Sustainable Optimisation of Australian Almond Production

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Almond Board of Australia Inc

Project Number: AL07005

AL07005
Sustainable Optimisation of Australian Almond Production

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Purpose of Report
This Final Report has been prepared following the conclusion of the final year of the Sustainable Optimisation of Australian Almond Production project (i.e. AL07005) and its preceding projects, AL01001, AL04009, AL05002 and AL06004. The project summarises the methodology and results of the field trial, and its implications for the management of Australian almonds under intensive, drip irrigated water and nutrient programs.

Acknowledgements
This project has been funded by HAL using the Australian almond industry levy and a voluntary contribution from the Almond Board of Australia and Clark Taylor Farms and matched funds from the Federal Government.

June 2011

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1 Media Summary

By the mid to late 1990's, the Australian almond industry had developed and adopted world's best practices and had reached a point where it was producing equivalent or slightly greater yields than the Californian industry, achieving a benchmark kernel yield of 2.45 tonnes per hectare. The Australian almond industry sought to continue this development but regarded the traditional approach of researching and adopting new, but discrete technologies as too slow in advancing orchard management.

The industry required a holistic approach to water, nutrition and canopy management. To achieve this objective it engaged Professor Rafael Assaf, previously of the Volcani Institute of Israel to conduct a R&D project. The aim was to combine the key disciplines of soil science, physiology, nutrition and irrigation to develop management options with optimal efficiencies and efficacy, to substantially enhance tree crop performance.

The Sustainable Optimisation of Australian Almond Production trial was set up in 2001 on a three year old, 7.64 hectare almond orchard, located on the commercially operated property of Clark-Taylor Farms, in Berri, South Australia.

The trial consisted of seven experimental treatments; three irrigation treatments, three nutrition treatments and one treatment that continued existing property management of irrigation and nutrition. The irrigation and nutrition treatments all received the same foliar nutrient applications and pruning regime.

The key outcomes of the trial were:

- An average kernel yield of greater than 4.0 tonnes per hectare was achievable.
- Successful management of almond orchards using drip irrigation rather than the traditional approach of sprinkler irrigation was achievable.
- Increased tree crop performance by daily managing water and nutrient requirements.
- An optimal application rate of 13 ML/ha suitable for drip irrigated almond orchards.
- No additional yield benefits were observed with nitrogen and potassium applications above 240 kg/ha and 400 kg/ha, respectively.
- Nutrient loss beyond the root zone was apparent through late winter, early spring and post harvest and needs to be monitored and managed.
- High water application rates (>1132mm or 11.32ML/ha) led to increased vegetative growth, without an equivalent significant increase in yield.
- A higher application of water led to increased shading and a greater need for pruning.

The key recommendations for future R&D are:

- A requirement to continue researching the nutritional requirements and application protocols of almond orchards.
- The need to review and produce new critical values of almond leaf tissue analysis.
- Research the potential use of more vigorous rootstocks to maintain or continue to improve yield by more efficiently utilising water and nutritional inputs.
- Research the potential to increase tree densities, "lower" water and nutrient inputs and maintain light interception, bud numbers and high yield through more fruiting units (i.e. trees) – not inputs.

Whilst a "recipe" outlining the best water and nutrition inputs for almond orchards is ideal, it does not suit every orchard. To ensure successful practical application, individual onsite execution is required.

2 Technical Summary

By the mid to late 1990's, the Australian almond industry had developed and adopted world's best practices and had reached a point where it was producing equivalent or slightly greater yields than the Californian industry and was achieving a benchmark kernel yield of 2.45 tonnes per hectare. The Australian almond industry sought to continue this development; however, it was becoming increasingly obvious the traditional approach of researching and adopting new, but discrete technologies was proving increasingly limiting to orchard management improvements and a more holistic approach to water, nutrition and canopy management was required.

The Sustainable Optimisation of Australian Almond Production trial was set up in 2001 on a three year old, 7.64 hectare almond patch, located on the commercially operated property of Clark-Taylor Farms, in Berri, South Australia.

The trial consisted of seven experimental treatments; three irrigation treatments, three nutrition treatments and one treatment that continued existing property management of irrigation and nutrition. The irrigation and nutrition treatments all received the same foliar nutrient applications and pruning regime.

The yield of the three irrigation and three nutrition treatments (T1 – 6) was clearly superior to the existing orchard management (T7) and demonstrated the significant advantages of meeting the daily water and nutrient requirement as determined by the climate and orchard phenological stage as well as by including a comprehensive foliar nutrient program.

The key findings of the research indicated there was a approximately a 10% and 17% increase in mean Nonpareil and Carmel yield, respectively, from 60% Etc to 100% Etc. However, the result was not statistically significant ($p<0.05$). The mean Nonpareil yields of 60% Etc and 100% Etc were 3,690 kg/ha and 4,071 kg/ha, respectively. The trial achieved a considerable yield increase in comparison to the 1999 or 2007 benchmark yield and current Australian industry average, of 2.45 t/ha, 3.20 t/ha and 2.97 t/ha, respectively.

60% Etc was more efficient than 100% Etc in its water use, producing 3.67 kg/mm compared to 2.52 kg/mm of Nonpareil yield. 60% Etc was also more efficient than 100% Etc in its productivity, producing 0.32 kg/cm^2 compared to 0.25 kg/cm^2 of Nonpareil yield. 60%Etc was a considerably smaller, more compact tree compared to 100% Etc with increased light interception throughout more of the canopy, and likely to be more suitable for commercial orchard management. When incorporating Trial's yield results with the value of water ($545/ML) and the value of harvested kernel ($5.70/kg) the optimum Nonpareil water use figure was approximately 72% Etc (13 ML/ha).

It is recommended to further research the effects of lower water applications, the contribution of evaporative losses from daily drip irrigation, the benefits of plant based measurements, and the subsequent opportunities to increase water savings and water use efficiency

No significant yield difference was achieved between the three fertiliser treatments, with mean Nonpareil yields of 3,947 kg/ha (240:400), 4,071 kg/ha (320:600) and 4,027 kg/ha (480:800), respectively. In addition there were no obvious differences between dry weight nutrient concentrations within the leaf tissue or harvested fruit. However, crop removal calculations from T1 (240:400) harvested fruit suggested nitrogen use efficiency (NUE) of 112%. >100% NUE may have been achieved due to the build up of nitrogen reserves in the trees from when the Trial began applying 240 kg/ha on three year old trees. If >100% NUE were to continue, it is likely a yield decline would occur.

Soil sampling results indicated a trend toward increased nitrate concentrations below 50cm soil depth until 2008, and a trend toward increasing potassium concentrations below 50cm until 2010.

Soil solution sampling suggested that nutrient applications well matched plant nutrient uptake from September to November but high nutrient concentrations deeper in the soil profile were recorded in the off-season following the profile establishment irrigations in July and after the post harvest nutrient applications in May. The application of potassium nitrate in July/August following the profile establishment irrigations was thought to be too high and due to its association with the large application of water, needs to be monitored carefully or possibly reduced and reapportioned from September to November. The application of post harvest fertiliser was too late (i.e. May) and required earlier (e.g. March) applications when climatic conditions were more favourable for tree water use and nutrient uptake.

The Trial results indicated nitrogen requirements were greater than 240 kg/ha due to 112% NUE and thus approximately 269 to 320kg/ha. Potassium requirements were likely to be approximately 338 to 400 kg/ha of potassium. The most critical period of nutrient application was between the beginning of the season to the end of embryo (i.e. kernel) growth – approximately 18 to 20 weeks following the beginning of flowering.

It is recommended to further research the nutrient requirements of almond orchards, in particular the effects of relatively low application rates, and their interaction with low irrigation rates. This should include considerations of the balance between additional major and minor nutrients (e.g. Magnesium and Calcium) to better understand the fate of all elements within the soil/plant system and the subsequent opportunities to increase efficiencies and environmental sustainability.

Although applied research is an expensive and time consuming form of R&D, it is an integral part to an industry's R&D program and with an increasing scarcity of resources, increasing growing costs and the requirement to increase productivity; it should continue to receive long term investment.

3 Introduction

Global almond consumption has more than doubled over the past decade from nearly 291,000 tonnes in 1998 to 583,000 tonnes in 2008 (ABA, 2010).

With the aim of taking advantage of increased global consumption and the fact domestic consumption of almonds in Australia was lower than domestic production at the change of the century, the Australian almond industry increased its plantings more than six-fold from 2000. Currently, one quarter of the plantings are yet to reach full maturity and future production will continue to rise until 2017 when it is estimated to achieve 86,500 tonnes (ABA, 2010).

Almonds have always been an attractive crop for investment because the industry had always been profitable, stable and internationally competitive. To maintain the industry competitiveness and to ensure its continued and sustainable expansion it required a research program to evaluate alternative irrigation and nutrient management practices with the potential to increase productivity. Drip irrigation in particular needed to be tested because most new orchard developments had decided to install it as their system of choice. 90% of almond plantings are now drip irrigated (ABA, 2010).

New orchard development in Australia always faces the challenge of limited soil and water resources. In addition, intensive agricultural practices may result in soil structural decline, acidification, salinisation, erosion, nutrient depletion and deep percolation losses of water and nutrients. Furthermore, indiscriminate use of water and fertilisers may result in ground water contamination, leaching of nutrients and volatilization of nitrogenous fertilizers, leaving an adverse effect on the environment.

Consequently, the Australian industry decided a more holistic approach to water, nutrition and canopy management was required to achieve its aims:

- Assess the effectiveness of 7 water and nutrient programs in a field experiment.
- Determine the consumptive use of water and nutrients by almonds.
- Determine the optimal rate of water and nutrient uptake of almonds.
- Investigate the possibilities of saving water and increasing yield efficiency.
- Double the commercial yields of almond orchards and their profitability.

Water

Determining the quantity of irrigation water to be applied at different stages can avoid problems associated with over and under irrigation (Warren, 1996). Research findings indicate certain stages of almond fruit growth are more sensitive to water stress than others. Understanding these stages permits growers to minimise damage to trees, in the current and the subsequent year (Prichard, 2001).

Nutrition

Nutrient availability depends on the type of soil, soil chemical properties, and the amount of organic matter. Maintaining adequate moisture supply in the soil will enhance the supply of nutrients to a plant. Nitrogen is lost from the soil more easily than the other nutrients through leaching, volatilisation and denitrification and hence must be cautiously applied and closely monitored.

Nitrogen (N) and potassium (K) play important roles in tree health, growth and yield because they are essential to most important physiological processes. Nitrogen is important for the vegetative growth and photosynthetic efficiency of the tree. Almond tree growth and productivity depends on

the availability and assimilation of nitrogen and its shortage limits productivity (Weinbaum et al., 1996).

Nitrogen in the form of nitrate (NO_3^-) is freely mobile in the soil; it is readily available to the plants but is also more easily leached out of the active root zone than ammonium (NH_4^+) nitrogen (Nommik and Vahtras, and Legg and Meisinger, 1982). Therefore, care must be taken in the application of nitrate to avoid environmental hazards. Ammonium containing fertilizers are a better choice than nitrate or urea during or before winter.

