each soil layer in a profile to the rooting depth of trees. Alternatively, these parameters can be estimated from the data on particle size distribution in the soil and bulk density measurements. For the modelling sites in the Soil Amendment Trial (Drip, and Sprinkler), measured water content (θ) - pressure head (h) relation and saturated hydraulic conductivity (Ks) measurements were used to develop the soil hydraulic parameters. Historical and initial soil survey at the study site were also given due consideration in developing different sets of soil hydraulic parameters for the sites. Final calibrated values of soil hydraulic properties, soil texture, particle size and bulk density data are shown in Table 10-1.

Table 10-1. Soil texture, particle size distribution, bulk density (Db) and estimated soil hydraulic parameters in the Soil amendment trial (*θr* is the residual water content; *θs* represents saturated water contents; *α* represents inverse of air entry value; *n* & *l* are the pore shape parameters and K_s is the saturated hydraulic conductivity of soils) for Soil amendment (Trial-1) sites.

Soil depth (cm)	Texture	Sand	Silt (%)	Clay	Db (g/cm³)	θ_r	θ_s (cm³cm⁻³)	α (cm⁻¹)	η	Ks (cm day⁻¹)	l
Drip irrigation											
0-15	SL	87.5	3.4	9.1	1.6	0.09	0.37	0.05	2.07	157.83	0.50
15-30	LSCL	82.2	5.1	12.7	1.6	0.09	0.37	0.04	1.53	71.99	0.33
30-50	LSCL	76.1	8.6	15.2	1.56	0.10	0.39	0.03	1.55	46.27	0.34
50-100	LSCL	72.1	8.7	19.2	1.58	0.10	0.39	0.03	1.55	28.42	0.34
100-120	SCL	67.9	10.3	21.9	1.62	0.09	0.37	0.02	1.32	17.42	0.24
120-150	SCL	64.9	7.2	27.9	1.62	0.09	0.37	0.02	1.32	14.05	0.24
Sprinkler irrigation											
0-15	LS	91.1	2.8	6	1.57	0.04	0.38	0.03	2.63	333.22	0.59
15-40	LS	89.5	4.4	6.1	1.65	0.04	0.38	0.06	2.35	205.95	0.59
40-70	LS	90.8	2.9	6.3	1.65	0.04	0.39	0.05	2.46	243.74	0.59
70-90	SL	81.6	4.8	13.6	1.63	0.06	0.40	0.03	1.63	57.27	0.41
90-150	LSCL	76.1	8.6	15.2	1.56	0.06	0.40	0.03	1.52	46.27	0.34

Soil texture for the Soil amendment trial drip irrigated modelling site was sandy loam at the surface and light sandy clay loam to clay loam at deeper depths (Table 10-1). The sprinkler irrigated modelling site was deep loamy sand, with light sandy clay occurring below 90 cm depth. Profile average clay contents at the drip site were approximately double the values observed at the sprinkler site. Measured saturated hydraulic conductivity (Ks) values at the sprinkler site were more than twice those at the drip site (Table 10-1). Hence, it is reasonable to expect that the contrasting soil hydraulic parameters at the two sites would influence water and solute movement processes in the soil.

Water content monitoring

Continuous water content monitoring is important to understand daily and seasonal plant water uptake, storage, leaching, and evaporation losses of water from the soil. Spatiotemporal estimation of these fluxes helps increase water use efficiency and reduce unwanted water losses, which in turn helps develop better irrigation scheduling of crops, including almond. Therefore, a well-developed water content monitoring program was installed in both treatments, with focus on understanding comparative water use. Capacitance probes were installed in the tree line (0 cm), at the edge of the dripper wetted area (120 cm from the tree) and mid-way between two tree rows (mid, 350 cm), under drip treatment, while Gypsum Blocks (GB-Lite) were installed in the same positions in the sprinkler treatment. Capacitance probes measure soil water content while GB Lites measure soil matric suction (kPa), indicating the ease with which water can be extracted from the soil. Capacitance sensors were located at every 10cm depth to a maximum depth of 120 cm, whereas GB Lite sensors were placed at 20, 40, 60 and 80 cm soil depths. The location of capacitance probes and gypsum blocks in these treatments is shown in Figure 10-1.

Soil solution salinity (ECsw) and N measurements

A soil salinity and nutrient (nitrate) monitoring program was established across both (drip and sprinkler) irrigation treatments. To achieve this, SoluSamplers were installed at 30, 60, and 90 cm soil depths in the tree line under both irrigation treatments, to extract soil solution and evaluate the nutrient movement and soil solution salinity dynamics in the soil. However, the extent of solution extraction depends on a number of factors, including soil texture, position of SoluSampler installation, irrigation amount and frequency. The model was calibrated by comparing the measured and model simulated daily values of water content dynamics in the soil. Subsequently, the model was calibrated for soil solution salinity (ECsw) and N dynamics in the soil by comparing the modelled values with the measured values determined at 30, 60 and 90 cm soil depths under both irrigation systems. Electrical conductivity of the soil solution was measured with an EC meter while the NO_3-N in the soil solution was measured with nitrate test strips (Quantofix, Macherey-Nagel, GmbH & Co.) which had a measurement range from 10-500 mg/L. Soil analysis for nitrate was also done during the post-harvest season for both locations.

Weather parameters

Daily values of potential transpiration (Tp) and potential evaporation (Es) during the almond growing season are essential for simulating soil water balance in the soil, including actual root water uptake by almond. These inputs were estimated following the FAO-56 dual crop coefficient (DCC) approach (Allen, 1998). Climate parameters such as daily rainfall, reference evapotranspiration (ET_0), maximum temperature, relative humidity etc. were obtained from the weather station installed on-site at the ACE property, for 2019-20 and 2020-21 seasons (July-June). Other important parameters of the soil, crop and irrigation system required for the FAO-56 DCC approach were estimated from soil analysis, tree growth measurements (LAI) and irrigation design parameters.

Irrigation and fertigation details

Irrigation and fertigation scheduling (timing, rate and amount) for drip and sprinkler treatments were recorded for the entire season and were used in HYDRUS-2D to generate real time water and fertiliser movement in the soil. The irrigation scheduling and fertiliser application at the ACE site is as described in SECTION 5.

Model domain, initial and boundary conditions

The modelling domain for both irrigation systems consisted of a two-dimensional vertical plane extending from the tree line to the mid-row (350 cm). In the vertical direction it extended to a depth of 200 cm, thus creating a 350 cm x 200 cm rectangular domain with 3,692 nodes and 7,134 2D elements (Figure 10-1). A fine mesh size (1 cm) was constructed just below the dripper to facilitate modelling of rapid changes in the water content in this region, for better convergence of the numerical solution of non-linear water and solute movement equations. At other locations, mesh size was gradually increased from 2 to 10 cm. A variable flux boundary was imposed on the surface just below the dripper, and an atmospheric boundary at the rest of the soil surface. No flow was imposed along the vertical side boundaries and free drainage was as allowed at the bottom boundary as the water table is too deep to be able to generate any upward flow into the domain. Simulations were performed on a daily basis for a period of one year, from July 1 to June 30, thus covering the entire growth season including the dormant period.

The simulated surface drip irrigation system design characteristics were typical of the dual drip line systems adopted in Australia (Figure 10-1) with drip lines offset 100 cm from the tree row on both sides, and an emitter spacing of 50 cm. Drip irrigation was simulated assuming an infinite line source, which was shown previously (Skaggs et al., 2004, Skaggs et al., 2010, Hanson et al., 2008, Phogat et al., 2012, Phogat et al., 2013) to be a good representation of the drip irrigation system. The constant water flux was applied over the variable flux boundary, which is equal to the water application rate, as described in (Phogat et al., 2012). Observation nodes were selected at specific locations in the domain to monitor levels of water content and soil water salinity over time, as simulated by the HYDRUS model. Measured values of water content and soil salinity for different soil layers were imposed as initial conditions in the model.

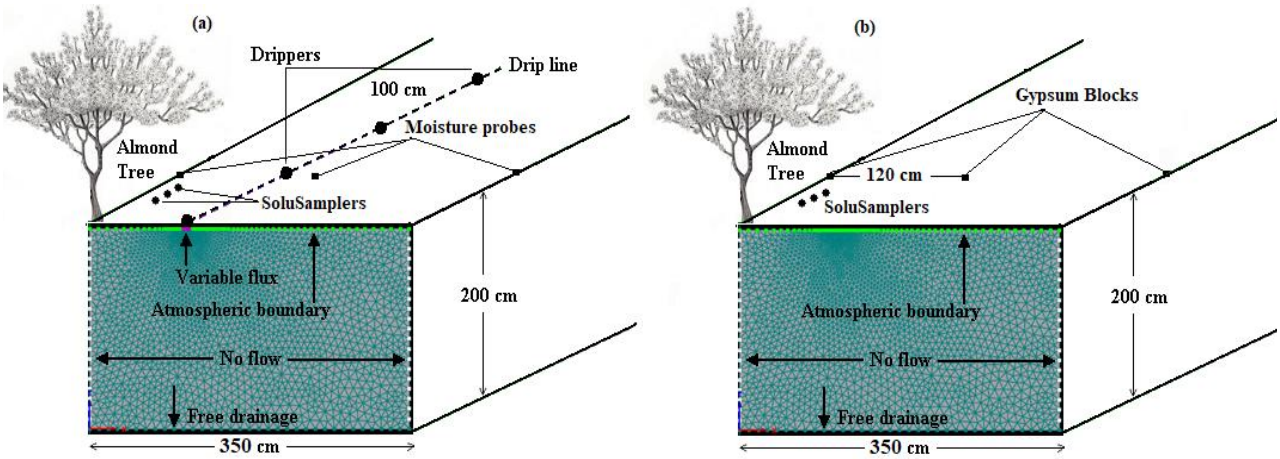


Figure 10-1. Schematic diagram showing sensor location, modelling domain and imposed boundary conditions for (a) drip and (b) sprinkler irrigated almond.

Model evaluation

Modelling performance was evaluated by comparing measured (M) water content values in the soil at various depths with corresponding values simulated by HYDRUS-2D (S) for the 2019-20 and 2020-21 season. The statistical error estimates [mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and normalised RMSE] and percent bias (PBIAS) between the measured and simulated spatiotemporal water content were estimated as:

$$ME = \frac{1}{N}\sum_{i=1}^{N}\left(M_i - S_i\right)$$ **(Equation 10-1)**

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|M_i - S_i\right|$$ **(Equation 10-2)**

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(M_i - S_i\right)^2}$$ **(Equation 10-3)**

$$\boldsymbol{PBIAS} = \frac{\sum_{i=1}^{N}(\boldsymbol{Mi-Si})}{\bar{\boldsymbol{M}}}\boldsymbol{x100}$$ **(Equation 10-4)**

A good prediction is one which shows error estimate (MAE, ME, RMSE) values close to 0. PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999). Positive PBIAS values indicate model underestimation bias, and negative values indicate model overestimation bias. PBIAS values <±15% indicate very good prediction, between ±15 to ±30% indicate good, ±30 to ±55% indicate satisfactory, and >±55% indicate unsatisfactory prediction by the model (Moriasi et al., 2007).

10.4 Results and Discussion

Calibration and validation of the HYDRUS-2D profile averaged daily values of measured soil water content (drip irrigation) or suction (sprinkler) were compared with the corresponding model produced values for two years. Statistical error estimates between measured and simulated water content values at different soil depths and different locations within the tree zone (tree line, edge and mid-row) for drip system are presented in Table 10-2, and for sprinkler system in Table 10-3.

RMSE, MBE and MAE values for water content in drip irrigation simulations (Table 10-2) were generally less than 0.08, within the accepted range reported in other similar studies (e.g., Phogat (Phogat et al., 2012, Phogat et al., 2013, Phogat et al., 2016, Ramos et al., 2011). More than half of the PBIAS values were below 15%, indicating very good prediction, and all but one value was less than 30%, indicating good prediction.

Sprinkler simulations modelled the soil suction (kPa). RMSE and MAE values at all locations during 2019-20 ranged from 35 - 96.8 and 31.7 - 93.9 kPa, which are in the high range. Average MBE values for tree line, edge and mid-row locations were -5.4, 49.7 and -6.7 kPa, respectively, representing relatively good prediction of soil suction. Similarly, average PBIAS values (-13.6 and -21.1 kPa) for tree line and edge locations were in the acceptable range, with excellent matching at the mid-row location (0.2%). The only unsatisfactory value of PBIAS (-60.4%) was estimated at 80 cm depth at the edge location.

During the 2020-21 season, the values were higher at some specific locations. However, average values of RMSE, ME and MAE remained within 39 - 57 kPa range while the PBIAS values ranged between 7.7 - 17.5 kPa, showing good simulation of dynamics of water stress levels in the soil. Nevertheless, soil suction frequently exceeded the lower measurement limit (-300 kPa) of gypsum blocks during the 2020-21 season, indicating reduced water availability in the soil. During this period (measured values <-300 kPa) modelled values of soil suction gradually decreased lower than -300 kPa at 40, 60 and 80 cm, indicating that the soil was very dry.

Table 10-2. Error estimates between measured and predicted water content in the soil at different depths in tree line, edge and mid-row locations for drip-irrigated almond.

Location	Statistical tests	20cm	40cm	Soil Depth 60cm	80cm	Average
2019-20						
Tree line	RMSE (cm^3cm^{-3})	0.05	0.04	0.05	0.02	0.03
(0 cm)	ME (cm^3cm^{-3})	0.02	-0.01	-0.04	-0.01	-0.01
	MAE (cm^3cm^{-3})	0.04	0.04	0.04	0.01	0.03
	PBIAS (%)	6.70	-6.18	-16.05	-2.01	-4.26
Edge	RMSE (cm^3cm^{-3})	0.02	0.04	0.06	0.06	0.04
(120 cm)	ME (cm^3cm^{-3})	0.00	-0.03	-0.05	-0.05	-0.03
	MAE (cm^3cm^{-3})	0.02	0.04	0.05	0.06	0.04
	PBIAS (%)	1.50	-16.23	-26.58	-28.36	-17.06
Mid-Row	RMSE (cm^3cm^{-3})	0.02	0.03	0.03	0.03	0.02
(350 cm)	ME (cm^3cm^{-3})	0.01	-0.03	-0.02	-0.01	-0.01
	MAE (cm^3cm^{-3})	0.02	0.03	0.03	0.02	0.02
	PBIAS (%)	4.87	-13.67	-9.84	-4.09	-5.62
2020-21						
Tree line	RMSE (cm^3cm^{-3})	0.04	0.04	0.08	0.03	0.04
(0 cm)	ME (cm^3cm^{-3})	-0.02	-0.04	-0.08	-0.03	-0.04
	MAE (cm^3cm^{-3})	0.03	0.04	0.08	0.03	0.04
	PBIAS (%)	-8.85	-20.48	-40.74	-10.44	-19.48
Edge	RMSE (cm^3cm^{-3})	0.04	0.02	0.04	0.05	0.02
(120 cm)	ME (cm^3cm^{-3})	0.03	-0.01	-0.04	-0.04	-0.02
	MAE (cm^3cm^{-3})	0.03	0.02	0.04	0.04	0.02
	PBIAS (%)	15.16	-6.22	-20.43	-22.00	-7.80
Mid-Row	RMSE (cm^3cm^{-3})	0.01	0.02	0.01	0.01	0.01
(350 cm)	ME (cm^3cm^{-3})	0.01	-0.02	-0.01	-0.01	-0.01
	MAE (cm^3cm^{-3})	0.01	0.02	0.01	0.01	0.01
	PBIAS (%)	6.13	-10.57	-7.44	-5.18	-4.30

Table 10-3. Error estimates between measured and predicted soil matric suction (kPa) at different depths in tree line, edge and mid-row locations for sprinkler irrigated almond. Overall, statistical comparison showed mixed reVelations for the modelled comparison of soil suction values with the gypsum block measured values.