Studies in almonds have shown the nitrogen applied during the growing season (spring to harvest) is available to the blossoms the following spring. In contrast, nitrogen applied during dormancy (start of winter) is not detectable in the spring blossoms. Nitrogen is absorbed and stored in the roots, crown and limbs prior to leaf fall and redistributed during spring (Weinbaum et al., 1996). Bi et al. 2004 suggested nitrogen fertilisers applied to the variety Nonpareil on "Lovell" rootstock in spring, during rapid new growth, resulted in maximum nitrogen uptake with significant improvement in vegetative growth for the current and through remobilisation for the subsequent season. They also concluded, both reserve nitrogen and spring applied nitrogen fertilisers are important for enhancing the regrowth in Nonpareil on Nemaguard.

Potassium influences the viability of the fruit bearing spurs, increasing flowering, fruit set, fruit size and yield (Reidel, 2000) as it positively influences much of the plant physiological process like photosynthesis, CO_2 assimilation and leaf respiration (Bednarz and Oosterhuis, 1999; Huber, 1985 and Osaki et al., 1993). Basile et al (2003) reported that leaf K concentration less than 0.5 - 0.6% apparently limited CO_2 exchange rate, affected tree light interception and accelerated premature leaf senescence. Reidel et al (2004) observed the Nonpareil cultivar exhibited the impact of nutritional deficiency, especially of potassium, on yield in the subsequent year rather than the current year.

Nutrients are absorbed and utilized more effectively when applied in line with tree requirement and therefore should be applied frequently but in small quantities rather than applying infrequent but large doses of nutrients. Fertigation is the most effective and efficient method of nutrient applications, allowing as many events as required, at desired concentrations.

Leaf nutrient concentration decreases when the osmotic pressure is high, and this frequently occurs when leaf tissues is water deficient (Isaakidis, et al. 2004). During drought or low moisture availability in the soil, the nutrient concentration in the soil solution rises and inhibits the metabolic activity of roots because of increased osmotic pressure further limiting nutrient uptake and transport into the leaf (Mengel and Kirkby, 1987, Karmer and Broyer, 1995).

To meet the objectives of this project the almond industry required a person with a good understanding of soil science, plant physiology, plant nutrition and irrigation. The industry engaged Professor Rafael Assaf, previously of the Volcani Institute of Israel to conduct a R&D project to evaluate and develop efficient and effective management options with the potential to significantly increase tree crop productivity.

The Sustainable Optimisation of Australian Almond Production trial was set up in 2001 on a three year old, 7.64 hectare almond orchard, located on the commercially operated property of Clark-Taylor Farms, in Berri, South Australia. This final report summarises the projects over this period; AL01001, AL04009a, AL05002, AL06004 and AL07005.

4 Materials and Methods

4.1 Experimental Design

HAL Project: AL07005 – Sustainable Optimisation of Australian Almond Production, (hereafter referred to as the "Trial") was set up in 2001 on a three year old, 7.64 hectare almond planting, located on the commercially operated property of Clark-Taylor Farms, in Berri, South Australia. The site is located in inland south-eastern Australia (34°20 S 140°36 E) and has a Mediterranean climate, characterised by winter rainfall (average of 273.5mm/year) and hot, dry summers. The orchard was planted to 50% Nonpareil, 33% Carmel, 17% Ne-Plus Ultra. Trees were spaced 6.7 metres between rows and 6.1 metres within rows (that is, 245 trees/ha). All cultivars were grafted onto Nemaguard rootstock. Soils were typical of the Southern Mallee, with loamy sand to light sandy clay loam topsoils, varying in depth from 50cm to 160cm and a pH (water) of 8.5 to 9.5.

The trial design was an incomplete factorial design (i.e. nine treatments), but rather a design incorporating six experimental treatments (Table 2) and one treatment (i.e. T7) that continued the existing orchard management protocols at the time of the trial commencing (Table 1). The six experimental treatments consisted of three nutrient treatments (i.e. T1, 2 and 3) and three water treatments (i.e. T4, 5 and 6).

The aim of the treatment design was to produce a yield response curve (e.g. Figure 1) for either the three nutrient or three water levels. An interpretation of the two yield response curves would then enable a more accurate assessment of the nutrient and water requirements to achieve optimum almond production. The interactions between nutrient and water were to be more difficult to assess due to the four missing treatments from the complete factorial design.

T4, 5 and 7 were modified (Table 2) from 2008/09, 2007/08 and 2008/09 respectively, due to the reduced water allocations South Australian irrigators incurred in those seasons.

T1-6 each had four replications of two rows, with the Nonpareil and Carmel varieties evaluated. T7 consisted of a single block and was only used for comparison. Refer to Figure 2.

Table 1: Treatment design.

		Water		
		60% Etc	**100% Etc**	**160% Etc**
Nutrition (N:K)	**240:400**		T1	
	320:600	T6	T2 & T4	T5
	480:800		T3	

Table 2: Nutrient and water treatments.

TREATMENT No.	WATER	NUTRIENT (N:K, kg/ha)	REMARKS
1	100% Etc, pulsed	240:400	Equal applications of P, Zn, B, Mg, & Fe
2	100% Etc, pulsed	320:600	Equal applications of P, Zn, B, Mg, & Fe
3	100% Etc, pulsed	480:800	Equal applications of P, Zn, B, Mg, & Fe
4^	100% Etc, pulsed	320:600	Equal applications of P, Zn, B, Mg, & Fe
5#	160% Etc, pulsed	320:600	Equal applications of P, Zn, B, Mg, & Fe
6	60% Etc, pulsed	320:600	Equal applications of P, Zn, B, Mg, & Fe
7*	Pre 2001 orchard practice, non-pulsed, irregular watering	180:87	Equal applications of P, Zn, B, Mg, & Fe

^T4 was 50% water from 2008/09.

#T5 was 100% water from 2007/08.

*T7 was irrigated with irregular watering based on a wetting and drying cycle from 2007/08. From 2008/09, it was modified to consider more current best practice, i.e. T1 (100% Etc, 240:400).

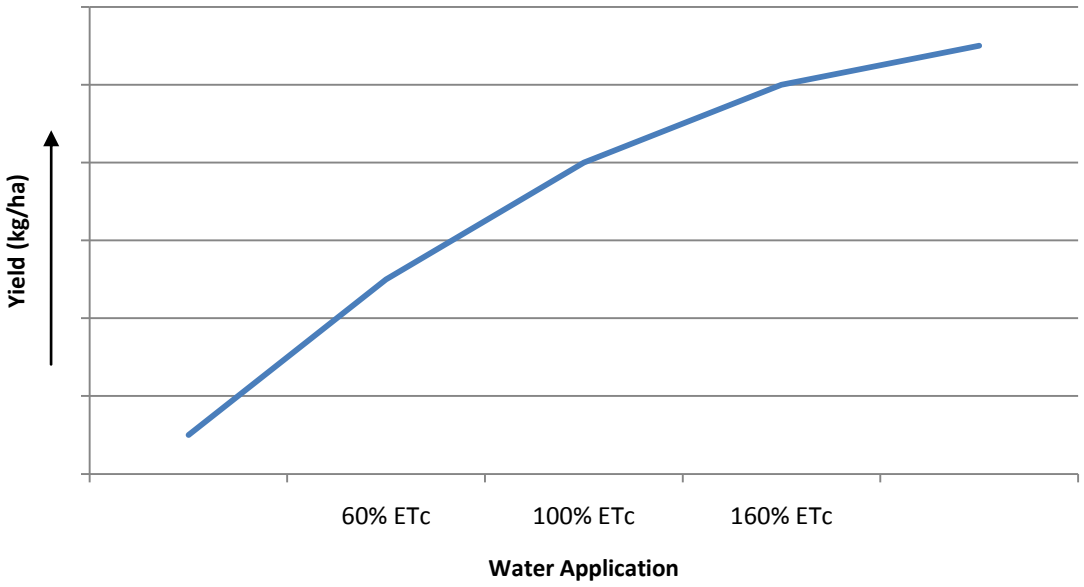

Figure 1: Example yield response curve from varying water applications.

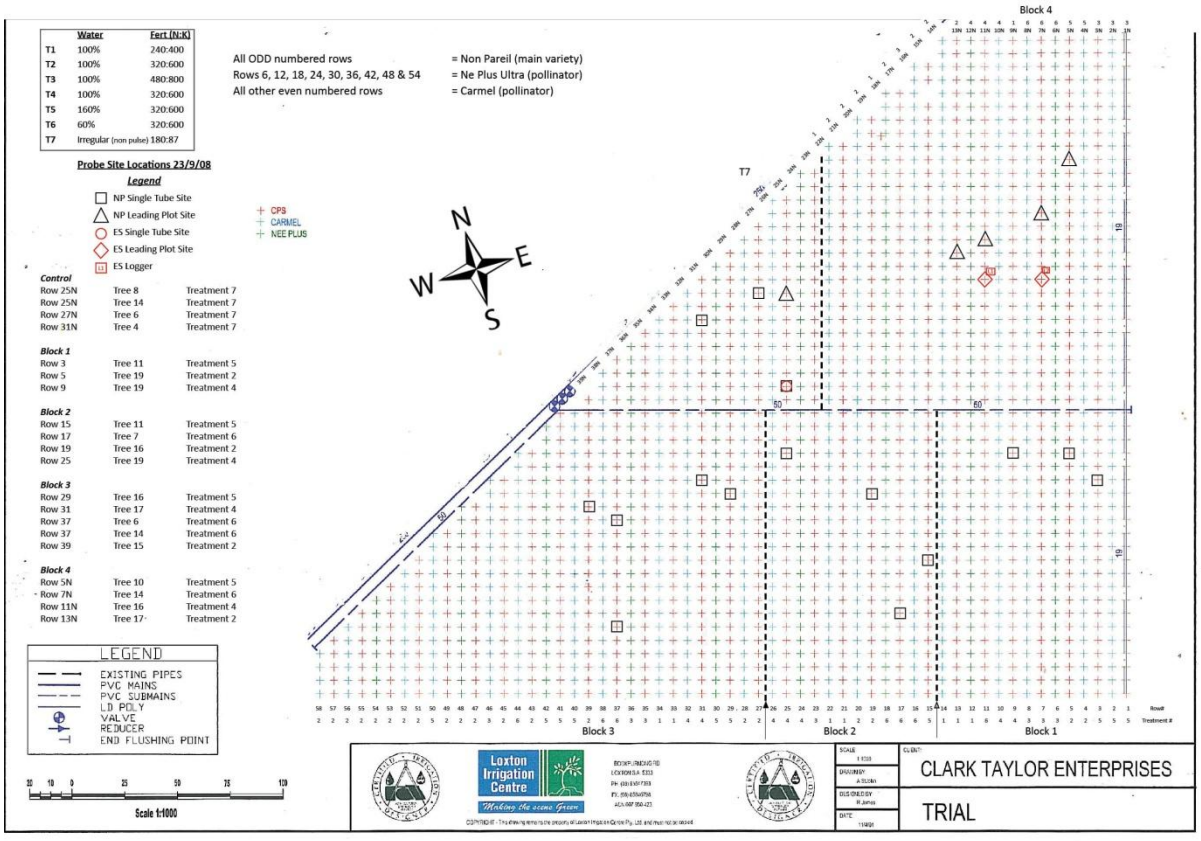

Figure 2: Trial layout.

4.2 Irrigation

The experiment used a pressure compensated, drip irrigation system. The system specifications for each treatment are shown in Table 3.

Irrigation applications were scheduled using a set of crop factors which had been developed by previous research conducted by Prof Assaf. Plant water requirement was determined by multiplying the crop factor with *predicted* daily evaporation readings from a Class A Evaporation Pan, and were then corrected for any deficit or surplus obtained from the *actual* evaporation reading of the previous 24 hours. *Predicted* daily evaporation readings were determined from the daily weather forecasts. The Class A Evaporation Pan was read at 9:00am Monday to Friday. Weekend readings were totalled with a reading on Monday morning.

Water was applied predominantly on a daily basis, through a cycle of 1 hour on, 1 hour off pulses beginning at 8:00am for Treatments 1-6. The minimum irrigation time was one hour.

Table 3: Drip irrigation system specifications.

TREATMENT No.	DRIP LATERALS/ROW	EMITTER FLOW RATE (L/Hr)	EMITTER SPACING (m)	INSTALLATION METHOD	PRECIPITATION RATE (mm/hr)
1	2	4	1	Subsurface, surface emitting	1.19
2	2	4	1	Subsurface, surface emitting	1.19
3	2	4	1	Subsurface, surface emitting	1.19
4	2	4	1	Subsurface, surface emitting	1.19
5	2	8.5	1.5	Subsurface, surface emitting	1.69
6	2	4	1	Subsurface, surface emitting	1.19
7	2	2.2	0.75	Above ground	0.87

In order to accurately establish the crop factors for 100% Etc of almonds (i.e. T2) and to monitor the water applications of all treatments, weekly readings were taken with a calibrated (Appendix 1) Neutron Probe. Readings were taken on Friday mornings at 5:30am, 6 hours after the last irrigation. Readings were taken at both leading/index plots (Figure 3), using a nest of tubes installed at 0, 20, 40, 60, 80 and 100cm from a dripper, and from single tube sites located at a distance of 20cm from the dripper. The monitoring depths were 10, 20, 30, 40, 60, 70, 80, 90, 100, 120, 140 and 160cm.

T7 was irrigated on an irregular basis involving a wet/dry cycle. The profile was wet until field capacity in one continuous irrigation event (i.e. non-pulsed) and would dry to a "refill" point signified on a soil water monitoring graph. The determination of field capacity was based on water penetrating the deeper soil depths (i.e. 80cm) and the refill point occurred when the soil water trace of the 0-80cm depths slowed and flattened. As a result, the irrigation frequency varied based on changing water use demands.

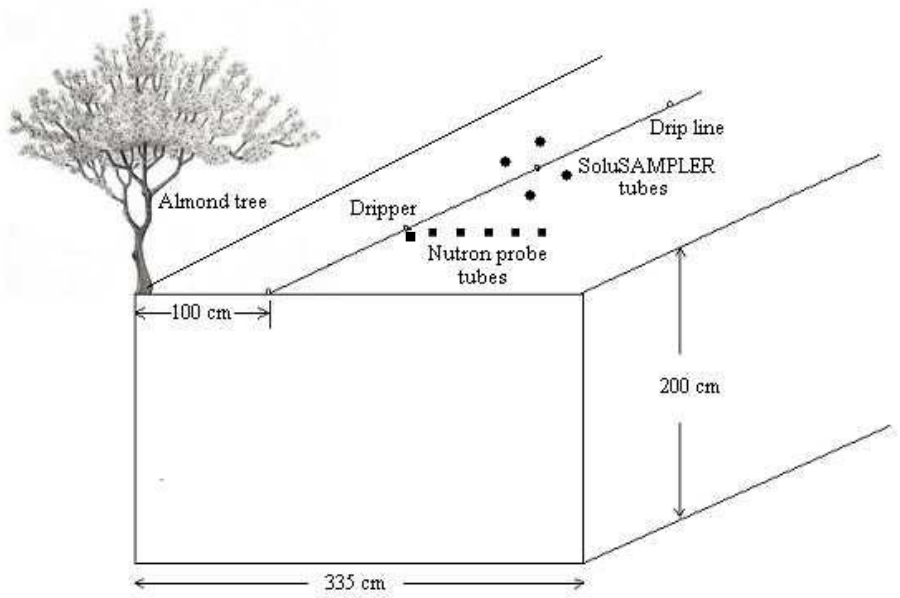

Figure 3: Neutron Probe and SoluSAMPLER™ layout (source: Vinod Phogat, SARDI)

4.3 Nutrition

4.3.1 Fertigation

Fertilisers for T1-7 were applied through the injection of dissolved solids and liquids from individual 220 litre pressure differential tanks, directly into the irrigation stream. Each treatment had its own sub-main to avoid cross-contamination of fertiliser.

The applications for T1-6 were made in the second last pulse of daily irrigation events between Monday and Friday. The applications for T7 were made with two hours remaining in each irrigation event between Monday and Friday.

Treatments 1, 2 and 3 were used to evaluate the influence of variable rates of nitrogen and potassium applications on almond yield. Additional injection of fertiliser required for the high nutrient rates were accomplished by lengthening the fertigation season for the respective treatments. That is, T1, 2 and 3 had a similar nutrient program for the first 7 weeks, then T1 ceased and T2 and T3 had a similar program for weeks 8-12, and then T2 ceased and T3 had a separate program for weeks 13-21. Variation in weekly nutrient concentrations was not assessed in the Trial. Treatments 1, 2 and 3 all received equal amounts of phosphorus, EDDHA iron chelate and micro elements (Yara Ferti Mix).

4.3.2 Foliar Nutrient

The foliar nutrition program included several exhaustive and comprehensive spray regimes, dependent on the phenological stage of the tree and the specific aims to be achieved. The effects of the foliar nutrient program were not part of the statistical analysis, as all treatments (i.e. T1-6) received the same program. The foliar nutrient program consisted of:

- Dormancy breaking sprays of potassium nitrate to assist the overlapping of Nonpareil and Carmel blossom.
- Boric acid sprays through blossom to assist fruit set.
- One to two sprays per week of potassium nitrate, lo-biuret urea (0.45% biuret) and zinc nitrate (specifically, NZn) from September to November to promote leaf size and shoot extension.
- Bud building sprays of lo-biuret urea (0.45% biuret) following harvest and prior to defoliation.
- Defoliation spray of urea (1.5% biuret).

Prior to 2008/09, T7 had not received a foliar nutrient program. However, in the subsequent seasons, a foliar nutrient program was introduced based around a commercial and practical program of fortnightly sprays of potassium nitrate, lo-biuret urea (0.45% biuret) and NZn from September to November. A defoliation spray was also applied at the end of May. Dormancy breaking, boron and bud building sprays were not included.

4.4 Canopy Management

The same management program occurred across all treatments and was carried out in two steps: 1) young tree training, and 2) mature canopy management.

Young trees were trained in spring 2002 when they were four years old. The aim was to train previously vertical, vegetative limbs and create a “Y” shape that would position the surface area such that light interception and fruiting potential would be optimal.

Aims of the canopy management program were to maintain the "Y" shape and develop a tree structure capable of minimising fungal inoculums, optimising light interception, and supporting the long term sustainability of the significantly increased yields achieved in the Trial.

4.5 Diagnostics

Standard errors were used to signify statistical differences on the charts. If differences between treatments were greater than 3x the standard error of the mean, there was a high probability these differences were real (i.e. significant) and not merely due to chance.

4.5.1 Soil Analysis

Soil analysis was undertaken from the same location in each of the three nutrient treatments (i.e. Treatments 1, 2 and 3) in July, October and January. Soils of each block were sampled 20cm from a drip emitter from depths 0-20cm, 20-40cm, 40-60cm, 60-80cm, 80-100cm, 100-130cm and 130-160cm. Samples from each block were bulked for each treatment and each composite sample was chemically analysed.

4.5.2 Leaf Analysis

Leaf analysis was undertaken from the three nutrient treatments (i.e. Treatments 1, 2 and 3) in October, November, December and January. The same trees were sampled on each occasion.

4.5.3 Fruit Analysis

Fruit analysis was undertaken from the three nutrient treatments (i.e. Treatments 1, 2 and 3) at harvest in March, as well as additional samples taken from the SoluSAMPLER^{TM} monitoring trees mentioned below. The same trees were sampled on each occasion.

4.5.4 Soil Solution Analysis

Weekly sampling of the soil solution occurred every Friday, beginning on 9th January 2009. The soil solution was extracted using SoluSAMPLER's^{TM}; a ceramic, porous cup placed under suction (-60kPa) and were installed at a distance of 15cm from a drip emitter and at depths 30cm, 60cm, 90cm and 150cm within Treatments 1, 2, 3, 6 and 7. Three samplers were installed per treatment. All solution samples were analysed for pH, EC, nitrate, phosphorus, potassium, calcium, magnesium, sulphur, sodium, chloride, zinc, manganese, iron, copper and boron. To gain a more accurate analysis of the soil solution, intensive sampling also occurred daily during the post harvest fertiliser period, peak spring fertiliser applications and peak summer water applications.

4.5.5 Trunk Circumference

The trunk growth of sample trees in each of the treatments was evaluated each winter using a tape to measure the tree circumference at a fixed point, 20 cm above the ground.

4.5.6 Sap Flow

Leaf and stem water potential were measured using a pressure bomb on twelve dates during the 2009/10 season, in each replicate of each treatment to determine the water status of the trees.

Sap flow sensors were installed into three trees in each of Treatments 2 and 6 to measure water uptake. Each tree had two sensors; one sensor located on the northwest side of the trunk, and one sensor located on the southeast side of the trunk. The sensors operated from 23rd December 2009 until the trial ceased at the end of June 2010.

5 Results

5.1 Phenology

The phenology of Nonpareil was summarised in three stages, with each stage including smaller discrete stages of physiological development. The specific dates of the phenological stages varied slightly across the seasons, between varieties, and between water and nutrient treatments. A summary of the phenology of Nonpareil in T2 is summarised in Table 4.

Table 4: Phenology of Nonpareil, T2

Stage	Phenology	Approximate Completion	
		25%	100%
1a	Bud burst	7th August	15th August
	Flowering	10th August	24th August
1b	Fruit Set	20th August	30th August
	Rosette (fully developed)	22nd August	31st August
	2cm elongation	5th September	20th September
	4cm elongation	10th September	25th September
2a	Pit hardening	10th to 15th October	
2b	Beginning of split in fruit	7th to 14th January	
	Hull split	5th to 10th February	
3	Harvest	24th to 31st March	
	Leaf drop	29th May	

5.2 Water

5.2.1 Water Applications

The irrigation season for T2, 5 and 6 began in the first two weeks of July with a management practice known as profile establishment. Profile establishment was used as a specific management practice for drip irrigation in low rainfall climates. The purpose was to achieve a very uniform and complete distribution of soil moisture, to remove wet dry interfaces from the soil, prepare a well buffered system from potential irrigation break downs that may occur in critical periods of the growing season, and create favourable conditions for root growth, initial vegetative growth as well as flowering and fruit set.