Location	Statistical tests	20cm	40cm	Soil Depth 60cm	80cm	Average
2019-20						
Tree line	RMSE (kPa)	60.8	96.8	73.4	65	49.5
(0 cm)	ME (kPa)	-29.1	-53.1	37.7	23.1	-5.4
	MAE (kPa)	41	93.9	57.9	40.6	50.7
	PBIAS (%)	14	17.4	-35.7	-37	-13.6
Edge	RMSE (kPa)	35	65.1	93.1	91	58.2
(120 cm)	ME (kPa)	8.9	27.5	72.1	90.2	49.7
	MAE (kPa)	31.7	66.1	86.3	92	57.6
	PBIAS (%)	-19.5	-28.6	-43.7	-60.4	-21.1
Mid-Row	RMSE (kPa)	68.6	67.9	54.8	63.8	44.9
(350 cm)	ME (kPa)	-12.3	-13.5	-13.9	12.8	-6.7
	MAE (kPa)	60.3	57.2	61	62.7	46.2
	PBIAS (%)	15.4	11.4	3.2	-23.7	0.2
2020-21						
Tree line	RMSE (kPa)	137.7	71.6	28.9	43.7	46.7
(0 cm)	ME (kPa)	-131.9	-29.4	-1.3	0.0	-40.7
	MAE (kPa)	133.2	29.4	1.3	0.0	40.7
	PBIAS (%)	52.1	10.3	-6.2	-10.5	11.1
Edge	RMSE (kPa)	65.3	30.3	40.6	151.9	44.8
(120 cm)	ME (kPa)	17.7	-1.8	-0.3	-173.7	-39.5
	MAE (kPa)	52.2	1.8	0.3	173.7	42.3
	PBIAS (%)	-7.7	-7.5	-9.8	52.2	7.7
Mid-Row	RMSE (kPa)	89.4	72.7	33.4	152.9	57.7
(350 cm)	ME (kPa)	-4.8	5.4	0.0	-174.6	-43.5
	MAE (kPa)	24.3	5.4	0.0	174.6	43.5
	PBIAS (%)	13.9	8.3	-2.1	53.4	17.5

A significant problem with gypsum blocks, especially in light textured soils, is loss of contact with soil at highly negative suction levels, and delays in regaining soil contact, which influences subsequent measurements. This problem is likely to have increased error estimates in the sprinkler irrigation simulations.

Water content/soil suction dynamics in the soil

Under drip irrigation (Figure 10-2) measured as well as predicted profile average water content remained around 0.2 cm^3/cm^3 during the entire season, indicating favourable water regimes in the soil profile, and facilitating normal canopy growth for young almond trees.

Under sprinkler irrigation (Figure 10-3) suction values remained wetter than -100 kPa up until December during 2019-20, especially in the tree line and edge locations. However, during January to May highly negative suction values (between -200 to -300 kPa) suggested that water stress condition occurred at these locations. During the following year (2020-21), the suction values increased steeply early in the season (November onwards).

Occurrence of flat lines in the measured values denotes the limit of the GB Lite gypsum blocks, and suction values beyond this threshold are not sensed by GB Lite. A similar pattern in daily suction values was observed irrespective of location.

The water stress period as shown in the suction values aligned with the pit hardening, hull split and harvest growth stages. Post-harvest (March-April) soil suction values were also relatively negative, with potential consequences for spur formation, floral bud development and early tree growth in the subsequent season.

Numerous studies have shown that the productivity of young almonds is highly influenced by the extent of shoot length and canopy growth, which in turn is directly related to optimum water regimes in the soil (Torrecillas et al., 1989, Girona J, 1993, Hutmacher et al., 1994). This suggests that water stress should be avoided before the trees reach their full canopy size, and that a certain amount of shoot renewal is required to maintain almond productivity even at full canopy size (Naor et al., 2018).

Water balance components

The stocktake of sources and sinks of water plays a crucial role in developing efficient production systems for irrigated crops. The sources of water for almond production include irrigation, rainfall, and soil storage at the beginning of the growing season, and the major sinks are root water uptake (RWU, which equates with plant transpiration), evaporation (Es) and drainage (Dr).

Figure 10-4 displays the seasonal totals for water balance components under drip and sprinkler irrigated almonds during 2019/20 and 2020/21, as modelled by HYDRUS 2D. Precipitation (P) was identical for both systems, but irrigation (I) was much higher under sprinkler than under drip, while soil depletion was more negative under sprinkler, indicating a greater increase in soil storage at the end of the season than under drip.

The higher water source values under sprinkler irrigation were reflected in higher sink values. RWU was higher in sprinkler in both seasons, Dr was higher in 2019/20 only, but Es was much higher in both seasons. Expressed in water use efficiency terms, RWU comprised 56 & 70% of applied water in 2019/20 & 2020/21 respectively under drip, but only 40 & 53% in the same seasons under sprinkler.

Two factors contribute to the lower efficiency of sprinkler irrigation under the conditions experienced at this site. The first is the need to wet the whole soil surface with sprinkler irrigation, even though the rooting area of the young trees in this planting was restricted, especially in the initial season. This contributed to the higher Dr in 2019/20, and also contributes to the much higher Es in both years. The second factor is the water use of the cover crop and weeds under sprinkler irrigation. This was not specifically modelled, but it is expected that some of the water identified as Es in these simulations was actually taken up by cover crop and weeds in the orchard, which whilst useful in maintaining soil coverage, was not useful in producing crop or tree growth.

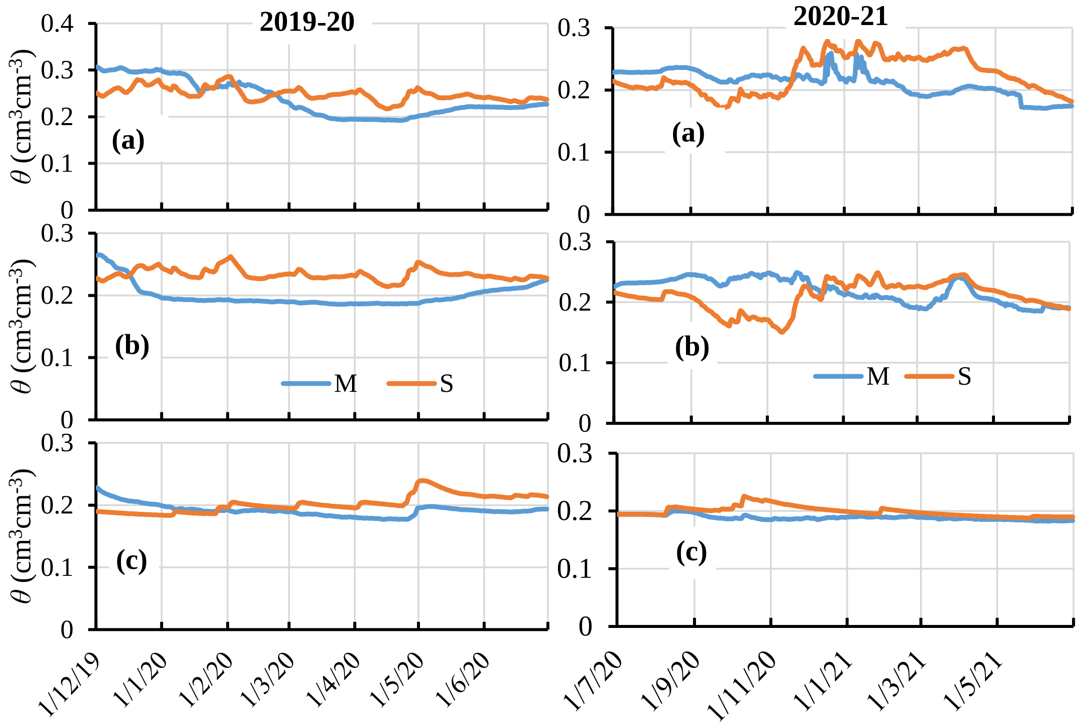


Figure 10-2. Comparison of measured (M) and simulated (S) average water content in the soil at (a) 0, (b) 120, and (c) 350 cm distance from the tree for drip-irrigated almond.

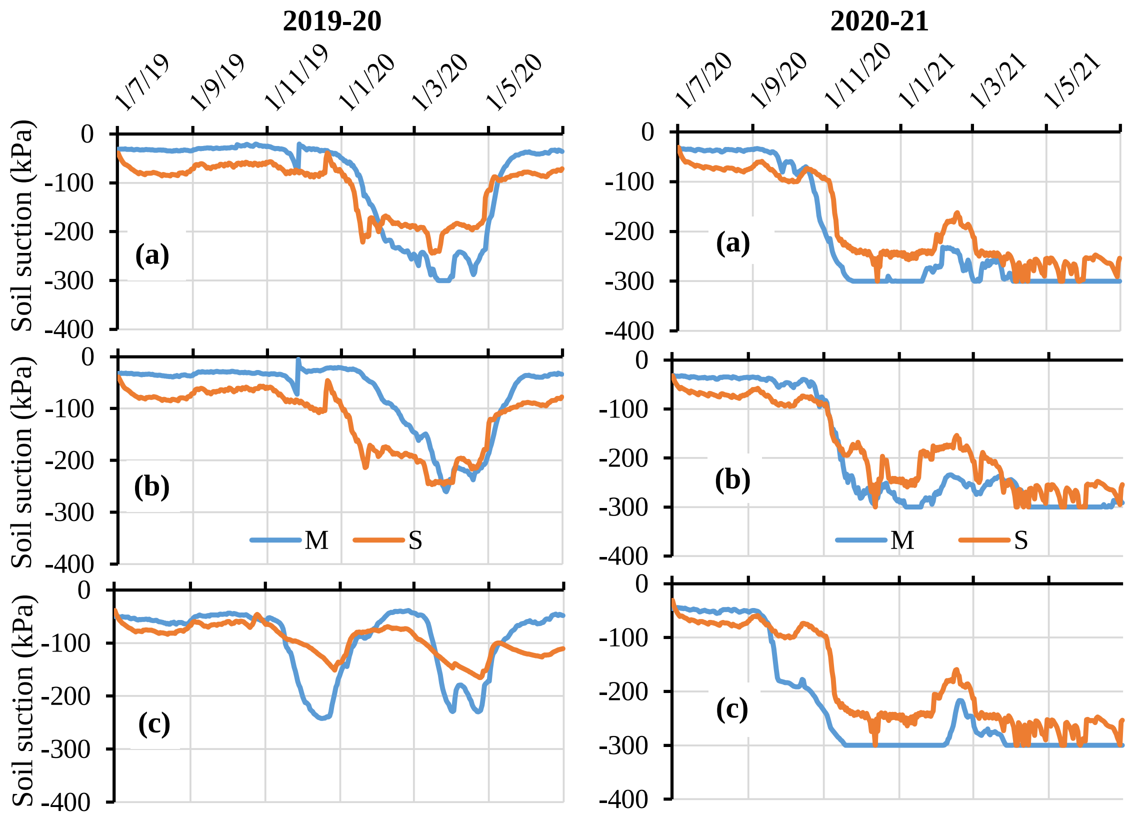


Figure 10-3. Comparison of measured (M) and simulated (S) average soil suction in the soil at (a) 0, (b) 120, and (c) 240 cm distance from the tree for sprinkler irrigated almond.

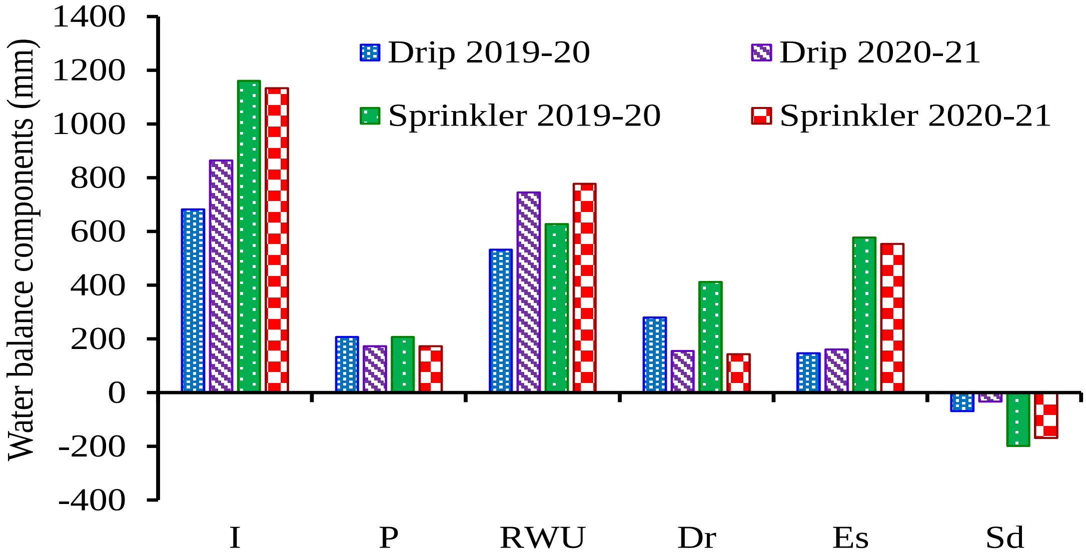


Figure 10-4. Seasonal water balance components (irrigation- I, precipitation- P, root water uptake- RWU, drainage- Dr, evaporation- Es, soil depletion- Sd) in drip and sprinkler irrigated almonds

Soil water salinity dynamics

Measured and model simulated soil solution salinity (ECsw) at 30, 60 and 90 cm depths under drip and sprinkler irrigated treatments are compared in Figure 10-5, respectively. Measurements of ECsw were only possible at times during the 2020-21 season when enough solution was collected in the SoluSampler. Since no solution was collected from December onwards (summer season), the comparison with modelled values was limited predominantly to the spring period. The error estimates (RMSE, MAE and ME) under drip irrigation corroborate well with other similar studies (e.g., (Ramos et al., 2011, Phogat et al., 2017). The PBIAS values of around 10% indicate an excellent match between measured and simulated values. Similarly, under sprinkler irrigation the error values of RMSE, MAE and ME demonstrate a close match between the measured and simulated ECsw values (Table 10-4). However, the PBIAS value at 30 cm was in the higher range, although the profile average attained a value close to 11%, indicating an excellent comparison between measured and simulated values overall.