The water was delivered in one hour on, one hour off pulses in lots of approximately 40mm, with a break of 48 to 72 hours between each 40mm event. Prior to 2007/08, the quantity of water delivered through profile establishment was variable and dependent on the water required to fill the soil profile (i.e. 0-80cm) to within ± 5% of field capacity, as determined by the calibrated neutron probe. The total depth of water applied could total 120 to 150mm. Following 2007/08, the water used for profile establishment was capped at 80mm, due to the introduction of water restrictions.

The mean profile establishment figures were 118mm, 159mm and 109mm for T2, 5, and 6, respectively. 109mm for T6 was not expected to be the lowest profile establishment figure, as each season it received 40% less water and therefore required more water to re-establish the profile to field capacity the following July. However, the reasons for the lower/similar profile establishment figure may have related to the post harvest fertiliser period where regardless of the treatment, the

same amount of water was applied to all treatments in order to dispatch the fertiliser. This may have gone some way to re-establishing the soil water content (SWC) of T6 (Figure 5) at the end of each season.

Following profile establishment a period of time was allowed for the water to infiltrate throughout the profile. Additional water was applied to: a) inject the first potassium nitrate fertigation b) to maintain the SWC close to field capacity prior to the first scheduled irrigation on 26th August.

Following the completion of profile establishment and the initial fertiliser injections, T2, 5 and 6 received 100%, 160% and 60% of notional water requirements, respectively, as determined by the evaporation from the Class A pan and the appropriate crop factors (Figure 4).

The mean water applications (Table 5) for T2, 5, 6 and 7 were 1,814mm, 2764mm, 1132mm and 1,453mm, respectively. This equated to 92%, 146%, 58% and 73% of irrigation season E-Pan readings, respectively.

It should be noted, three different locations were used for the Class A Evaporation Pan; 1) Bureau of Meteorology (BOM) Loxton Research Station (2002/03 to 2004/05), 2) Century Orchards (2005/06 to 2006/07) and 3) Bookpurnong Hill (2006/07 to 2009/10). Loxton and Century Orchards Class A Pans were located within 15km from Bookpurnong Hill.

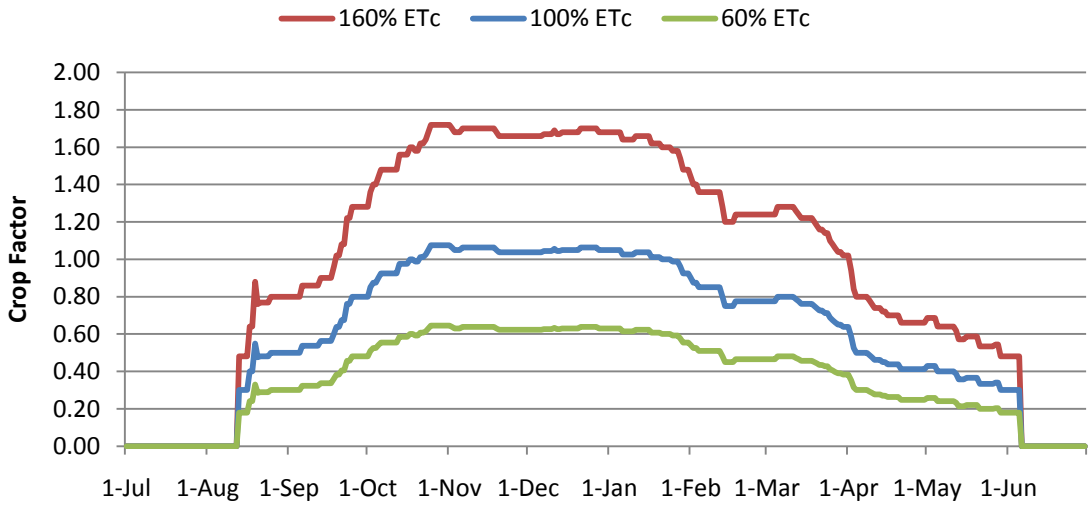

Figure 4: Mean crop factors used for 160% Etc, 100% Etc, and 60% Etc from 2002/03 to 2009/10.

Table 5: Mean water application, evaporation and water application as a % of evaporation for Treatments 2, 5, 6 and 7.

	Profile Establishment	**Stage 1a & 1b**			**Stage 2a & 2b**			**Stage 3**			**TOTAL**		
Date	15th – 31st Jul	21st Aug – 14th Oct			15th Oct – 27th Mar			28th Mar – 28th May					
Days	**17**	**55**			**164**			**62**					
Treatment#	Water mm	Water mm	E-pan mm	E-pan %	Water mm	E-pan mm	E-pan %	Water mm	E-pan mm	E-pan %	Water mm	E-pan mm	E-pan %
2 (100% Etc)	118	191	276	69	1,404	1,460	96	101	233	43	1,814	1,969	92
5* (160% Etc)	159	273	251	109	2,156	1,408	153	176	230	76	2,764	1,889	146
6 (60% Etc)	109	115	276	42	845	1,460	58	63	233	27	1,132	1,969	58
7 (irregular)	27	150	276	53	1,163	1,460	79	113	233	48	1,453	1,969	73

*T5 data includes 2002/03 to 2006/07

Early pit hardening is the end of Stage 1, Harvest is the end of Stage 2, and the end of irrigation is the end of Stage 3

5.2.2 Soil Water Monitoring

5.2.2.1 Neutron Probe Calibration

The neutron probe was calibrated on two occasions by the original project team in the early years of the Trial. The data collected from the second occasion (August 2006) was provided to Dr Cameron Grant, CPSS-3, School of Earth and Environmental Sciences, University of Adelaide to interpret the findings and provide conclusions and recommendations for irrigation practices (Appendix 1). The summary of the interpretation is provided in Table 6.

The ideal matric head (h_i) was to be used for monitoring irrigation using tensiometers, and the raw soil neutron probe count rates (C_{soil}) were to be used for neutron probes. In order to avoid drainage, the soil was not to become wetter than the ideal matric head or raw soil neutron probe count. If dielectric methods (e.g. EnviroSCAN's) were to be used to monitor volumetric water contents, these would require calibration.

Table 6: Link between critical matric head (h_i), and corresponding values for the volumetric water content ($\theta_v(h_i)$), plus ideal relative neutron probe count rate (RCR_i), and raw neutron probe count rate in soil (C_{soil}).

Soil Texture	Ideal Matric Head (h_i)		Ideal Volumetric Water Content $\theta_v(h_i)$	Ideal RCR_i $RCR_i = (\theta_v - a)/b$	Ideal C_{soil} $C_{soil} = RCR_i \times C_w$
	cm	kpa			
Sands	**213**	**20.9**	0.220	0.493459716	**11685**
Loams	**126**	**12.4**	0.264	0.608282675	**14404**
Clay loams	**129**	**12.6**	0.266	0.533718104	**12638**

Dr Grant noted in the calibration process, the gravimetric water contents (θ_m), of the calibration soil samples were determined incorrectly as the soil samples were not oven dried, just air dried. Consequently, the volumetric water contents were compromised, and thus the neutron probe calibrations were somewhat compromised, particularly for the loams and clay loams. The risk was considered acceptable for the sands due to the long duration of air drying in a protected, warm environment, and not a lot of water would have remained in the samples. Furthermore, most of the Trial, the data collected, and the critical root zone were located within the sands. It was therefore thought the critically precise information obtained from a further calibration was not considered necessary.

5.2.2.2 Neutron Probe Graphs

In order to accurately monitor the water applications of all treatments, the weekly reading taken from each of the four neutron probe sites located at 20cm from the dripper (Figure 2) were averaged at each of the monitoring depths (i.e. 10, 20, 30, 40, 60, 70, 80, 90, 100, 120, 140 and 160cm). To provide further interpretation, the mean of 0-80cm, 0-30cm and 80-160cm below the soil surface at 20cm from the drip emitter were calculated and are provided in Figure 5, Figure 6 and Figure 7, respectively. As expected, Figure 5, Figure 6 and Figure 7 generally indicated a higher soil water status for the treatments with higher water applications at all depths.

The data also indicated, that when using the most conservative (i.e. driest) C_{soil} of 11,685 (Table 6) and assuming the majority of the Trial consisted of deep sand; T2, 5, 6 or 7 did not exceeded field capacity at 0-80cm (Figure 5) or 80-160cm (Figure 7) within a season or across seasons. However, there were periods where the C_{soil} measured 8,000 to 10,000 at all treatments in the profile establishment period (i.e. July) and at T2 (100% Etc) and T5 (160% Etc) during October and

November. The profile establishment in July was of most concern due to the considerable volume of water applied and the additional negative impact of leaching residual nutrient that may have remained from the previous season. Whether these periods experienced smaller, more discrete episodes of C_{soil} greater than 11,685 was difficult to determine as the neutron probe readings occurred weekly and were not continuously logging.

0-30cm (Figure 6) on the other hand, regularly recorded C_{soil} of 10,000 to 12,000 from July to the end of January (i.e. profile establishment to beginning of hull split) and possibly exceeding field capacity and causing a degree of drainage beyond a depth of 30cm. However, this was considered necessary in order for the water to fill the profile beyond 30cm, and thus maintain a buffer of soil water, and meet the requirements of the entire root zone.

A trend of particular interest (Figure 5) was seen between the treatments that applied 60% and 100% of notional water requirements. Both treatments received similar quantities of water in July to establish the SWC within the profile; after which, the 40% reduction was applied to T6 (i.e. 60% Etc). However, the buffer and the soil water reserves provided to both treatments from the profile establishment appear to have created a similar SWC from July to the end of September. It wasn't until October that the decrease in soil water content between 60% and 100% of notional water requirements became evident. Consequently, both treatments would have experienced adequate levels of water to provide for the critical periods of root development, flowering, fruit set, and initial fruit growth and vegetative growth.

An additional trend of particular interest was the inability to meet the complete consumptive requirements of T2 (100% Etc) through December and January, a period which largely consisted of a crop factor greater than or equal to 1.0. The Trial protocol of capping daily irrigation applications at 12mm may have contributed to this trend.

The irregular watering of T7 (prior to 2007/08) was also clearly evident and resulted in periods of very low SWC. It was also observed that regardless of a greater mean water application in T7 (1,453mm) compared to T6 (1,132mm), the irregular watering pattern of T7 did not result in a correspondingly higher C_{soil} at 0-80cm until approximately mid way through Stage 2a (December). Consequently, T6 would have experienced a greater SWC during most of the critical physiological periods resulting in a higher yield relative to T7.