Table 10-4. Error estimates between measured and simulated soil solution salinity (ECsw) at different depths in the soil for drip and sprinkler irrigated almonds during 2020-21.

Statistical tests	30cm	60cm	90cm	Average
Drip				
RMSE (cm^3cm^{-3})	--	0.52	0.35	0.40
ME/MBE (cm^3cm^{-3})	--	0.33	0.13	0.23
MAE (cm^3cm^{-3})	--	0.43	0.15	0.24
PBIAS (%)	--	11.09	9.90	12.00
Sprinkler				
RMSE (cm^3cm^{-3})	0.31	0.20	0.04	0.11
ME/MBE (cm^3cm^{-3})	0.31	0.17	-0.01	0.10
MAE (cm^3cm^{-3})	0.31	0.18	0.03	0.10
PBIAS (%)	29.45	19.47	-1.69	11.61

Simulated salinity was modelled according to initial, irrigation water and rainwater salinity, for drip and sprinkler irrigation of almond (Figure 10-5) during 2020-21 season. The ECsw showed an increasing trend, especially at 60 and 90 cm soil depths, under drip irrigation (Figure 10-5a). It reached to a peak level of 3.1 dS/m at 90 cm during the second half of November, which coincides with the pit hardening stage of almond growth. Subsequently, ECsw reduced and attained a constant value around 1 dS/m across the soil profile (Figure 10-5).

Trends in the simulated ECsw under sprinkler irrigation during 2020-21 were similar to drip irrigation, however the salinity distribution in the soil profile was lower than drip and attained a constant value around 0.7 dS/m (Figure 10-5).The maximum salinity of 3.7 dS/m was reached during the first half of January, and then gradually decreased and attained a constant value between 1 - 1.5 dS/m at different depths after the post-harvest time (first half of March). This level of salinity is expected to have very low osmotic impact on the growing plants, as the threshold ECsw (2x ECe) for almond is 3 dS/m (Mass, 1990).

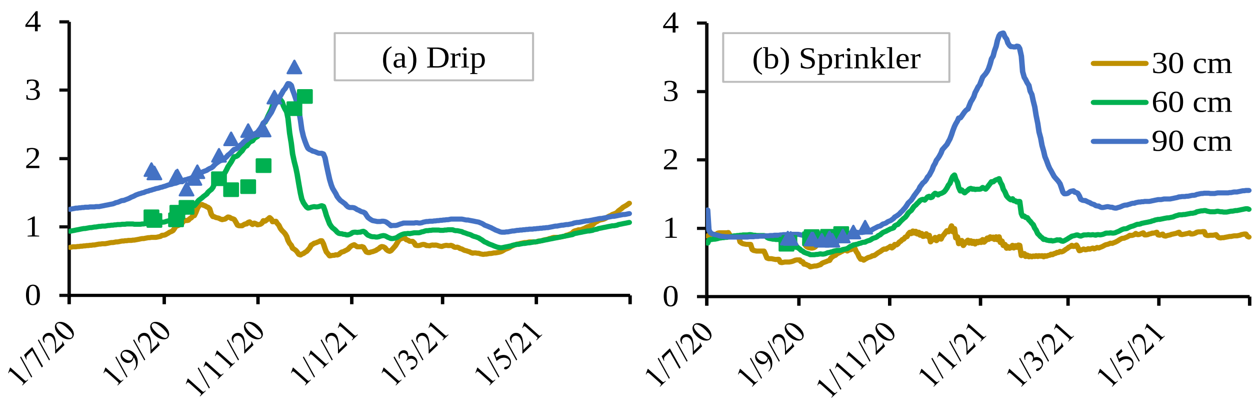


Figure 10-5. Comparison of measured (dots) and simulated (lines) soil solution salinity (ECsw) at 30, 60 and 90 cm depth in the soil under (a) Drip and (b) sprinkler irrigated almond (spacing 7.0 x 4.5 m) during 2020-21.

Nitrate dynamics

Model calibration for NO_3-N movement in the soil was impacted by the limited availability of measured data. SoluSampler installation was delayed, which prevented the collection of soil solution and measurements of NO_3-N in 2019/20. During the subsequent year (2020-21), limited measurements were possible due to inability to extract soil solution on many sampling occasions, and possibly as a consequence of the nitrate measurement methodology used (test strip). There was relatively good matching of measured and simulated data during the initial- and late-season under both irrigation systems (Figure 10-6a and Figure 10-6b). However, measured NO_3-N data at other times in the season, coinciding with fertigation doses, especially at 30 and 60 cm under drip and at all depths under sprinkler was not available where model showed concentration of NO_3-N in the soil solution as high as 60 mg/L for both systems. This suggest that more reliable methods for NO_3-N estimation in the soil solution are required to improve the accuracy of N measurements. Obviously, intensive soil observation of nitrogen transformation, losses and soil solution species could improve our understanding of spatiotemporal N dynamics in the soil, as well as matching the timing and magnitude of fertigation schedule with plant requirements.

The reason for differences in NO_3^--N values may be partially due to the fact that model reports point values, whereas the SoluSampler draws in solution under suction from a variable sampling volume, which depends on the soil hydraulic properties, water content, and the applied suction within the ceramic cup (Weihermüller et al., 2005, Ramos et al., 2012). Hence the measured parameters considered in modelling may not represent the inherent spatial variability of the soil. In addition, while an isotropic soil environment is assumed by the model, the field site could be far more heterogeneous and anisotropic. The model simulations considered only a 2D movement of nitrogen and the nitrification process, while more complex nitrate processes (e.g., mineralisation, ammonification, denitrification, immobilization through carbon-nitrogen complex formation and microbial interaction) were not taken into account. (Ramos et al., 2012) documented numerous factors influencing the correspondence between measurements and simulations of water content and solute concentration in the soil under drip irrigation conditions, which may contribute to the error in the simulated NO_3^--N values.

The simulated spatiotemporal dynamics of NO_3-N concentration in drip and sprinkler irrigated almonds shows a very similar pattern across seasons and irrigation systems (Figure 10-7). Early in the season NO_3-N concentration increased at all depths in response to N fertilization, with delayed movement of nitrogen to deeper locations. The appreciable amount of NO_3-N detected at 90 cm depth in November and December indicates the potential for subsequent N losses through leaching. NO_3-N concentration at 30 and 60cm decreased in early January, suggesting that NO_3-N was either taken up by roots or leached by irrigation.

Postharvest fertigation during late March to April again increased the NO_3-N concentration at all depths. At the end of the simulation NO_3-N was almost depleted at the 30 cm depth, but the high concentration at 90 cm suggests the potential for subsequent leaching under the influence of rainfall in the absence of plant uptake during winter.

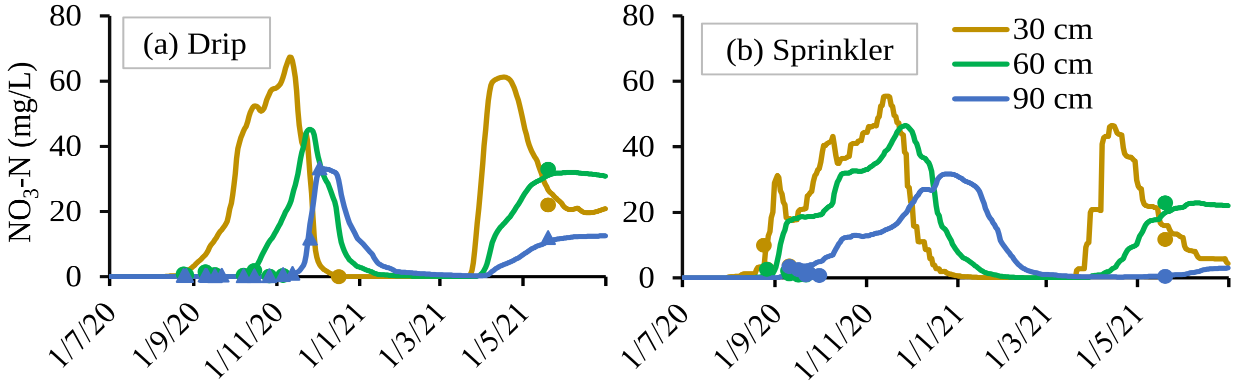


Figure 10-6. Comparison of measured (dots) and simulated (lines) values of nitrate-nitrogen (NO_3-N) in the soil solution at 30, 60 and 90 cm soil depth under (a) drip and (b) Sprinkler irrigated almond (spacing 7.0 x 4.5 m) during the 2020-21 season.

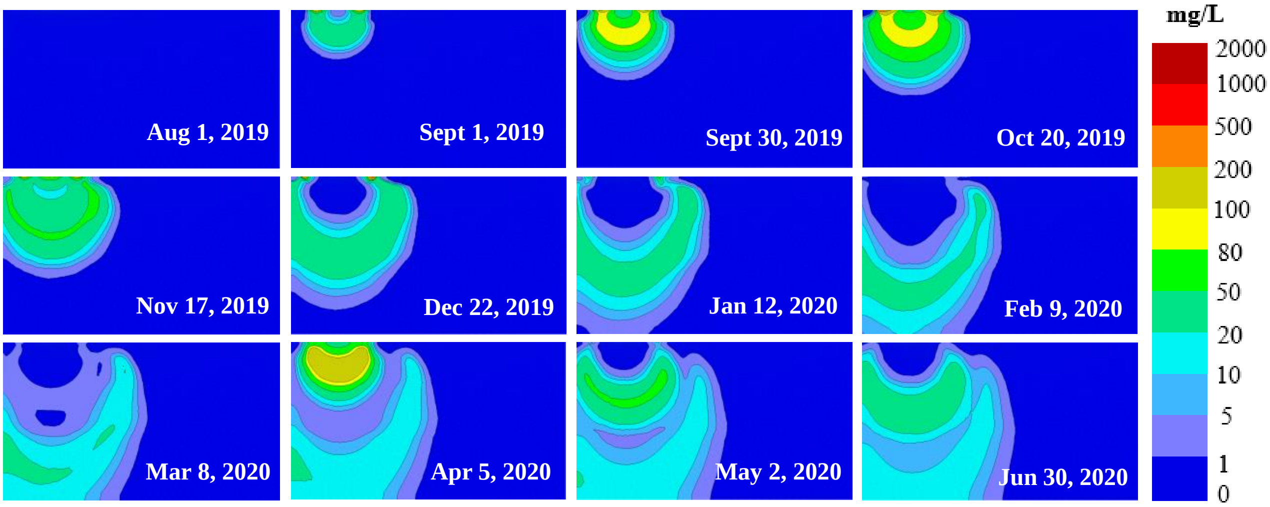


Figure 10-7. HYDRUS-2D simulated NO3-N (mg/L) distribution in the soil at different times under drip fertigated almond planted at 7.0 m x 4.5 m density (H1 plantings) during 2019-20.

The nitrogen modelling approach followed in this study only considered the processes involved in a sequential-first order decay chain i.e., processes involved in nitrification (NH4+-N transformation into NO_2-N and then into NO_3-N. Nitrogen fixation from the atmosphere, mineralization of crop residues and other organic wastes, mineralization of the soil humus fraction and so on are not considered in this approach, and so may be the cause of differences between measured and simulated values.

Simulated real-time spatial extent of NO_3-N in the domain, and its movement in the soil at various times during the almond growing season (2019-20) for drip irrigated almond plantings is shown in Figure 10-7. Nitrate fertigation increased the nitrogen content in the soil as the season progressed, as evidenced by the increasing size of the concentration plume below the dripper. This indicates that the NO_3-N application was higher than the demand, and young (2 year old) plants were unable to take up all the nitrogen added through fertigation, allowing NO_3-N to build up in the soil with time. Ultimately, nitrogen started moving downwards after mid-January when total water additions exceeded ET_C. Similar distribution was also observed during the 2020-21 season.

A range of studies (Silva, 2013, Saffigna and Keeney, 1977, Baram et al., 2016b, Baram et al., 2016a, Neilsen and Neilsen, 2002), as well as the current data suggest that the fate, distribution and leaching of added N under perennial horticultural crops is highly dynamic and influenced by the time and extent of N and water application, orchard N demand, and inherent soil heterogeneity. (Neilsen and Neilsen, 2002) stated that the accurate assessment of tree N demand is highly crucial to regulate the fertiliser application and N dynamics in the soil. Thus, timing of N supply to periods of high demand is crucial for improving N use efficiency.

Estimation of plant uptake and losses is critical to understand the possible fate of N in the soil system. Nitrogen balance of the added N under drip and sprinkler irrigated young almond orchard during the 2019-20 and 2020-21 season is given in Table 10-5. The nitrogen fertiliser was applied either in the form of NH_4^+ or NO_3^-, but model simulations showed that nitrification of NH_4^+ was very rapid and most of the NH_4-N converted to NO_3^- before it moved to deeper depths, so that no traces of NH_4^+ were observed below 20 cm depth. As a result, the simulated plant NH_4^+-N uptake was very low (Table 10-5).

Hence, the NO_3^--N form was responsible for most of the plant uptake, accounting for 61 - 77% of applied N in response to variable amount of N fertigation across treatments and seasons. In a similar study (Phogat et al., 2017) reported 85% of applied N uptake by a drip fertigated mandarin tree; while N recovery was only 50% in a lysimeter planted orange tree due to high drainage losses amounting to 49% in a sandy soil (Phogat et al., 2013).

Nitrate-nitrogen leaching accounted for only 7 - 13% of the applied nitrogen (Table 10-5). Model simulations also highlight the large degree of spatiotemporal variability in NO_3-N leaching below the root zone and suggest that a small fraction of the soil water (mobile water) is responsible for most of the NO_3-N transport below the effective root zone of an orchard. Nitrate, being an anion, moves freely in mineral soils and hence has the potential to leach into groundwater and waterways if fertigation is not well scheduled (Gardenas et al., 2005, Phogat et al., 2014).

Table 10-5. Components of the nitrogen balance for drip and sprinkler irrigated almond (7.0 x 4.5 m) during 2019-20 and 2020-21.

N source	N Balance (kg/ha)	Drip 2019-20	Drip 2020-21	Sprinkler 2019-20	Sprinkler 2020-21
NH4-N	$Soil_{initial}$	0.0	0.0	0.0	0.0
	Added	52.2	74.0	69.1	64.8
	Adsorbed	0.0	0.0	0.0	0.0
	Uptake	0.6	1.5	0.4	0.4
	Leached	0.0	0.0	0.0	0.0
	Nitrification	52.0	73.1	68.7	64.1
	$Soil_{end}$	0.0	0.0	0.0	0.0
NO3-N	$Soil_{initial}$	0.0	37.0	0.0	30.0
	Added	93.6	68.0	122.4	75.1
	Uptake	100.0	128.1	161.5	130.1
	Leached	12.3	18.1	4.7	22.8
	$Soil_{end}$	37.0	31.8	30.0	25.3
Mass balance error		*-2.9*	*-0.3*	*-2.3*	*-5.1*

Timing of N application in response to crop demand is one of the crucial factors for controlling NO_3-N leaching in the almond orchards. (Muhammad et al., 2015) suggested that the majority of macro and micronutrient uptake occurred between anthesis and kernel fill, with 35–50% of total N uptake occurring before 40 days after full bloom (DAFB) and 80–90% of the total N being accumulated by 112 DAFB, coinciding with kernel filling. Thus, N application following this period or excess N in the soil after this stage (kernel filling) may contribute to NO_3-N leaching. Therefore, supplying adequate N to the plant in a timely manner is essential to improve N-use efficiency and reduce nitrate losses (Weinbaum et al., 1992). Better understanding of the role of tree N demand in the regulation of soil N uptake may allow increased efficiency of fertiliser recovery.

Water productivity and N use efficiency

Water productivity of almond under drip and sprinkler irrigation relative to amount of irrigation (WPI), evapotranspiration (WPET) and transpiration (WPT) were estimated as kernel yield divided by the respective water balance component (I, ET and T) during 2020-21 (Almond water productivity (kg/m3) in relation to irrigation (WPI) applied, model simulated values of evapotranspiration (WPET) and transpiration (WPT) in (a) and Nitrogen use efficiency in terms of fertiliser applied (NUEf) and kernel yield (NUEf) in (b) under drip and sprinkler irrigation systems.

WPI for drip was 0.15 kg/m^3 while it was only 0.08 kg/m^3 under sprinkler irrigation due to the higher amount of I applied in the latter. Similarly, WPET values for drip and sprinkler were 0.14 and 0.08 kg/m^3, respectively. WPT under drip was 0.18 as compared to 0.14 kg/m^3 under sprinkler system. The drip system showed higher values of water productivities as compared to sprinkler irrigation irrespective of the denominator components i.e., amount of seasonal irrigation, ET and T. It is well understood that drip irrigation systems are relatively efficient as compared to sprinkler, as the chances of water losses are higher under the latter due to a large soil surface wetted by the irrigation, leading to high evaporation losses.

The average WPET and WPT values for young almond trees (3 years old) in the current study are lower than the reported values of 0.23 and 0.32 kg/m^3 by (López-López et al., 2018) for mature trees. Similarly, (Phogat et al., 2013) reported the values of WPET and WPT in the range of 0.43 to 0.47 and 0.56 to 0.59 kg/m^3, respectively for a mature almond orchard under Australian conditions. This may reflect the limited rooting zone of these young trees, potentially leading to greater drainage losses under sprinkler irrigation, and the relatively low canopy cover across the inter-row space, increasing the evaporative demand in both system types.

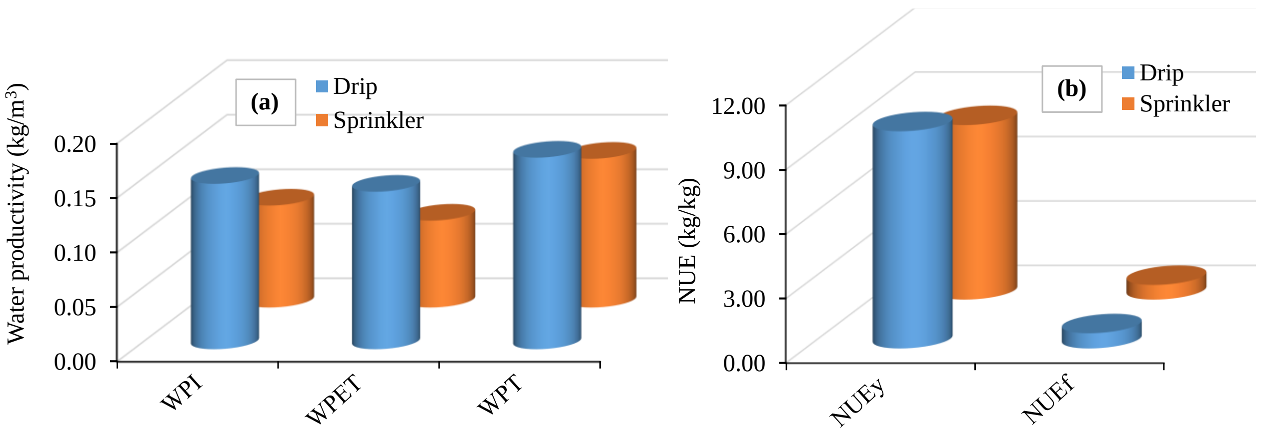


Figure 10-8. Almond water productivity (kg/m^3) in relation to irrigation (WPI) applied, model simulated values of evapotranspiration (WPET) and transpiration (WPT) in (a) and Nitrogen use efficiency in terms of fertiliser applied (NUEf) and kernel yield (NUEf) in (b) under drip and sprinkler irrigation systems.

Nitrogen use efficiency (NUE) was estimated in terms of kernel yield (NUEy) and fertiliser N uptake (NUEf) by almond, divided by total N applied through fertigation (Figure 10-8b). NUEy was 10 and 8 kg/kg of fertiliser applied, respectively for drip and sprinkler irrigation systems, higher under drip irrigation. NUEf was 0.68 kg/kg for drip and 0.71 kg/kg for sprinkler irrigation, which means 68 - 71% of the applied N was consumed by the almond trees. To maximise N use efficiency, a nutrient demand curve is key to supplying the correct amount of N when it is needed (Muhammad et al., 2015). This is possible only when accurate estimation of temporal N requirement has been carried out in correspondence with plant growth over the entire season.

10.4 Conclusions

This study used a numerical model (HYDRUS-2D) to assess the water balance and solute movement (salinity and nitrate) processes in the soil under drip and sprinkler irrigated young almond orchard. The model was calibrated and validated over a complete growing season, during 2019-20 and 2020-21 respectively, to determine the seasonal water and applied N balance in the soil. Model simulated values of root water uptake (RWU), evapotranspiration (ET) and applied irrigation (I), N fertiliser (f) and yield (y) data were used to estimate water productivity (WP) for irrigation (WPI), ET (WPET) and transpiration (WPT), as well as nitrogen use efficiency (NUE) for kernel yield (NUEy) and N uptake (NUEf).

Comparisons between drip and sprinkler irrigation revealed that almond RWU under drip irrigation was around 16% higher than under sprinkler irrigation. Moreover, the seasonal evaporation (Es) losses were 22% higher under sprinkler than drip system, highlighting significant water losses in response to evaporative demand. Such losses could also occur in other horticultural production systems grown in similar climate and soil conditions across the Murray Darling Basin. These observations suggests that appropriate interventions (e.g., mulching) are needed for reducing evaporation losses and enhancing the long-term sustainability of horticultural crops irrigated with sprinkler system.

The results showed increased estimates for a range of water productivities and N use efficiency in terms of kernel yield (NUEy) under drip system compared to sprinkler irrigation of almond orchards. However, NUEf was similar (60%) under both irrigation systems. There is room for further reductions in N losses in both irrigation systems, through better matching of timing and quantity of fertiliser N application to tree requirements.

There is a need to further strengthen the model calibration for salinity and N transport processes by integrating robust and intensive spatiotemporal measurement program in the soil. These measures will improve our understanding on spatiotemporal soil salinity and N dynamics in the soil, as well as matching the timing and magnitude of fertigation with plant requirements.

The calibration of the model for water balance and nitrogen dynamics in the soil for drip and sprinkler irrigation systems was adequate, but there are numerous uncertainties associated with the field measurements such as root dynamics, canopy growth, gypsum block anomalies, water uptake by weeds and cover crops especially in sprinkler, varied soil conditions, varied irrigation application rate, and deep drainage inconsistencies. These issues can be addressed quite comprehensively in a closed system of measurement such as lysimeters.

Well calibrated and validated numerical models are valuable tools for predicting the response of production systems to climate stresses and/or challenging water availability and quality.

SECTION 11. Modelling the impact of tree density on rootzone water, salinity and nutrient dynamics

Key points

- A numerical model (HYDRUS-2D) was calibrated and validated for water balance, salinity distribution and applied N dynamics for two seasons (2019/20 and 2020/21) in soils under almond plantings ranging from low (H1) to medium (H2) density.
- Medium density Nonpareil (615 trees/ha) registered 12% higher transpiration as compared to low density (308 trees/ha).
- Evaporation losses were similar under both Nonpareil and Shasta genotypes (18 - 21%), indicating significant unproductive water loss.
- Simulated drainage losses amounted to 11 - 26% across genotype and planting density.
- Simulated N balance showed medium density plantings of both Nonpareil and Shasta attained higher nitrogen use efficiency (yield) than low density plantings.
- Water productivity (WP) for irrigation (WPI), transpiration (WPT) and evapotranspiration (WPET) increased by 42 - 62% under medium density Nonpareil plantings as compared to low density.
- Estimated N use efficiency (NUE) in terms of kernel yield was 63% higher under medium density planting as compared to low density. However, N uptake efficiency (NUEf) was similar across density and genotype.
- Well calibrated numerical models are a useful tool for predicting the response of production systems to scenarios such as climate change, water scarcity, poor water quality and alternate irrigation and nutrient programs.

11.1 Abstract

In this study, a numerical model (HYDRUS-2D) was used to assess alternative almond production systems for water balance, salinity dynamics and nutrient (nitrogen) transport in the soil under varied planting densities (308, 440, and 615 trees/ha) of Nonpareil and Shasta genotypes. These simulations were calibrated against measured data that was collected at SARDI's Almond Centre of Excellence during the 2019-20 and 2020-21 seasons. Model simulated values of water and N balance were used to estimate water productivity and N use efficiency in the young almond orchard.

Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), Mean Error (ME) and Percent Bias (PBIAS) were used to evaluate the performance of the model against measured values of soil water distribution, salinity dynamics and nitrate dynamics.

Soil water distribution performance of the model was generally good, as was the ability of the simulations to model salinity dynamics and N dynamics in the soil. Model calibration for nitrate dynamics can be improved further through intensive field measurements.

Water balance results suggest that almond root water uptake (RWU), or actual transpiration (Ta) accounted for 56 - 66% of water applied to Nonpareil trees during 2020-21, while it was only 40 - 42% during 2019-20. Medium density Nonpareil planting (615 trees/ha) registered about 10% higher RWU than 308 trees/ha. RWU in Shasta accounted for 61 - 65% of applied water.

Evaporation losses were similar under both genotypes (18 - 21%), indicating an appreciable amount of unproductive water loss.

Measured and predicted salinity dynamics remained below the crop threshold (ECsw = 3 dS/m) at the soil surface, while ECsw rose rapidly at 60 and 90 cm depths in response to fertigation and remained above the crop tolerance threshold for much of the season. Simulated seasonal NO_3^--N concentrations in the model domain varied from 0.0 - 500 mg/L, and an appreciable amount of NO_3-N was detected at 90 cm depth. Model simulated NO_3-N uptake in Nonpareil and Shasta averaged around 66%. Medium density plantings showed increased nitrogen use efficiency over low density plantings Nitrate leaching accounted for 14 - 20% of the applied nitrogen, and around 15 - 16% of applied N remained in the soil profile at the end of the simulation and was therefore susceptible to leaching in the ensuing winter.

Estimated water productivity (WP) for irrigation (WPI), evapotranspiration (WPET) and transpiration (WPT) for Nonpareil at medium density (615 trees/ha) increased by 42, 49 and 62% respectively as compared to low density planting (308 trees/ha). The equivalent WP values for Shasta increased by 9 - 16% only. Estimated N use efficiency (NUE) in terms of kernel yield was 63% higher under medium density as compared to low density planting. However, NUE in terms of N uptake against added N was similar under both genotypes and planting densities.

The data can be further improved by strengthening the model calibration through robust and intensive field measurements of soil salinity and N dynamics in the soil at multiple locations.

11.2 Background and aims

Almond is one of the promising and high value nut crops in Australia, and the area under almond is expanding at a rapid rate. Total almond plantings cover an area of 58523 ha, increased from 7036 ha in 2006 (ABA, 2021). Most of the almond plantings in Australia are under drip irrigation systems to make optimum use of scare water resources. Almond growers are increasingly interested in optimizing their production systems with closer planting densities. However, developing an efficient production system for almond requires precise application of water and nutritional inputs to achieve profitable production potential.

Recently, close growing and high yielding genotypes have been incorporated into higher density planting systems in the pursuit of improved production efficiencies. These genotypes have varying vigour and growth habits making them suited to dense canopies that facilitate higher light interception and increased productivity. As the growing conditions, tree growth and vigour characteristics among different genotypes vary, their requirement for water and nutrient will also change. These factors necessitate the development of appropriate irrigation scheduling aligned to the crop demand so that sustainable orchard production systems can be developed.

Providing adequate nutrition to the growing trees is essential to develop an efficient production system. With most of the almond growing soils in South Australia being nutritionally poor, the application of fertiliser is an important source of supply for essential nutrients for better growth and profitable nut production. However, there are numerous challenges in the estimation of fertiliser requirement of a crop, such as amount, type and timing of application. Excess application of fertilisers such as nitrogen could end up leaching deeper in the soil and may degrade the groundwater and associated environment. Irrigated horticulture has, in general, been identified as the major source of nitrogen in drainage waters in the Murray Darling Basin (Harrison, 1994). A significantly high nitrate level has been reported in drainage water (60 mg L^{-1}) and soil solution (100 mg L^{-1}) under grapevines (Correll, 2010) in the Murray Darling Basin. These values are significantly higher than the Australian environmental trigger value (0.5 mg L^{-1} for lowland rivers) for nitrate (ANZECC, 2000).