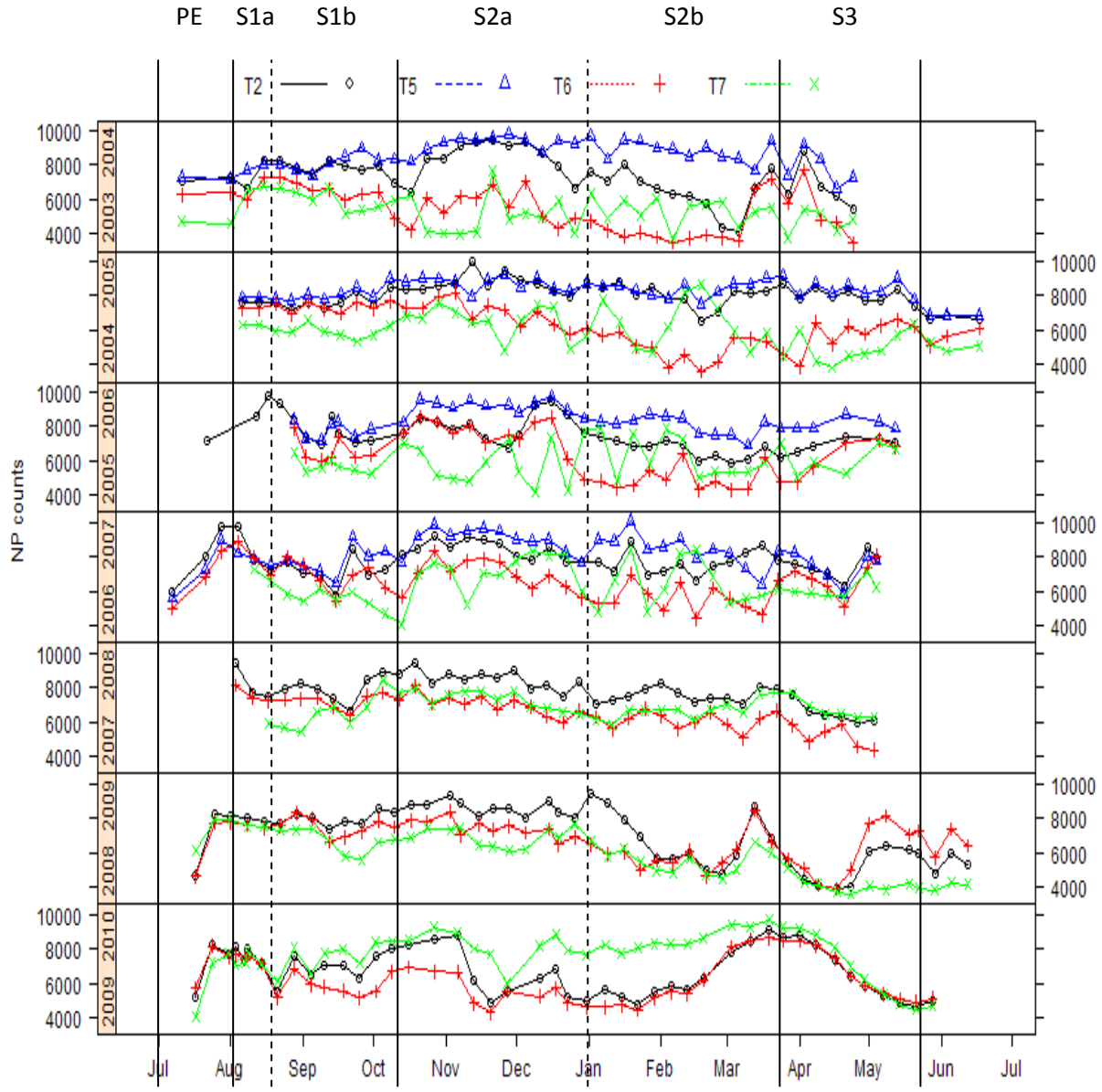

Figure 5: Mean neutron probe counts from 0-80cm below the soil surface of Treatments 2, 5 (prior to 2007/08), 6 and 7, 20cm from the drip emitter. PE = profile establishment, S1a, S1b, S2a and S2b = phenological stages.

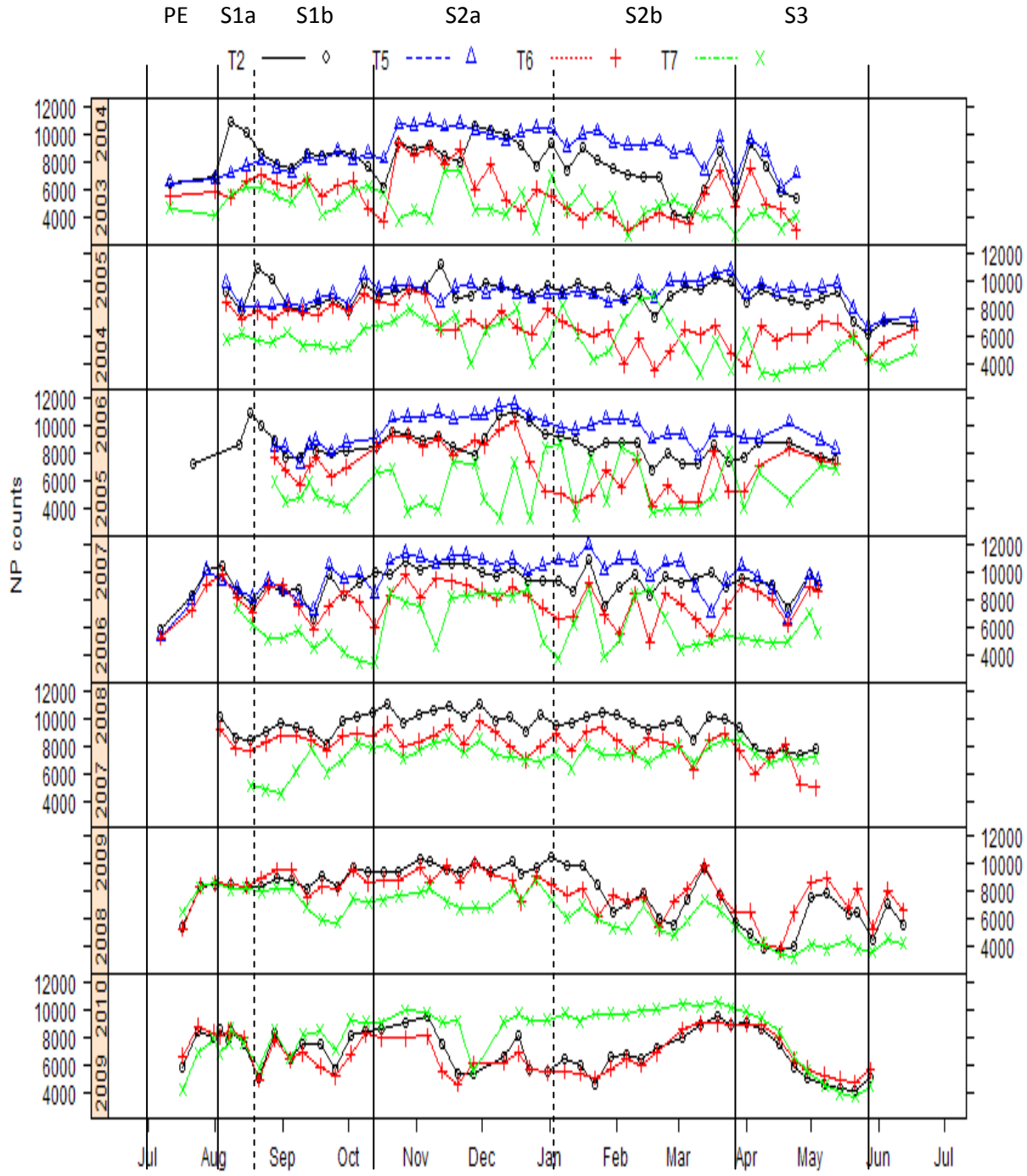

Figure 6: Mean neutron probe counts from 0-30cm below the soil surface of Treatments 2, 5 (prior to 2007/08), 6 and 7, 20cm from the drip emitter. PE = profile establishment, S1a, S1b, S2a and S2b = phenological stages.

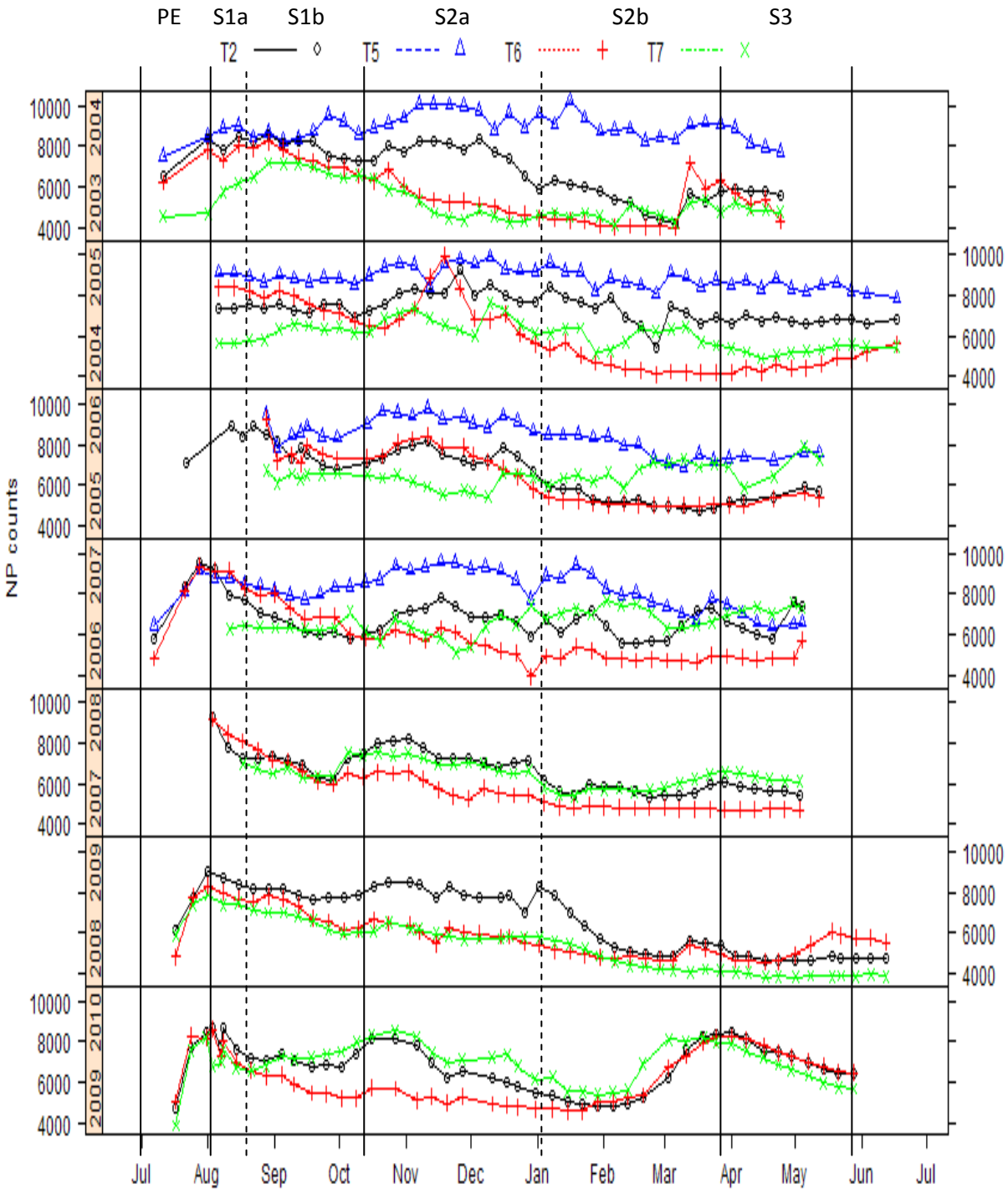

Figure 7: Mean neutron probe counts from 80-160cm below the soil surface of Treatments 2, 5 (prior to 2007/08), 6 and 7, 20cm from the drip emitter. PE = profile establishment, S1a, S1b, S2a and S2b = phenological stages.

5.2.3 Plant Based Monitoring

5.2.3.1 Midday Stem Water Potential and Sap Flow

Stem water potential results (Figure 8) confirmed T6, which received 40% less irrigation than T2, was more stressed (more negative water potential) on most measurement dates. Water potential readings for all treatments varied according to the timing of readings relative to irrigation and rainfall events.

Sap flow readings were plotted against the calculated evapo-transpiration (Eto) rate from weather data. Sap flow in T2 closely matched Eto (Figure 9), where as sap flow in T6 was significantly less than Eto (Figure 10), indicating the lower irrigation level in T6.

Furthermore, during the peak atmospheric demand period of December to January, nocturnal water (i.e. sap flow) uptake by trees was in the order of 20% and 15% of daily water use for the 100% Etc and 60% Etc treatments respectively. Therefore, although nocturnal transpiration was non-existent or minimal, the tree did uptake water through the night period and tried to maintain its hydraulic status. Nocturnal water uptake was particularly evident when it proceeded a high stress day measured as midday stem water potential.

Differences in water uptake were registered by the NE and SW sensors only for the 60% Etc treatment, with less water uptake measured for the NE side. This was consistent with the sun path, where the NE side received maximum direct solar incidence on the canopy, and lower stem water potentials for that side resulting in less leaf stomata conductance.

Of particular interest was the lack of correlation between the daily water applied via irrigation and the daily water uptake measured as sap flow (Figure 11). The data suggested approximately 50% of daily water applications, from either T2 or T6, were not taken up by the plant. The discrepancy may have been a result of losses from surface evaporation due to the continuous, daily wetting of the soil surface from irrigation events. Unutilised drainage was unlikely to be the cause, as the neutron probe readings for December and January 2009/10 indicated decreasing SWC below 80cm (Figure 7).

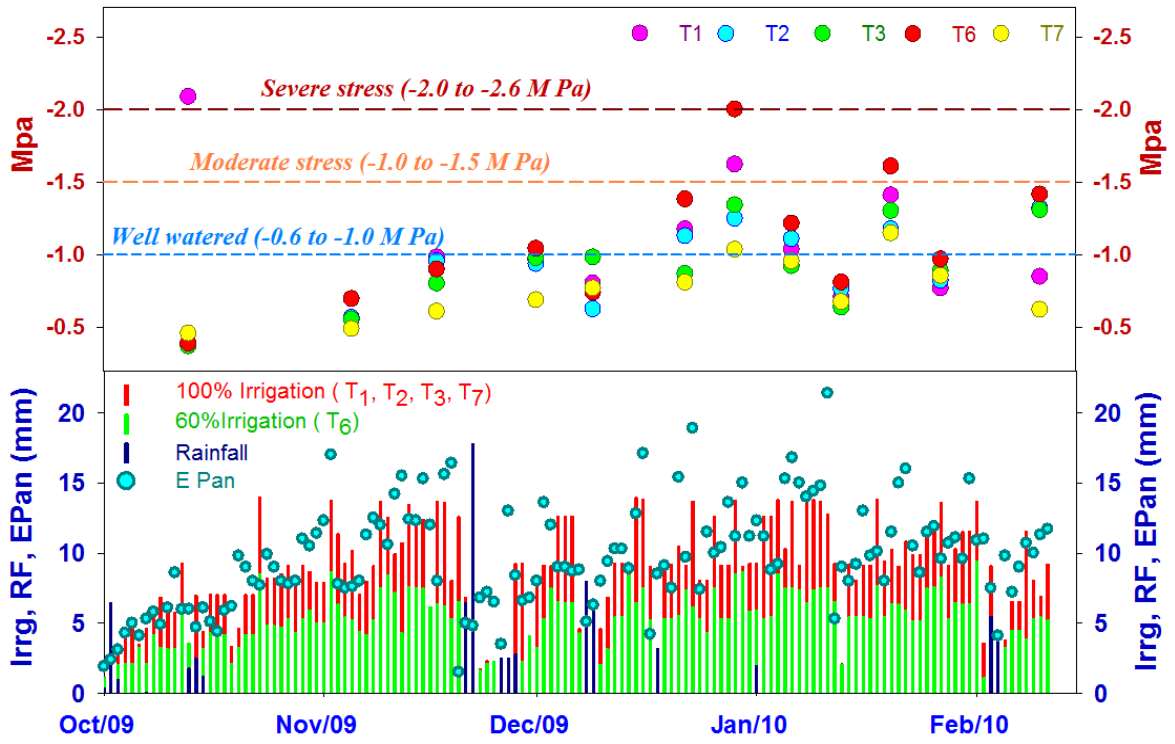

Figure 8: Midday stem water potential, T1, 2, 3, 6 and 7 2009/10.

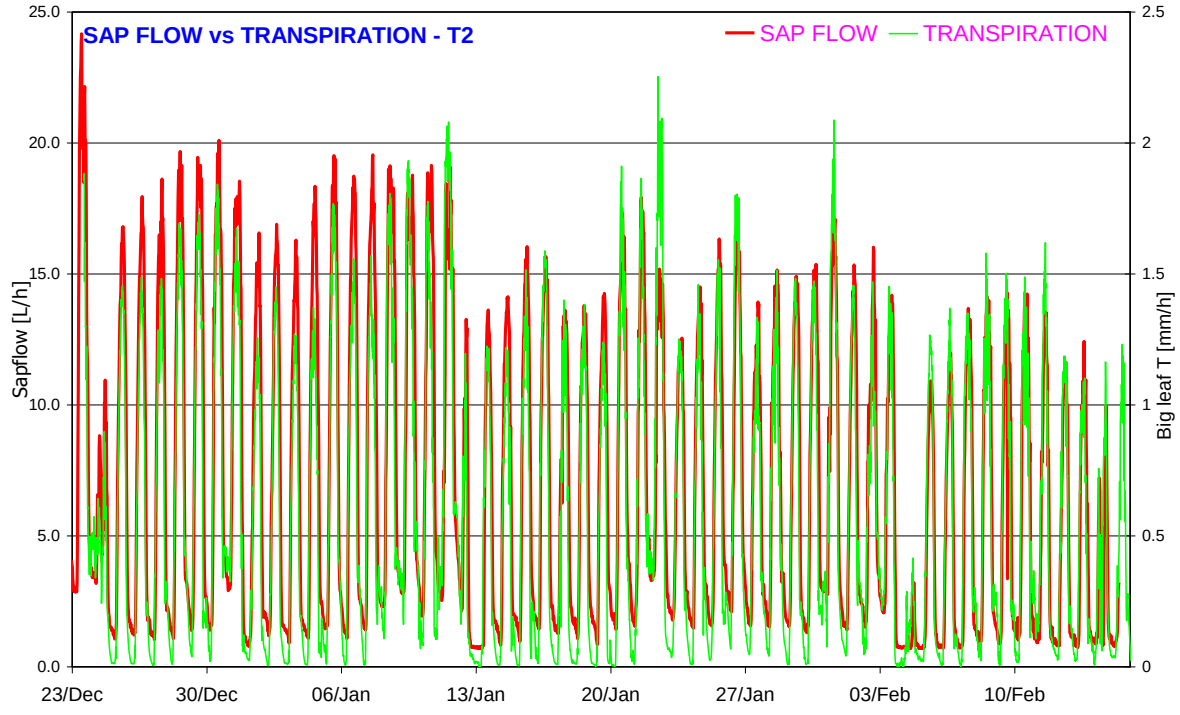

Figure 9: Sap flow versus transpiration, T2, 2009/10.

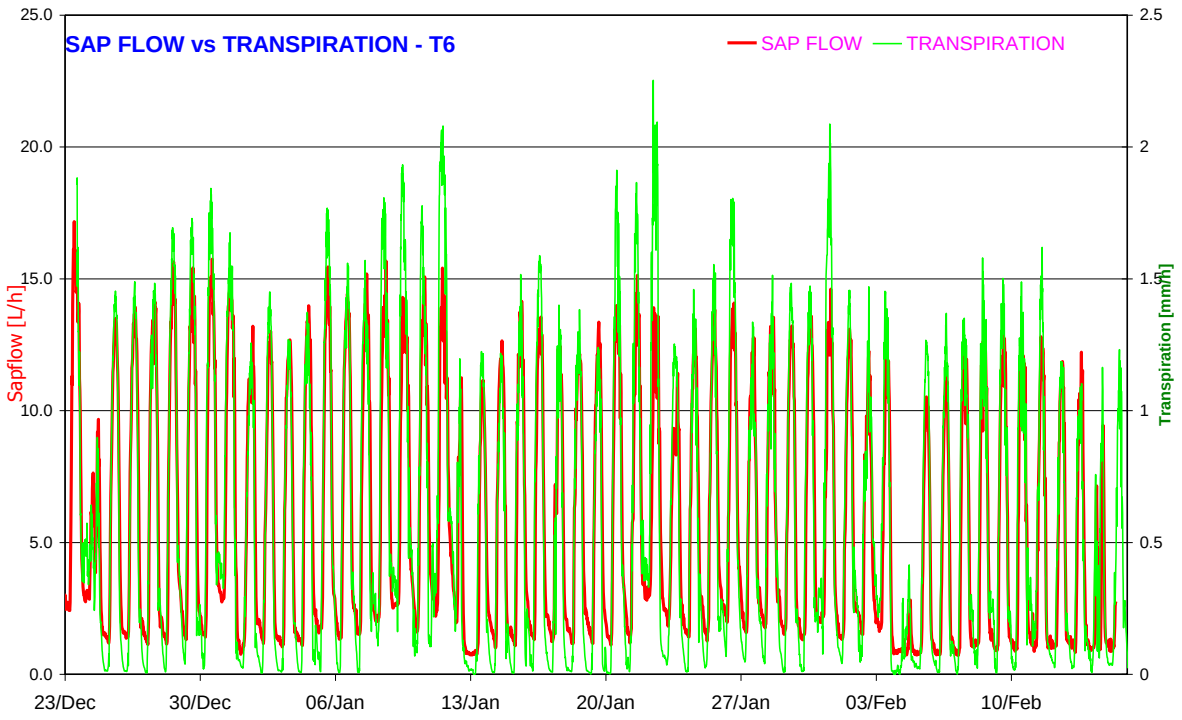

Figure 10: Sap flow versus transpiration, T6, 2009/10.