Therefore, it is important to assess the whole entire production system (soil, water, crop, and climate) to devise better guidelines for irrigation and fertiliser application to almond and support more efficient orchard production systems. This study is aimed at:

1) calibrating and validating a numerical model (HYDRUS-2D) for water content, soil solution

salinity (ECsw) and applied nitrogen (N) dynamics in the soil under different planting densities (308, 440, 615 trees/ha) over two seasons (2019-20 and 2020-21),

2) assessing the seasonal water balance and N balance components in the soil for different density plantings and two genotypes (Nonpareil and Shasta) of almonds, and
3) estimating water and N use efficiencies of almond by utilizing the model simulated root water uptake (RWU) and crop evapotranspiration (ET) components.

The outcome of this study will be helpful in devising the guidelines for developing an efficient almond production system in the Riverland.

11.3 Materials and methods

This modelling study was focussed on estimating the water balance, salinity distribution and applied nitrogen usage under 3 tree density plantings (308, 440, 615 trees/ha) and two genotypes (Nonpareil and Shasta) in the Low (H1) to Medium (H2) Optimised Density Trial at the ACE. All the experimental details and orchard management practices are discussed in SECTION 7 of this report.

HYDRUS-2D was calibrated and validated under low density (308 trees/ha) Nonpareil genotype for water content dynamics, salinity build up and nitrate dynamics in the soil. Subsequently the simulations were extended to other, higher densities (440 and 615 trees/ha) and another genotype (Shasta) for optimizing and establishing a high density planting for efficient almond production system.

Estimating input parameters for HYDRUS-2D

Soil hydraulic parameters (SHP) for different soil texture layers at the Low (H1) to Medium (H2) Optimised Density Trial site were estimated from the particle size analysis and bulk density determination for each of the soil layer in the soil profile (Table 11-1). Information from a soil survey conducted at the beginning of the trial was used to develop different sets of soil hydraulic parameters for each of the modelling sites. Final calibrated values of soil hydraulic properties, soil texture, particle size and bulk density data is shown in Table 11-1. Refer to SECTION 10 for more details on soil characterisation.

Table 11-1 Soil texture, particle size distribution, bulk density (Db) and estimated soil hydraulic parameters at the Low (H1) to Medium (H2) Optimised Density Trial (θr is the residual water content; θs represents saturated water contents; α represents inverse of of air entry value; n & l are the pore shape parameters and Ks is the saturated hydraulic conductivity of soils).

Soil depth (cm)	Texture	Sand	Silt (%)	Clay	Db (g/cm^3)	θ_r	θ_s (cm^{3}cm^{-3})	α (cm^{-1})	η	K_s (cm day^{-1})	l
308 trees/ha (Pit 19)											
0-10	SL	83.7	4.5	11.8	1.59	0.06	0.37	0.03	2.03	160.54	0.42
10-35	LSCL	75.7	7.9	16.4	1.54	0.06	0.39	0.03	1.71	96.23	0.35
35-90	LSCL	76.1	8.6	15.2	1.56	0.06	0.38	0.03	1.72	90.54	0.34
90-115	SCL	67.9	10.3	21.9	1.62	0.06	0.37	0.03	1.62	50.32	0.24
115-160	CLS	61.9	10.2	27.9	1.63	0.06	0.37	0.03	1.45	30.25	0.24
440 trees/ha (Pit 9)											
0-10	SL	81.6	4.8	13.6	1.63	0.06	0.36	0.03	1.63	57.27	0.41
10-25	LSCL	75.7	7.9	16.4	1.54	0.06	0.39	0.03	1.51	46.42	0.35
25-45	LSCL	76.1	8.6	15.2	1.56	0.06	0.38	0.03	1.52	46.27	0.34
45-80	SCL	67.9	10.3	21.9	1.62	0.06	0.37	0.03	1.46	37.42	0.24
80-120	LSCL	72.1	8.7	19.2	1.58	0.06	0.38	0.03	1.40	28.42	0.34
120-180	SCL	64.9	7.2	27.9	1.62	0.07	0.38	0.03	1.26	14.05	0.24
615 trees/ha (Pit 16)											
0-10	KSL	90.8	2.9	6.3	1.65	0.05	0.37	0.03	2.16	243.74	0.59
10-40	SL	83.7	4.5	11.8	1.59	0.06	0.37	0.03	1.79	91.06	0.42
40-65	LSCL	76.1	8.6	15.2	1.56	0.06	0.38	0.03	1.52	46.27	0.34
65-110	SCL	67.9	10.3	21.9	1.62	0.06	0.37	0.03	1.32	17.42	0.24
110-150	SCL	64.9	7.2	27.9	1.62	0.07	0.38	0.03	1.26	14.05	0.24

The textural observation at the H2 optimised density modelling sites revealed an increased presence of light sandy clay loam texture across all locations (pit no. 9, 16 and 19) with sandy loam and silty loam texture at the soil surface. Normally, sandy clay loam soils are present at lower profile depths. Clay content varied from 6.3 to 27.9% at various depths across all sites (Table 11-1).

Water content monitoring in the soil

Continuous water content monitoring is important to calibrate and validate the model for water content dynamics in the soil. It helps in understanding the daily and seasonal plant water uptake, soil storage, leaching, and evaporation losses of water from the soil. Therefore, Capacitance probes were installed close to the tree line (0 cm) with sensors located at every 10 cm depth up to a depth of 120 cm in all planting density and genotype combinations. The location of Capacitance probes in the soil is shown in Figure 11-1. Water content was measured continuously over the two seasons (2019-20 and 2020-21). Daily data obtained from the Capacitance probes were used to calibrate (2019/20) and validate (2020/21) the model (HYDRUS-2D) for water content distribution in the soil.

Sol solution salinity (ECsw) and N measurements in the soil

Soil salinity and nutrient (nitrate) monitoring was established under Nonpareil plantings in medium (615 trees) and low (308 trees) density treatments. To achieve this, SoluSamplers were installed at 30, 60, and 90 cm soil depths close to the tree line as shown in Figure 11-1. Soil solution was extracted during the crop season, and was analysed for EC, NO-N and NH_4-N contents in the soil. The success of solution extraction depends on a number of factors including soil texture, position of SoluSampler installation, irrigation amount and frequency. The model was calibrated and validated for soil solution salinity (ECsw) and N dynamics in the soil in low density (308 trees) Nonpareil planting treatment by comparing the modelled values with the measured values determined at 30, 60 and 90 cm soil depths.

Weather, irrigation and fertigation parameters

Refer to SECTION 10.

Model domain, initial and boundary conditions

The modelling domain for the optimized density comparison was similar to that adopted for the comparison of drip and sprinkler irrigation (SECTION 10), except that the horizontal axis was 325 cm, due to the closer row spacing in the Low (H1) to Medium (H2) Optimised Density Trial. In the vertical direction the domain extended to a depth of 200 cm, with the resulting 325 cm x 200 cm rectangular domain containing 4412 nodes and 8577 2D elements (Figure 11-1). Refer to Chapter 10 for further description of boundary conditions and other details.

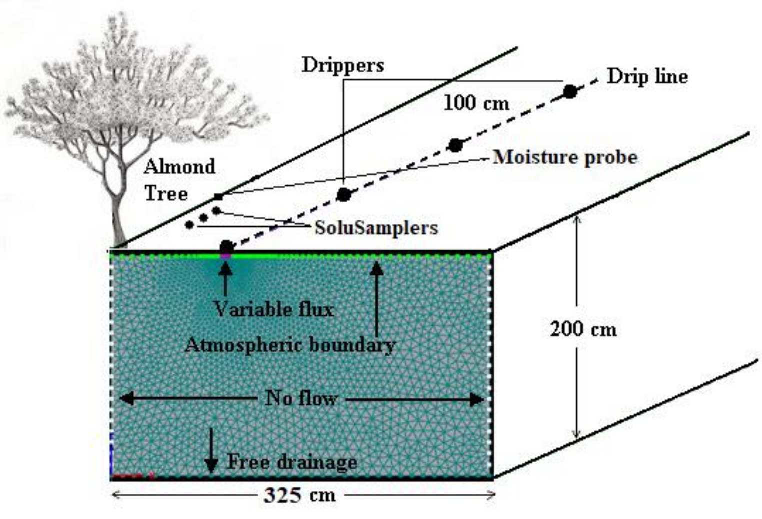


Figure 11-1 Schematic diagram showing sensor locations, modelling domain and imposed boundary conditions for optimised density trial (Horizon 2 plantings) Low (H1) to Medium (H2) Optimised Density Trial.

Model evaluation

Refer to SECTION 10.

11.4 Results and Discussion

Calibration and validation of HYDRUS-2D

Statistical error estimates between measured and simulated water content at different soil depths and planting densities during 2019-20 for Nonpareil almonds are shown in Table 11-2. Profile average RMSE, ME and MAE values were all below 0.05 cm^3 cm^{-3}, which is within the accepted range reported in other similar studies (Phogat et al., 2012, Phogat et al., 2013, Phogat et al., 2016, Ramos et al., 2011, Ramos et al., 2012). Furthermore, PBIAS remained close to 10% indicating excellent agreement between modelled and measured values. Negative percent bias (PBIAS) values indicate overestimation of water content but within accepted limits. Comparatively higher error values were recorded for 308 trees/ha density as compared to other densities, especially between 40 & 80 cm depth. The PBIAS values were also higher (23 - 32%) at this location but were within the good to fair range.

Similarly, during the 2020-21 season under Nonpareil plantings, the average RMSE, ME and MAE values were below 0.04 cm^3 cm^{-3}, for all density plantings (Table 11-3). The average PBIAS values all showed an excellent matching between measured and simulated water content dynamics in the soil. Comparatively higher error values (0.05- 0.06 cm^3 cm^{-3}) were recorded for 440 trees/ha as compared to other densities, especially between 40 & 80 cm depths. Such variations are bound to occur between the modelled and measured values. These deviations highlight the immense variability in the soil due to varied textural formations.

The average RMSE, ME and MAE estimates observed at different depths in the soil under Shasta genotype during the 2020-21 season are shown in Table 11-4. The average values of RMSE, ME, MAE and PBIAS generally indicated an excellent prediction of water content dynamics in the soil by the model. However, relatively high values of error estimates and PBIAS values at 110 cm for 308 trees/ha, and higher RMSE (0.06- 0.07 cm^3 cm^{-3}) for 440 trees/ha indicate divergence between the modelled and measured values.

In general, average profile estimates fall within the accepted range as reported in other studies (Phogat et al., 2013, 2014, 2016; Ramos et al., 2012). This suggests that the model did a good job of modelling actual soil water content dynamics.

Water balance components

Model predicted data for seasonal water balance components under Nonpareil and Shasta genotypes planted at different densities (308, 440, and 615 trees/ha) for two seasons is presented in Table 11-5. During 2019-20, seasonal root water uptake (RWU), drainage (Dr) and soil evaporation (Es) for Nonpareil almond accounted for 40 - 42, 26 - 32, and 27 - 31%, respectively of the total water application. Total water application includes irrigation, rainfall and soil depletion in a 2 m profile. Marginally higher seasonal drainage occurred under medium density plantings (615 trees/ha) than lower densities, while more evaporation was observed under lower densities. Nevertheless, the impact of density on seasonal water balance during 2019-20 was inconsistent.

During the subsequent year (2020-21), seasonal RWU under Nonpareil increased to 56 - 69%, being higher under medium density (615 trees/ha), while drainage (Dr) reduced, and showed a greater reduction under medium density plantings compared to low density (308 trees/ha). The reduction in seasonal evaporation losses during the 2020-21 season was significant but relatively small (10- 11%) across all planting densities.

Results for Shasta in 2020/21 were different to Nonpareil, with lower RWU at the higher two densities, resulting in higher drainage. Evaporation was very similar in both varieties at all densities in 2020/21.

The results suggest that plant density optimization in terms of water use differs for different genotypes, being influenced by plant growth, root growth and canopy development patterns. However, such comparisons need continued observation extended over multiple years.

Table 11-2 Error estimates between measured and predicted water content in the soil at different depths in different tree spacing (308, 440 and 615 trees/ha) drip irrigated Nonpareil almond plantation during the 2019-20.

						Soil depth (cm)							
Tests	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**Av**
308 trees/ha, Nonpareil, 2019-20													
RMSE	0.05	0.06	0.06	0.07	0.07	0.06	0.07	0.06	0.05	0.04	0.03	0.03	0.05
ME	0.04	0.02	0.04	-0.05	-0.05	-0.05	-0.06	-0.07	-0.03	-0.03	-0.01	-0.03	-0.03
MAE	0.04	0.05	0.06	0.06	0.06	0.06	0.05	0.07	0.04	0.03	0.03	0.03	0.04
PBIAS	17.3	7.9	17.2	-23.4	-24.1	-21.9	-31.7	-28.3	-12.5	-9.0	-4.0	-8.3	-10.6
440 trees/ha, Nonpareil, 2019-20													
RMSE	0.06	0.04	0.03	0.03	0.03	0.05	0.02	0.03	0.04	0.04	0.04	0.03	0.03
ME	-0.02	-0.01	-0.01	0.00	-0.02	-0.05	-0.01	-0.03	-0.03	-0.04	-0.03	-0.03	-0.03
MAE	0.05	0.03	0.03	0.03	0.03	0.05	0.02	0.03	0.03	0.04	0.03	0.03	0.03
PBIAS	-10.2	-5.6	-4.5	-1.8	-8.2	-22.8	-5.8	-12.1	-12.4	-16.2	-12.2	-9.8	-10.1
615 trees/ha, Nonpareil, 2019-20													
RMSE	0.06	0.04	0.04	0.03	0.03	0.05	0.05	0.05	0.02	0.02	0.05	0.04	0.03
ME	0.03	-0.02	0.01	0.00	-0.02	-0.04	-0.04	-0.05	-0.01	0.00	-0.05	-0.04	-0.02
MAE	0.05	0.03	0.03	0.03	0.03	0.04	0.04	0.05	0.02	0.01	0.05	0.04	0.02
PBIAS	14.3	-14.6	6.0	0.2	-13.8	-24.8	-22.5	-26.8	-3.1	0.1	-21.2	-16.7	-9.5

Table 11-3. Error estimates between measured and predicted water content in the soil at different depths in different spacing (308, 440 and 615 trees/ha) drip irrigated Nonpareil almond plantation during the 2020-21.

						Soil depth (cm)							
Tests	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**Av**
308 trees/ha, Nonpareil, 2020-21													
RMSE	0.04	0.03	0.04	0.06	0.06	0.03	0.04	0.04	0.04	0.04	0.02	0.04	0.04
ME	0.02	0.02	0.02	0.04	0.04	0.02	0.03	0.03	0.03	0.02	0.01	0.03	0.03
MAE	0.03	0.03	0.03	0.05	0.05	0.03	0.04	0.03	0.03	0.03	0.02	0.04	0.03
PBIAS	12.86	10.47	11.84	20.02	19.03	7.74	11.33	11.27	11.66	10.25	2.20	12.06	11.62
440 trees/ha, Nonpareil, 2020-21													
RMSE	0.05	0.07	0.04	0.06	0.07	0.06	0.07	0.06	0.03	0.02	0.04	0.03	0.04
ME	-0.04	-0.06	-0.01	-0.05	-0.06	-0.05	-0.06	-0.06	-0.01	0.00	0.02	-0.02	-0.03
MAE	0.05	0.06	0.04	0.05	0.06	0.05	0.06	0.06	0.02	0.02	0.03	0.02	0.04
PBIAS	-25.66	-42.46	-3.08	-28.95	-31.93	-24.70	-34.82	-28.10	-4.14	-0.42	8.21	-6.26	-15.16
615 trees/ha, Nonpareil, 2020-21													
RMSE	0.05	0.03	0.04	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.04	0.01	0.02
ME	0.04	0.02	0.02	0.01	0.00	0.00	-0.03	-0.02	-0.02	-0.01	-0.03	0.00	0.00
MAE	0.04	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.03	0.02	0.03	0.01	0.02
PBIAS	20.15	8.45	10.98	4.14	-0.84	-2.23	-15.47	-8.57	-12.29	-3.05	-16.79	1.61	-1.05

Table 11-4. Error estimates between measured and predicted water content in the soil at different depths in different plant spacing (308, 440 and 615 trees/ha) drip irrigated Shasta almond plantation during the 2019-20.

						Soil depth (cm)							
Tests	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**Av**
308 trees/ha, Shasta, 2020-21													
RMSE	0.05	0.05	0.04	0.03	0.04	0.04	0.03	0.03	0.04	0.05	0.07	0.03	0.03
ME	-0.04	-0.04	-0.03	0.00	0.03	0.03	0.00	-0.02	-0.02	-0.04	-0.07	-0.02	-0.02
MAE	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.07	0.02	0.03
PBIAS	-33.00	-31.32	-19.81	2.26	13.33	12.73	-1.39	-8.50	-10.83	-22.77	-40.40	-10.28	-10.54
440 trees/ha, Shasta, 2020-21													
RMSE	0.06	0.06	0.07	0.06	0.06	0.06	0.05	0.04	0.05	0.04	0.04	0.03	0.04
ME	0.01	0.01	0.03	-0.01	-0.01	-0.02	0.00	-0.01	0.04	0.00	-0.01	0.00	0.00
MAE	0.04	0.05	0.06	0.05	0.05	0.05	0.04	0.04	0.05	0.03	0.04	0.03	0.04
PBIAS	4.23	5.00	14.23	-3.00	-4.21	-8.84	1.88	-6.15	12.88	1.74	-3.16	0.45	1.56
615 trees/ha, Shasta, 2020-21													
RMSE	0.04	0.03	0.05	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.01	0.02
ME	0.02	0.00	0.03	0.03	0.01	-0.01	-0.01	-0.02	0.02	0.03	-0.03	0.00	0.01
MAE	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.01	0.02
PBIAS	12.30	-2.77	16.18	12.97	3.49	-5.26	-6.06	-12.13	10.41	12.37	-11.13	0.50	2.97

Numerous studies have shown that the productivity of young almond trees is highly influenced by the extent of shoot extension and canopy growth, which is directly related to optimum water regimes (Torrecillas et al., 1989, Girona, 1993, Hutmacher et al., 1994). This suggests that water stress should be avoided before trees reach their full canopy size, and that a certain amount of shoot renewal is required to maintain almond productivity even at full canopy size (Naor et al., 2018).

Table 11-5 Seasonal water balance components (irrigation- I, precipitation- P, root water uptake- RWU, drainage- Dr, evaporation- Es, soil depletion- Sd) at different tree spacing (308, 440 and 615 trees/ha) of drip irrigated Nonpareil (NP) and Shasta (SH) genotypes during 2019-20 and 2020-21.

	308 trees/ha			440 trees/ha			615 trees/ha		
	NP	NP	SH	NP	NP	SH	NP	NP	SH
	2019-20	2020-21	2020-21	2019-20	2020-21	2020-21	2019-20	2020-21	2020-21
I (mm)	790.7	1054.5	1054.5	794.3	1054.6	1054.6	752.2	1054.5	1054.5
P (mm)	194.4	173	173	194.4	173	173	194.4	173	173
RWU (mm)	434.8	774.5	773.8	445.1	847	812.6	429.6	883.5	822.5
Dr (mm)	291.3	358.1	236	274.6	146.1	164.4	336.8	209.5	250
Es (mm)	301.7	250.2	240.3	323.6	257.4	262	289.7	232	236
St/dep (mm)	-52.8	-148.5	-32	-64.5	-33.7	-22.1	-114.3	-53.6	-90.5
Error (%)	1	0.8	0.8	1	0.9	0.9	0.5	0.8	0.8

Soil water salinity dynamics

The values of statistical error estimates (RMSE, ME and MAE) and PBIAS between measured and model simulated soil solution salinity (ECsw) values are compared in Table 11-6. The error estimates (RMSE, MAE and ME) at 30 and 90 cm depths during 2019-20 indicated good prediction by the model, while error estimates at 60 cm increased by two-fold. However, percent bias (PBIAS) values across all depths showed good prediction of soil water salinity by the model. Similarly, during 2020-21 some higher values of error estimates were observed at a few locations, but average data remained within the accepted range, and PBIAS values also fell within the accepted range.

Table 11-6 Error estimates between measured and simulated soil solution salinity (ECsw) at different depths in the soil for drip irrigated Nonpareil genotype planted at 308 trees/ha during 2019-20 and 2020-21.

Statistical tests	30cm	60cm	90cm	Average
2019-20				
RMSE (cm^3cm^{-3})	0.30	0.65	0.32	0.37
ME/MBE (cm^3cm^{-3})	0.31	-0.60	0.15	0.03
MAE (cm^3cm^{-3})	0.29	0.70	0.27	0.33
PBIAS (%)	27.14	-23.36	7.62	1.47
2020-21				
RMSE (cm^3cm^{-3})	0.52	0.42	0.45	0.34
ME/MBE (cm^3cm^{-3})	0.11	-0.40	0.21	0.11
MAE (cm^3cm^{-3})	0.45	0.40	0.41	0.27
PBIAS (%)	21.77	-17.43	5.60	12.73

Measured and simulated values of ECsw at 30, 60 and 90 cm in the soil under low density (308 trees/ha) Nonpareil trees are displayed in Figure 11-2.

Modelled ECsw values at 30 and 90 cm soil depths remained within the almond salinity threshold (ECsw = 3 dS/m) during the entire 2019/20 season (Figure 11-2a). However, the values at 60 cm showed a steep increase early in the season (> 6dS/m) and remained higher than the almond tolerance threshold (ECsw= 3dS/m) from October onwards. Measured data also confirms this pattern. Towards the end of the cropping season ECsw values at 60 cm dropped below the crop threshold. The elevated values of ECsw are potentially related to nutrient rather than chloride salts.

During the 2020-21 season (Figure 11-2b), the elevated ECsw values occurred at 60 and 90cm depths, with ECsw above the threshold from November onwards and right up to the end of the season. Exposure of young almond trees to elevated salinity could have a drastic impact on normal growth and canopy development. Elevated salts can impact root water uptake and increase Cl uptake by the plant, both of which can impact tree growth and many physiological processes in the plant, such as transpiration, photosynthesis and nutrient uptake.

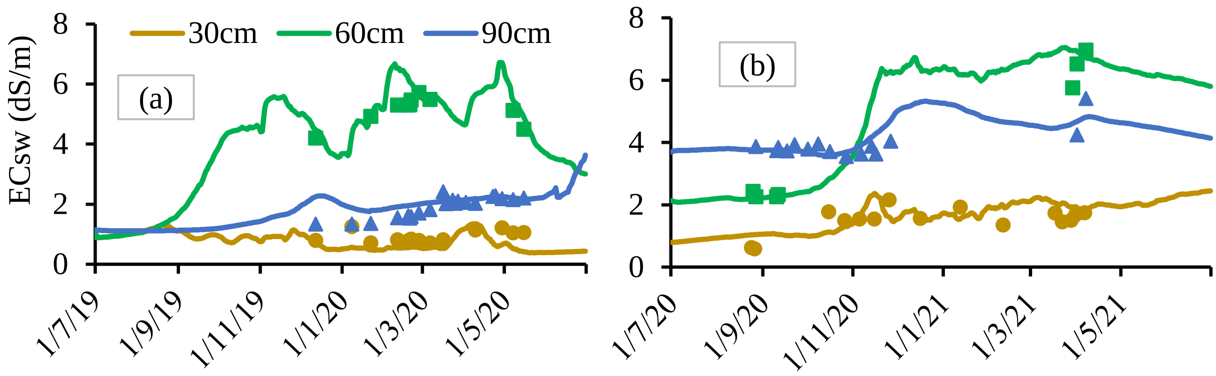


Figure 11-2 Comparison of measured (dots) and simulated (lines) soil solution salinity (ECsw) at 30, 60 and 90 cm soil depth in drip irrigated Nonpareil almonds at 308 trees/ha during (a) 2019-20 and (b) 2020-21 season.

Nitrate dynamics

The spatiotemporal dynamics of NO_3-N concentration in low density (308 trees/ha) Nonpareil is shown in Figure 11-3. Unavailability of measured NO_3-N in soil solution samples collected early in the season during 2019-20 impacted the calibration of the model. However, the measured data corresponds quite closely to the simulation across the seasons.

During 2019-20 (Figure 11-3a), the NO_3-N concentration at 30 cm rose as high as 407 mg/L in response to N fertiliser application during September to November. Similarly, the concentration at 60 cm depth peaked at around 275 mg/L and 135 mg/L at 90 cm. The concentration at 30 and 60 cm quickly depleted to insignificant values from January to mid-March due to rapid downward movement and plant uptake of soil N. An appreciable amount of NO_3-N detected at 90 cm depth indicates the potential for N losses through leaching.

There was a similar surge in NO_3-N dynamics during postharvest fertigation. The pattern of increase and decrease at different depths from mid-March to the end of June suggests some uptake of applied N, but also the rapid movement of some of the N through the profile and beyond the rootzone.

During 2020-21 (Figure 11-3b), simulated NO_3-N concentration peaked at 67, 57 and 40 mg/L, respectively at 30, 60 and 90 cm depth during the first fertigation schedule, suggesting movement of some N through the profile before being taken up by the trees. The pattern of increasing and decreasing N concentration in response to the post-harvest fertiliser application suggests that a large proportion of the applied N was slowly leached through the soil profile.

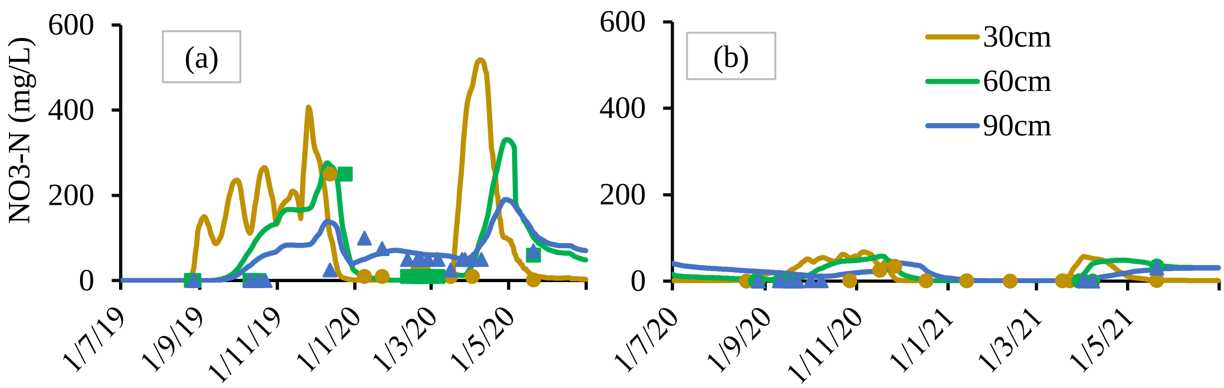


Figure 11-3 Comparison of measured (dots) and predicted (lines) values of nitrate-nitrogen (NO_3-N) at 30, 60 and 90 cm depth in soil under drip irrigated Nonpareil almonds at 308 trees/ha during (a) 2019-20 and (b) 2020-21.

Spatial simulation of the extent of NO_3-N in the domain and its movement in the soil at various times during the almond growing season (2019-20) is shown in Figure 11-4. Nitrate fertigation increased the nitrogen content in the soil as the season progressed, as evidenced by the increasing size of the concentration plume below the dripper. This indicates that the NO_3-N application was higher than the demand, and the young trees (2 years old) were unable to take up all the nitrogen added through fertigation, causing NO_3-N to build up in the soil. Nitrogen began moving downwards through the soil profile after Mid-January when total water additions exceeded ET_C.

High concentration of NO_3-N near the soil surface is associated with the upward movement of water due to surface evaporative flux, which removes water but leaves N behind. Significant concentration of NO_3-N in the soil during late December-January coincides with the hull split stage of almond growth. Overabundance of NO_3-N at this critical growth stage has been associated with pest and disease issues such as Hull Rot (Saa et al., 2016).

It is worth noting that excess NO_3-N moves rapidly to deeper soil layers. Excess NO_3-N started moving out of the domain from mid-December onwards, and continued to leach until the end of the simulation (30^{th} June 2020). The remaining portion of the applied NO_3-N, which remained in the soil when the trees entered dormancy, can also potentially be leached out of the root zone with subsequent winter rainfall.