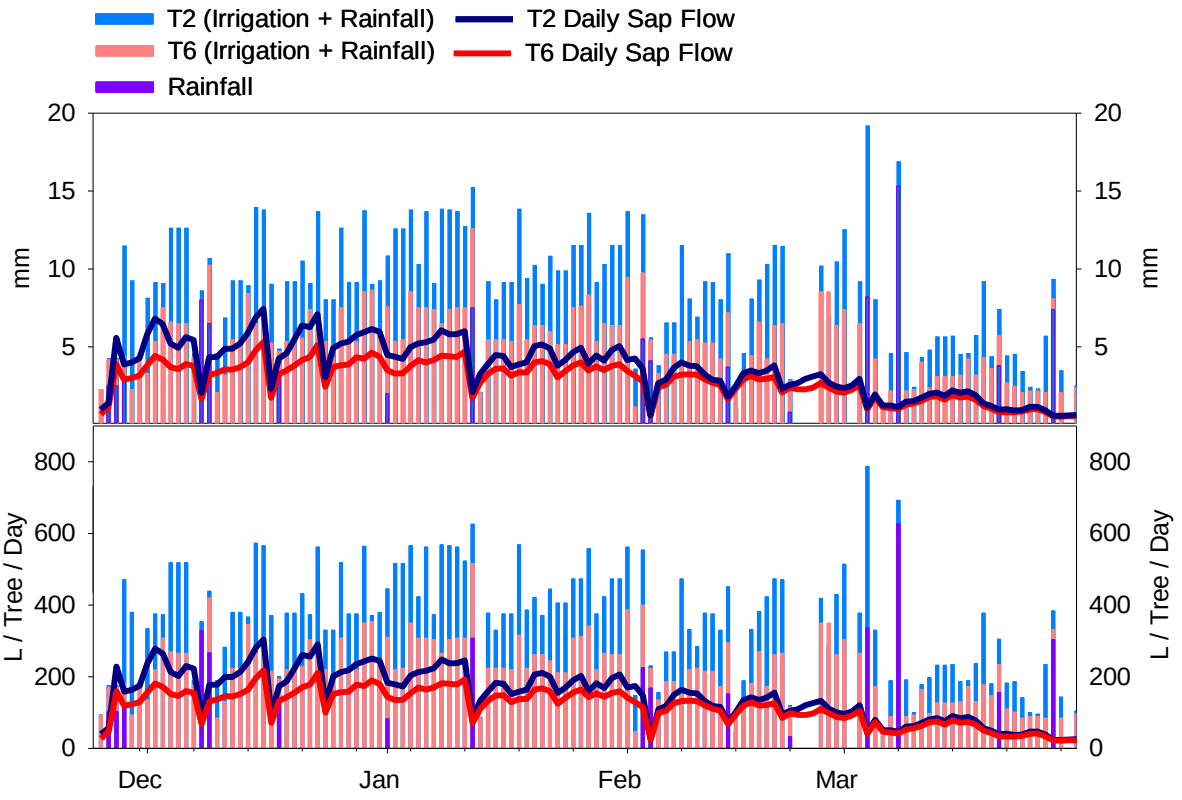

Figure 11: Daily water applications via irrigation versus sap flow, 2009/10

5.2.4 Yield Response to Water Applications

Yield increased from 2002 (3 year old, first harvest) to 2005 (6 year old, fourth harvest) as the trees became mature, thereafter the yield tended to plateau and seasonal yield variations were most likely attributable to climatic differences from season to season.

The data indicated there was no consistent seasonal trend of increased Nonpareil yield (Figure 12) between 60% Etc and 100% Etc with only three seasons (2004/05, 2007/08 and 2009/10) recording a significant difference. Generally yield trends for Carmel were similar to Nonpareil but the reduction due to a lower irrigation volume for 60% relative to 100% Etc were greater for Carmel particularly in the seasons (2004/05, 2007/08 and 2009/10, Figure 13).

The absence of any consistent yield differences between the three watering levels either within (Figure 12 and Figure 13) nor across seasons (Figure 14) suggested watering at 60% Etc, was sufficient to achieve consistently high productivity relative to 100 and 160% Etc.

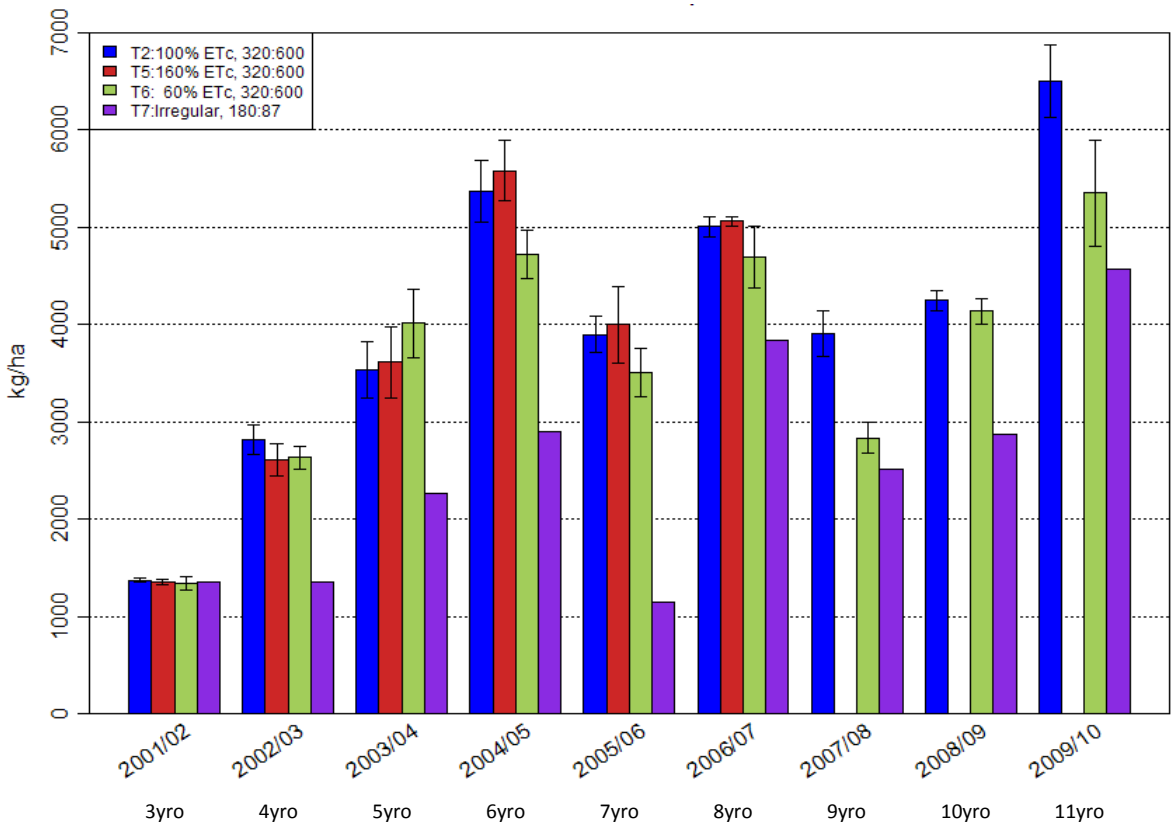

Figure 12: Annual water treatment effects on Nonpareil yield.

The bars shown are 2 x standard errors (1 up, 1 down). Statistical significance exists between treatments where the means differ by three standard errors.

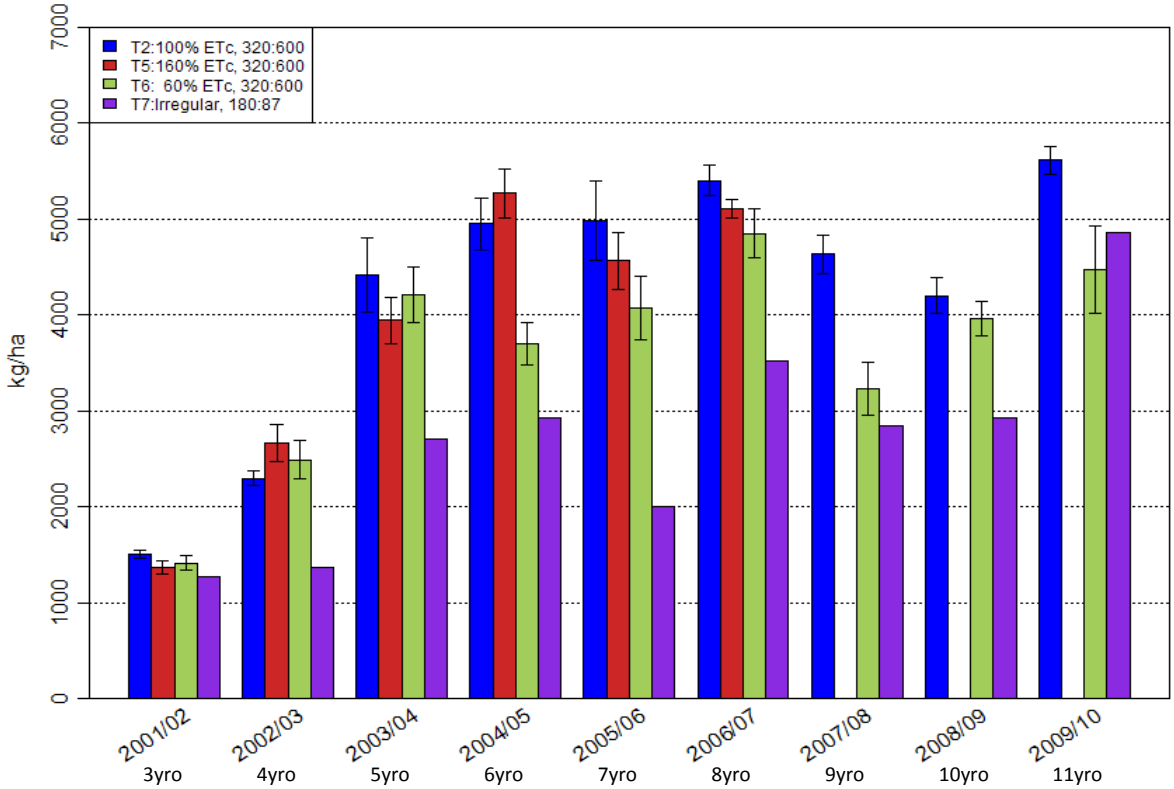

Figure 13: Annual water treatment effects on Carmel yield.