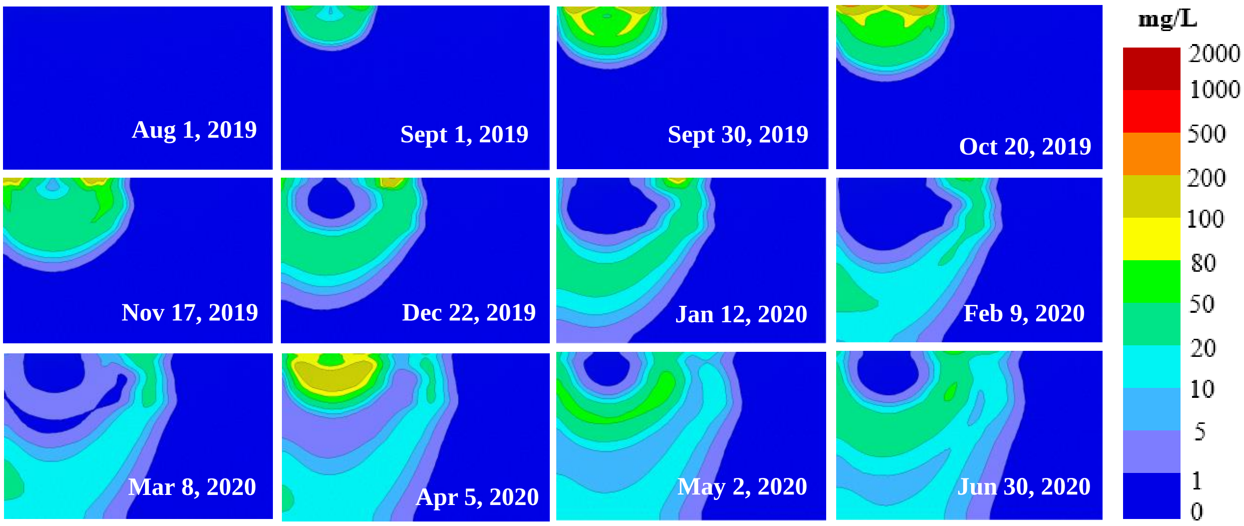


Figure 11-4 HYDRUS-2D simulated NO3-N (mg/L) distribution in the soil at different times during 2019/20 under drip fertigated almond planted at 308 trees/ha.

Model predicted values of applied nitrogen balance under different density almond planting for Nonpareil and Shasta genotypes during 2019-20 and 2020-21 are displayed in Table 11-7 and Table 11-8 respectively. N uptake by Nonpareil genotype during 2019-20 accounted for 63 - 66% of the total N applied as fertilisers (applied as both NH_4-N and NO_3-N). Plant uptake N increased to 67 - 69% and 66 - 67% respectively, under Nonpareil and Shasta genotypes during 2020-21.

Nitrate-nitrogen leaching accounted for only 5 - 13% of applied nitrogen during 2019-20 (Table 11-7). Extent of N leaching increased in 2020-21 and varied from 14 - 20% across all densities and genotypes. NO3-N leaching was lower under low density (308 trees/ha) as compared to high density planting (615 trees/ha) in 2019/20, but the relationship was reversed in 2020/21.

A large amount of added N remained in the soil at the end of both seasons, irrespective of density and genotype.

Table 11-7. Components of the nitrogen balance for Nonpareil almond planted at different densities (308, 440 and 615 trees/ha) during 2019-20.

N source	N Balance (kg/ha)	308 trees/ha NP	440 trees/ha NP	615 trees/ha NP
NH4-N	$Soil_{initial}$	0.0	0.0	0.0
	Added	52.2	52.2	52.2
	Adsorbed	0.0	0.0	0.0
	Uptake	0.5	0.6	0.6
	Leached	0.0	0.0	0.0
	Nitrification	52.1	52.1	52.1
	$Soil_{end}$	0.0	0.0	0.0
NO3-N	$Soil_{initial}$	0.0	0.0	0.0
	Added	93.6	93.6	93.6
	Uptake	96.1	94.9	91.6
	Leached	7.2	9.5	18.7
	$Soil_{end}$	41.5	40.0	34.7
Mass balance error		*0.3*	*0.6*	*0.1*

Table 11-8. Components of the nitrogen balance for Nonpareil and Shasta genotypes of almond planted at different densities (308, 440 and 615 trees/ha) during 2020-21.

N source	N Balance (kg/ha)	308 trees/ha		440 trees/ha		615 trees/ha	
		NP	SH	NP	SH	NP	SH
NH4-N	$Soil_{initial}$	0	0	0	0	0	0
	Added	79.7	79.7	79.7	79.7	79.7	79.7
	Adsorbed	0	0	0	0	0	0
	Uptake	1.6	1.6	1.6	1.5	0.5	1.8
	Leached	0	0	0	0	0	0
	Nitrification	79	79	78.3	78.4	78.1	78.2
	$Soil_{end}$	0	0	0	0	0	0
NO3-N	$Soil_{initial}$	41.5	41.5	40	40	34.7	34.7
	Added	73.2	73.2	73.2	73.2	73.2	73.2
	Uptake	128.9	125.2	129.1	127.8	129.2	126.5
	Leached	36.2	38.8	363.2	34.6	26.2	28.2
	$Soil_{end}$	28.8	30	29.2	30.1	30.9	31.2
Mass balance error		*-0.6*	*-0.6*	*-0.1*	*-0.6*	*0.4*	*-0.2*

Water productivity and N use efficiency

Water productivity of almond under different planting densities was estimated as the kernel yield divided by the irrigation term, i.e., amount of irrigation (WPI), seasonal evapotranspiration (WPET) and crop transpiration (WPT). The estimated values of various productivity measures during 2020-21 are illustrated in Figure 11-5. Water productivity by all measures (WPI, WPET, WPT) increased with an increase in the planting density under Nonpareil, while the values for Shasta were on a par for low/medium (440 trees/ha) and medium (615 trees/ha) planting density.

Medium density (615 trees/ha) Nonpareil trees showed 42 - 62% higher WP than under low density planting (308 trees/ha). On the other hand, in Shasta the increase was only 9 - 16%. However, the absolute values of WP at medium (615 trees/ha) density showed little difference between genotypes. These results are based on one year of data only, so there is a need to conduct a more long-term evaluation to have more confidence in the conclusions.

Nitrogen use efficiency (NUE) was estimated in terms of kernel yield (NUEy) and fertiliser N uptake (NUEf) divided by total N applied through fertigation. NUEy showed a positive response to increasing planting density (Figure 11-5). The corresponding values for Shasta showed a much smaller response to planting density, mainly due to higher efficiency at low density compared to Nonpareil.

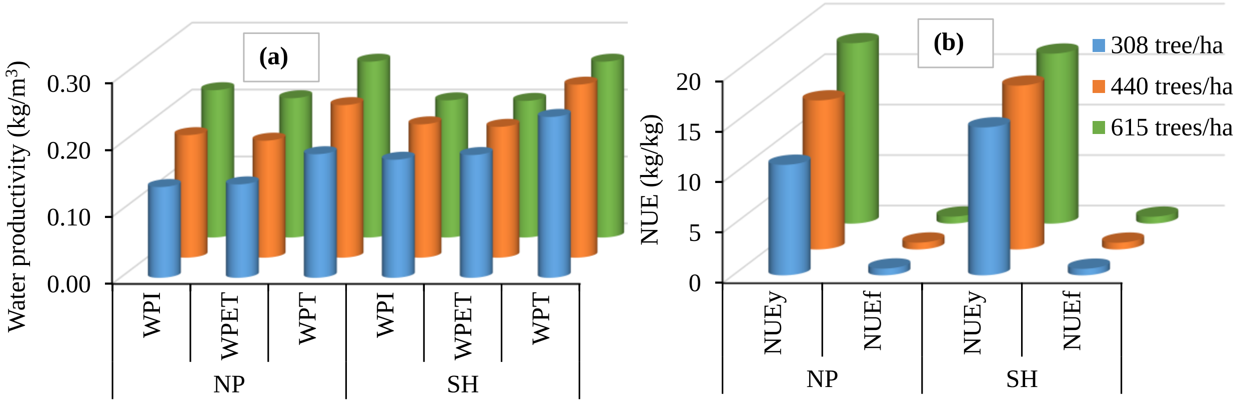


Figure 11-5. Almond water productivity (kg/m3) in relation to (a) irrigation (WPI) applied, model simulated values of evapotranspiration (WPET) and transpiration (WPT), and (b) Nitrogen use efficiency in terms of fertiliser applied (NUEf) and kernel yield (NUEf), under different planting densities.

The N uptake efficiency (NUEf) showed very little response to increase in planting density irrespective of genotype. The NUEf values varied from 65 - 69% across all densities and genotypes. Modelling and field measurements needed to be carried out over a much longer term to improve the data.

11.5 Conclusions

This study used a numerical model (HYDRUS-2D) to assess the water balance and solute movement (salinity and nitrate) processes in the soil under young almond plantings at a variety of tree densities.

The model was calibrated using data for 2019-20 and validated for 2020-21 data to determine the seasonal water and applied N balance in the soil. Model simulated values of root water uptake (RWU), evapotranspiration (ET) and applied irrigation (I), N fertiliser (f) and yield (y) data were used to estimate the water productivity (WP) for irrigation (WPI), ET (WPET) and transpiration (WPT). Furthermore, nitrogen use efficiency (NUE) was estimated for kernel yield (NUEy) and N uptake (NUEf) by almond tree.

The results revealed that RWU under medium density (615 trees/ha) Nonpareil almond plantation increased by 12% as compared to low density (308 trees/ha). This suggests that medium density plantings can enhance root water uptake, through increasing root biomass and more efficiently mine water from the crop rootzone. However, it is worth mentioning that the trees under the current study are still quite young and the impacts of high density may change when the trees are grown to full maturity. Long-term observations are required to understand the true competitive behaviour of high-density plantings for effective water use.

Similarly, the results showed higher estimates for water productivities and N use efficiency in terms of kernel yield (NUEy) under medium density almond plantations as compared to traditional low density production systems. The increase in water productivity at medium density over low density for Nonpareil was high (42 - 62%). Similarly, NUEy also showed a similar increase under medium density, although NUEf was similar (65-69%) irrespective of genotype and planting density. This clearly suggests that there are opportunities for developing more efficient almond growing systems compared to traditional low-density plantings and supports the prospect of monitoring production efficiencies over a longer time period.

There is a need to further strengthen the model calibration for salinity and N transport processes by integrating a robust and intensive spatiotemporal measurement program. Such measures would improve our understanding of the spatiotemporal dynamics of soil water solutes and assist with matching the timing and magnitude of fertigation applications to plant requirements.

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APPENDIX A Communication and extension activities

Date	Location	Audience	Activity
January 2017	Hort Innovation	Hort Innovation	ST16003 – MS101
February 2017	Loxton Research Centre	almond growers, industry, ABA	launch of the Almond Centre of Excellence on February 3rd 2017. ABA and SARDI were involved in communication at the launch, and an interview with Mark Skewes from SARDI about plans for research at the site was published by the Stock Journal http://www.stockjournal.com.au
May 2017	Hort Innovation	Hort Innovation	ST16003 – MS102
May 2017	DEDJTR Mildura Centre	HIA, ABA and Walnuts Australia State R&D providers	Oral presentation on the progress of the Loxton Almond Centre of Excellence field site. (J. Cox / M. Skewes / D. Graetz)
June 2017	Loxton Research Centre	ABA ACE committee members	Oral presentation on the progress of SARDI's soil amendment trial. Negotiation of variety and density trials. (N. Fleming / T. Pitt / M. Skewes)
July 2017	Virginia Hort. Centre Loxton Research Centre Mildura Golf Resort Griffith Ex-Servicemen's	ABA Regional almond growers, packers and marketers	Oral presentation detailing HIA project ST16003 and the proposed development of advance production systems for temperate nuts grown under Australian conditions. (T. Pitt / M. Skewes)
September 2017	Australian Nut Grower Journal	Australian nut growing industry	Article: New almond experimental orchard announced at Loxton. P13-14 Autumn 2017, Vol. 31 No. 1
September 2017	Loxton Research Centre	ABA ACE committee members	Negotiation of 2018 plantings including rationale behind SARDI trial designs (J. Cox / D. Graetz / M. Skewes / D. Thomas)
October 2017	Hort Innovation	Hort Innovation	ST16003 – MS103
October 2017	Renmark Golf Resort Lacton orchards Lindsay Point	ABA Regional almond growers, packers and marketers	SARDI staff attend almond variety and rootstock workshop and field day. Discuss rootstock options with ABA (D. Graetz)
October 2017	Loxton Research Centre	ABA Regional almond growers, packers and marketers	SARDI staff attend almond R&D forum and field walk. Airing of drone footage shot by SARDI (M. Wang) (D. Graetz / M. Skewes / D. Thomas / M. Wang)

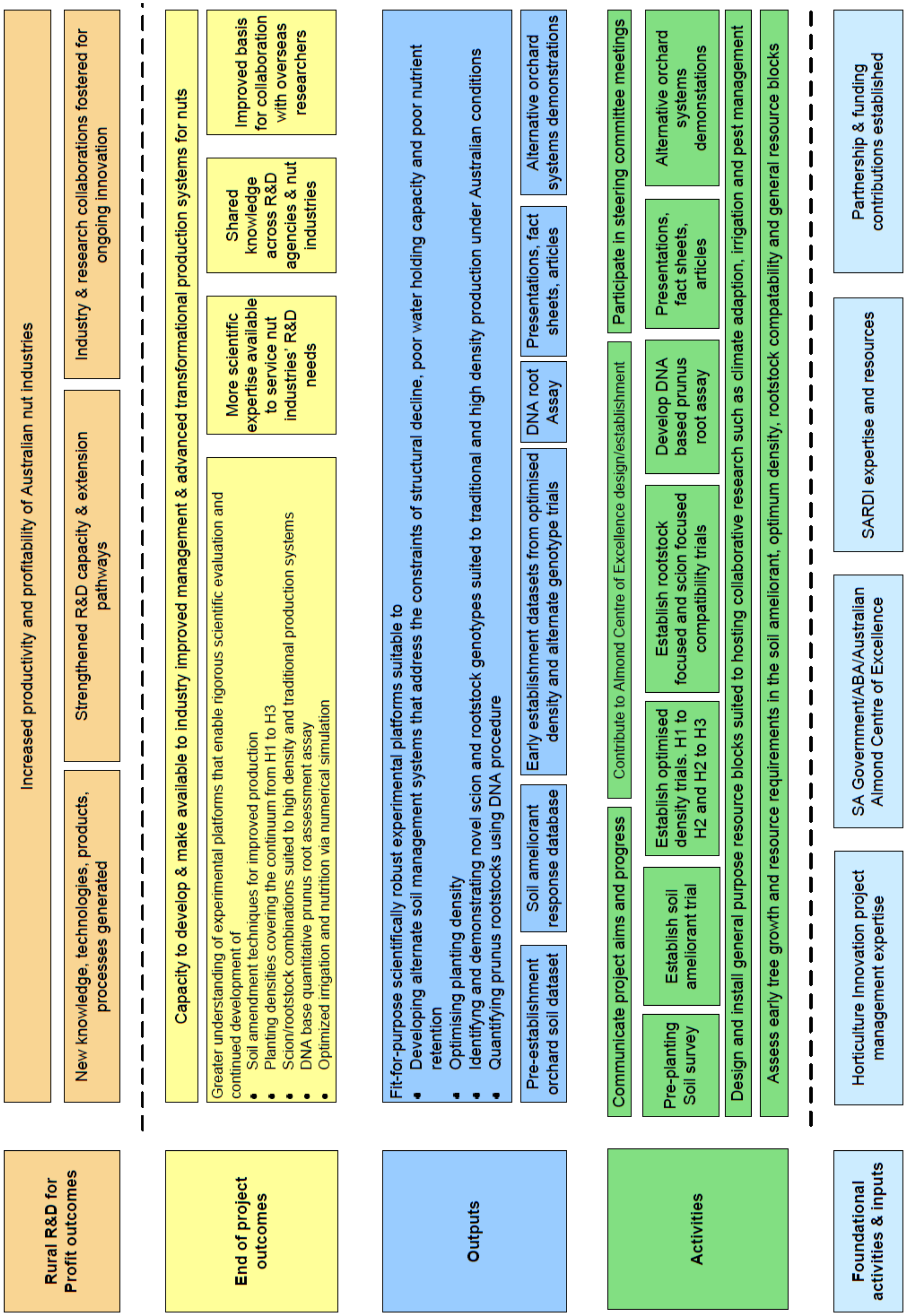
Date	Location	Audience	Activity
November 2017	Adelaide, SA	Australian and international growers, packers, marketers and researchers	SARDI staff made oral presentations at the International Society of Horticultural Science (ISHS) VII International Symposium on Almonds and Pistachios – Hayman P, et al. A calendar to link almond phenology to climate risk – Phogat V, et al. Modelling water and salinity risks to almonds – Pitt T, et al. Assessing the salt sensitivity of mature almond trees – Thomas D, et al. Evaluation of an almond phenology model under Australian conditions
January 2018	Journal of Agricultural Water Management	Irrigators and the scientific community	SARDI staff published numerical modelling protocols that will be used when assessing soil water and nutrient dynamics at SARDI's field trials the Australian Almond Centre of Excellence in Loxton. – Phogat V, et al (2018). Soil water and salinity dynamics under sprinkler irrigated almond exposed to a varied salinity stress at different growth stages. *Agricultural Water Management* 201, 70-8
April 2018	Yanco Agricultural Institute	HIA, ABA, Walnuts Australia and State R&D providers	Oral presentation on the progress of SARDI's almond program with specific reference to the soil amendment trial. (N. Fleming / T. Pitt / J. Cox)
May 2018	Hort Innovation	Hort Innovation	ST16003 – MS104
May 2018	Waikerie	Riverland irrigators	Oral presentation detailing SARDI's research activities in South Australia's Riverland. Included update on ACE activities. (P. Appleford)
August 2018	Almond Centre of Excellence	Regional almond growers, DJETR, ABA	*SARDI soil amendment field day* – SA, . SARDI researchers hosted a soil amendment field day where various heavy field implements and soil amendment strategies were demonstrated (@SA_PIRSA). The field day enabled growers to view the trial site, equipment and compost products at the point of experimental treatment establishment.
October 2018	Hort Innovation	Hort Innovation	ST16003 – MS105
October 2018	Melbourne, Vic	Australian and international almond growers, packers, marketers and researchers	*18th Australian Almond Conference*. SARDI displayed three posters and delivered an oral presentation (18th AAC - SARDI) detailing the research activities being conducted within the current program. SARDI's presentation was delivered in tandem with project collaborators, Agriculture Victoria Research (AVR). This ensured clear communication around the complementary nature of the South Australian and Victorian research programs.

Date	Location	Audience	Activity
September 2019	Robinvale, Vic	Australian almond and soil researchers	*Soil Society of Australia Workshop* – , (@SoilScienceAust). SARDI delivered two oral presentations and a poster detailing soil related research activities at the Almond Centre of Excellence and the soil water monitoring techniques being employed across various genotype and density trials at the site.
October 2019	Hort Innovation	Hort Innovation	ST16003 – MS106
October 2019	Almond Centre of Excellence	Regional almond growers and industry representatives	*Australian Almond R&D Forum and Field Day*. In tandem with project collaborators, AVR, SARDI presented research activities related to its component of the current ST15031 program (2019 R&D Forum - SARDI). Field walks at the Almond Centre of Excellence (ACE) experimental orchard introduced more than 250 growers and industry representatives to SARDI's optimised density trials, rootstock compatibility and architecture investigations and its soil amendment program. The forum subsequently featured in the Stock Journal as well as the ABA's own e-newsletter (Almond Bytes) and industry magazine (In A Nutshell).
November 2019	Almond Centre of Excellence	Horticultural research and funding body representatives	*National Horticulture Research* Network. SARDI hosted representatives from Hort Innovation as well as Commonwealth and State horticultural research agencies at the ACE experimental orchard. The field walk was aligned to a quarterly NHRN meeting and highlighted the progress that SARDI and the Almond Board of Australia (ABA) had made in establishing a platform of large-scale field trials and almond plantings suited to long term perennial horticultural research activities.
November 2019	Waite Institute, Adelaide	staff and students from University of Adelaide and Waite campus	*Waite Research Institute AgriFood & Wine Research Showcase*. SARDI presented an update of research activities at the ACE experimental orchard to an audience comprising more than 200 staff and students from Adelaide University and the broader Waite Research Institute.
February 2020	CMV Farms, Loxton North	Project partners (SARDI, ABA, Agric. Victoria Resarch)	*Tenias harvester demonstration.* SARDI helped coordinate project partners (SARDI, ABA and AVR) to participate in the demonstration of the Tenias almond harvesting system at CMV farms, north of Loxton SA. Viewing this alternate harvest technology enabled partners to further refine experimental orchard design options.
March 2020	Almond Centre of Excellence	Agromillora staff and project partners (ABA and AVR)	*Agromillora orchard walk.* SARDI hosted Agromillora staff and project partners (ABA and AVR) at their ACE H3 optimised density trial. Alternate orchard design options were discussed in the context of new and emerging planting material, tree geometries and harvest technologies.

Date	Location	Audience	Activity
March 2020	Almond Centre of Excellence	ABA, health, wellbeing and sports dieticians	*Educating Health Professionals.* SARDI participated in an ACE orchard walk with the ABA and a group of six nationally renowned health, wellbeing and sports dieticians. The orchard walk was conducted as part of the 'Educating Health Professionals' program (AL16007). SARDI described the key sustainability issues associated with traditional almond production systems and the role its researchers are playing in investigating improved production efficiencies.
May 2020	Hort Innovation	Hort Innovation	ST16003 – MS107
June 2020	(virtual)	ACE management committee	*Almond Centre of Excellence Committee Meeting.* SARDI delivered an oral presentation to ACE management committee to update on recent ACE research activities and trial management opportunities/challenges.
June 2020	Almond Centre of Excellence	SA Minister for Primary Industries and Regional Development	SARDI and ABA hosted The Hon. Tim Whetstone at the ACE experimental orchard. The Minister's tour highlighted the progress of large-scale field trials at ACE.
July 2020	(virtual)	ABA, Regional almond growers, researchers	*ABA Regional Webinar.* SARDI delivered a pre-recorded presentation to the annual ABA Regional Forum, this year hosted in webinar format with +75 live attendees. (2020 Regional Meeting, *password available from ABA*).
September 2020	Almond Centre of Excellence	key personnel from One Basin CRC bid consortium	*One Basin CRC Site Visit*. SARDI and ABA hosted key personnel from One Basin CRC bid consortium at the ACE orchard. Activities included a tour of the orchard and general discussions around ACE almond research and its relevance to water security and water use efficiency, key foci of the CRC bid.
September 2020	Almond Centre of Excellence	Unmanned Research Aircraft Facility (URAF), Glossop High School students	*URAF and Glossop High school Site Visit*. SARDI hosted the Unmanned Research Aircraft Facility (URAF) and ten students from the Glossop High School at its ACE Optimised Density trials. SARDI and URAF staff demonstrated the variation in field trial treatments and a range remote sensing systems that can be used to quantify that variation. Systems demonstrated included ground based and aerial RGB, spectral and LiDAR sensors with associated control points.
October 2020	Hort Innovation	Hort Innovation	ST16003 – MS108
November 2020	(virtual)	Hort Innovation Steering Committee	*Hort Innovation Steering Committee Meeting.* ST15031 collaborators updated program managers on the progress of their research activities. SARDI communicated ST16003 activities at the Almond Centre of Excellence (ACE) and the Plant Research Centre (PRC), together with final year research strategies and future opportunities.
December 2020	In A Nutshell industry magazine	Regional almond growers and industry	Industry Article – *In a nutshell*. SARDI presented its irrigation modelling expertise and the application of this capability in the pursuit of characterising resource use efficiencies. The article was published in the industry magazine, In A Nutshell, Summer 2020-21

Date	Location	Audience	Activity
December 2020	Almond Centre of Excellence	Regional pistachio growers	*Site visit by the Australian Pistachio Industry.* SARDI demonstrated and described the range of research being undertaken at the Almond Centre of Excellence and participated in discussion with Pistachio growers around similarities and differences in issues and research needs between the two industries.
January 2021	(virtual)	Almond Strategic Investment Plan	SARDI contributed to the Almond Strategic Investment Plan via the AVR, ABA and Hort Innovation
January 2021	(virtual)	ACE Commercial Trial Assessment Panel	*ACE Commercial Trial Assessment Panel.* SARDI contributed to the ABA's assessment of third-party trial plans for hosting within ACE resource blocks. Third party providers have tended to be producers/resellers of commercially available nutrients, plant growth regulators, soil ameliorants and fumigants.
February 2021	Mildura, Vic	SARDI and AVR collaborators	*Collaborator meeting.* SARDI and Agriculture Victoria Research (AVR) collaborators visited the Agromillora field trial and propagation facilities to view a demonstration of 'over the row' almond harvesting and discuss refinements to alternate orchard designs.
March 2021	Almond Bytes industry newsletter	Regional almond growers	Industry e-newsletter – *Almond Bytes*. SARDI and the Unmanned Research Aircraft Facility (URAF) promoted their aerial and ground based remote sensing activities at SARDI trial sites. Almond Bytes, March 2021
March 2021	Almond Bytes industry newsletter	Regional almond growers	Industry e-newsletter – *Almond Bytes*. Promotion of 2021 harvest activities. Almond Bytes, March 2021
May 2021	Hort Innovation	Hort Innovation	ST16003 – MS109
May 2021	Almond Centre of Excellence	Hort Innovation Program Reference Group	*Hort Innovation AS18000 Program Reference Group.* SARDI contributed to an ACE field walk and project update for the AS18000 almond Program Reference Group (PRG). The PRG comprised producers, Hort Innovation program coordinators (remote), Almond Board IDO's and researchers. SARDI discussed both AS18000 and ST15031 research activities.
August 2021	Almond Centre of Excellence	Almondco Growers, packers and IDO's	*Site visit by Almondco growers.* SARDI demonstrated and described the range of research being undertaken at the Almond Centre of Excellence.
October 2021	Almond Centre of Excellence	AWRI Advanced Viticulture Course	*Site visit by AWRI students.* Field walk and workshop discussing the production related research questions common to both almonds and viticulture.
In press	In A Nutshell industry magazine	Regional almond growers and industry	Industry Article – *In a nutshell*. SARDI summarised harvest activities from ACE optimised density and compatibility trials. The article entitled *High density plantings increase yields during orchard establishment* published in the online industry magazine In a Nutshell - Spring 2021

APPENDIX B Monitoring and Evaluation



APPENDIX C Project staff and collaborators

ST16003 was managed by SARDI's Irrigated Crops team with contributions from across the agency:

Prof Jim Cox	*Program Manager – Irrigated Crops (ex)*
Nigel Fleming	Research Scientist – Soil Fertility
Dr Danièle Giblot-Ducray	Senior Research Officer – Molecular Diagnostics
Darren Graetz	Research Scientist – Irrigated Crops
Dr Alan McKay	Program Manager – Molecular Diagnostics
Paul Petrie	Program Manager – Irrigated Crops
Dr Vinod Phogat	Research Scientist – Water and Nutrient Modelling
Tim Pitt	Subprogram Lead – Irrigated Crops
Michael Rettke	Research Scientist – Soil Diagnostics
Kavitha Shanmugam	Technical Officer – Irrigated Crops
Mark Skewes	Research Scientist – Irrigated Crops
Dr Dane Thomas	Research Scientist – Climate Applications
Mickey (Yeniu) Wang	*Technical Officer – Irrigated Crops (ex)*

A number of existing and new collaborative relationships supported ST16003 research activities:

The Almond Board of Australia		Principal project collaborator.
Terry Carter et al	EcoTrellis (AUS/NZ)	Orchard trellising.
Dr Ray Correll	Rho Environmetrics (SA)	Biometric advice
Dr Everard Edwards	CSIRO (SA)	Root quantification datasets.
Dr Omar Garcia	IRTA (SPAIN)	Sap flow and modelling advice.
Dr Louis (Kun) Fang	LC Technology (SA)	Remote phenotyping advice.
Jose Maria Lainez	Agrolainez (SPAIN)	Genotype and tree training advice.
Xavier Rius et al	Agromillora (SPAIN)	Genotype and tree training advice.
Dr Ramesh Raja Segaran	University of Adelaide (SA)	Remote phenotyping advice.
Prof. Jirka Simunek	UC Riverside (USA)	Soil water and nutrient modelling advice.
John Slaughter	Wawona-Prima (USA)	Genotype and tree training advice.
Dr Mark Sosnowski et al	SARDI (SA)	Disease incidence advice.
Eduardo Larraga Tenias	Tenias (SPAIN)	Alternate harvest technology advice.
Dr Grant Thorp	Plant & Food Research (AUS/NZ)	Genotype and tree training advice.
Dr Michael Treeby et al	Agriculture Victoria Research, Irymple (VIC)	Principal project collaborator.
Dr Michelle Wirthensohn	University of Adelaide (SA)	Genotype and tree training advice.

APPENDIX D Budget Reconciliation

Pending – Due early November 2021