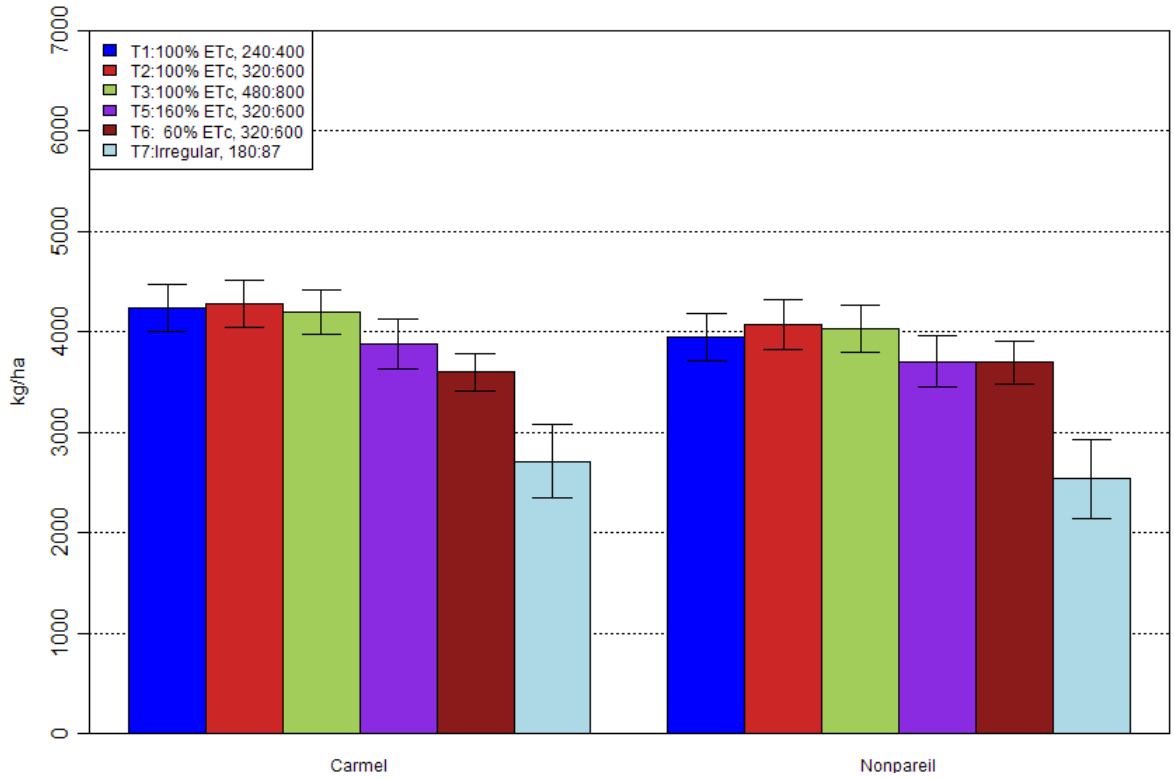

Figure 14: Nonpareil and Carmel mean yield of all seasons.

The bars shown are 2 x standard errors (1 up, 1 down). Statistical significance exists between treatments where the means differ by three standard errors.

Water use efficiency assessed as yield (kg) produced per water applied (mm) is represented in Figure 15. Decreasing water applications resulted in significantly higher water use efficiency, with T6 (60% Etc) the most water efficient, producing approximately 3.6 kg/mm in Nonpareil and 3.57 kg/mm in Carmel. There was little difference in water use efficiency between Nonpareil and Carmel.

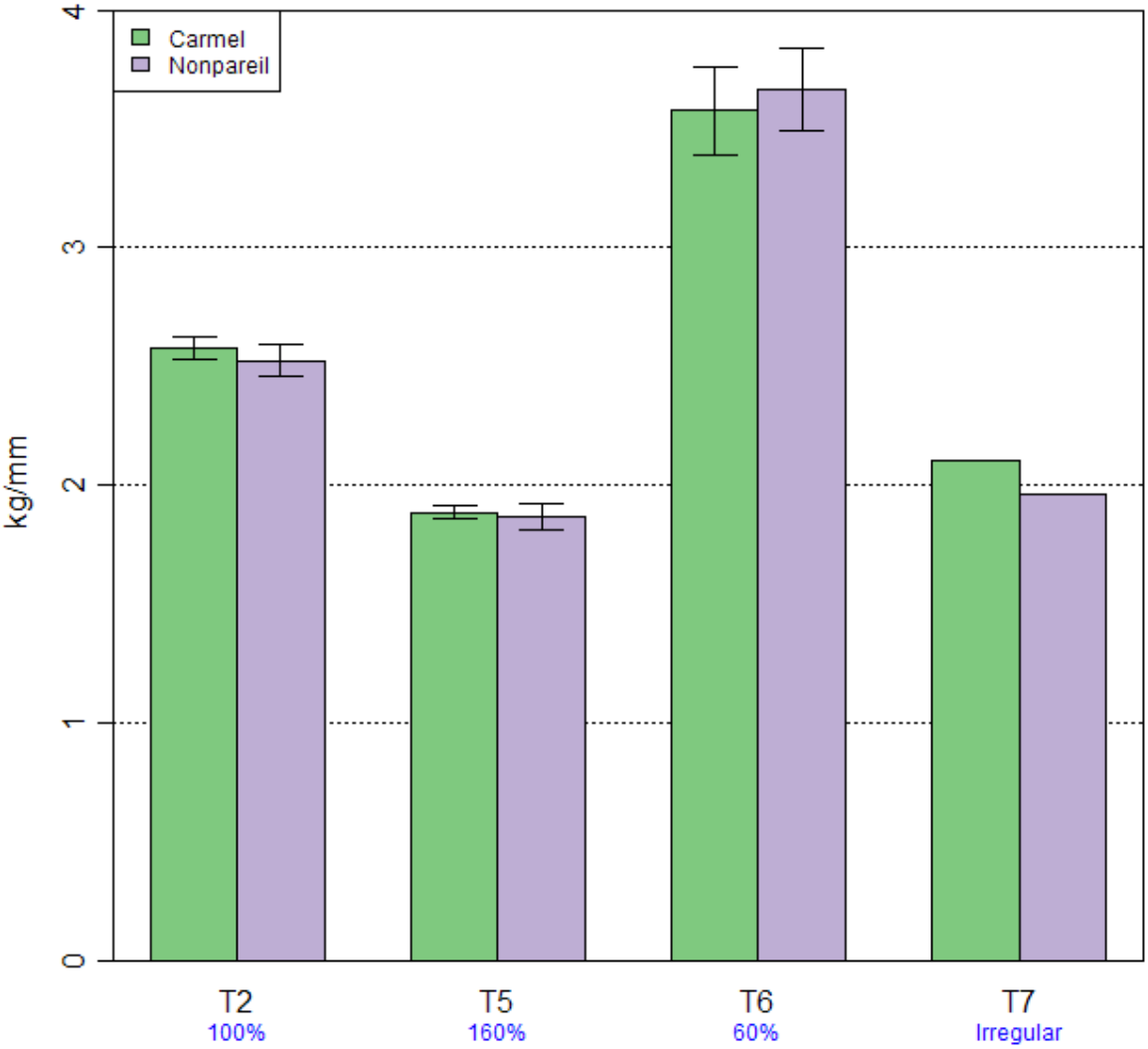

Figure 15: Water use efficiency (kg/mm) of Nonpareil and Carmel.
The bars shown are 2 x standard errors (1 up, 1 down). Statistical significance exists between treatments where the means differ by three standard errors.

5.3 Nutrition

5.3.1 Soil Data

A summary of the major nutrient applications for T1, 2, 3 and 7 is provided in Figure 16. Within each season, depending on soil temperature, crop load and vegetative growth the precise timing of the nutrient applications could vary from those presented in Figure 16.

Nitrogen was generally applied using ammonium nitrate (liquid or solid), potassium nitrate, UAN (21% N as urea, 10.5% N as ammonium, 10.5% as nitrate), urea, and/or MAP.

Potassium was generally applied using potassium nitrate, potassium sulphate and/or potassium chloride.

Approximately equal amounts of EDDHA iron chelate (8 x 1kg/ha) and Yara Ferti Mix (1.8% Mg, 1.0% B, 2.0% Cu, 3.0% Fe, 2.0% Mn, 6.0% Mo and 1.0% Zn) (4 x 3kg/ha) were applied to T1, 2 and 3 through September, October and November.

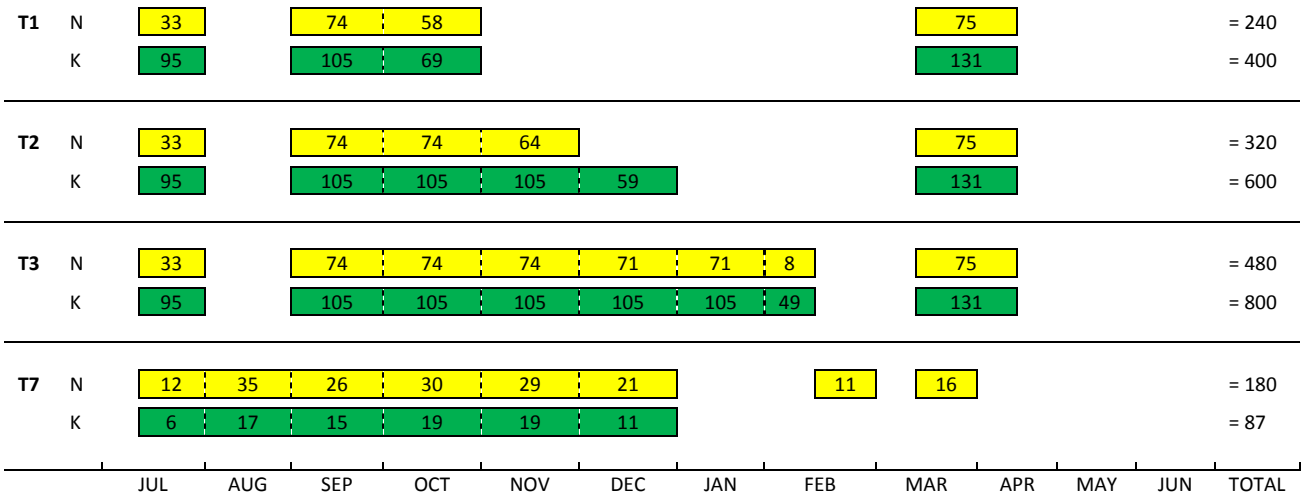

Figure 16: Nitrogen and potassium applications (kg/ha) for T1, 2, 3 and 7

The aim of the trial was to fully meet the trees' requirement of nitrogen and potassium as they are the mineral elements with the highest concentration in the leaf and fruit tissues. Nitrogen content of leaf dry weight normally ranges from 2.0-2.5% and that of potassium from 1.4-1.7%. Nitrogen content of fruit ranges from 1.5-2.0% and that of potassium from 2.0-2.5%. When the Trial was designed, T2 (320:600) was predicted to be the closest to the optimum requirements based on previous research of *prunus* crops in Israel by Prof Assaf and his colleagues. T1(240:400) and T3 (480:800) were predicted to be lower and higher than optimum, respectively.

5.3.1.1 Soil Nitrate

Soil nitrogen was assessed as nitrate (NO_3^-) and is represented in Figure 17. Soil analysis was undertaken from the same location in each of the three nutrient treatments (i.e. T1, 2 and 3) in July, October and January.

The nitrogen concentration in the surface soil was elevated in treatments with higher nitrogen application rates. A rise in nitrogen content was first apparent two to three seasons after the treatments were first applied. No clear difference in concentration was evident between treatments for soil depths greater than 20cm.

There were however, clear trends across all treatments: a) a rise in nitrate concentrations below depths of 50cm from 2001 to 2007 regardless of fertigation rate, b) the subsequent decline in nitrate concentrations at all sampling depths from 2008 to 2010, and c) the considerably higher nitrate concentrations in soil layers below 50cm as compared to shallower layers. There was little explanation for the peak in nitrate concentrations around 2007 as a closer analysis of the data indicated readings >100 mg/kg occurred at all treatments and within all sampling periods (July, October and January), regardless of the nitrogen applications. One explanation may have been the water applications increased from approximately 16 ML/Ha to 20ML/Ha between 2003/04 and 2006/07 respectively for T2. However, the E-Pan readings also increased over the same period from approximately 1800mm to 2000mm and the neutron probe data did not suggest a trend of increasing SWC.

The decline in the concentration of nitrate ions following 2008, particularly at depths below 50cm, was of some concern and suggests that some leaching may have occurred because of the high mobility of nitrate ions.

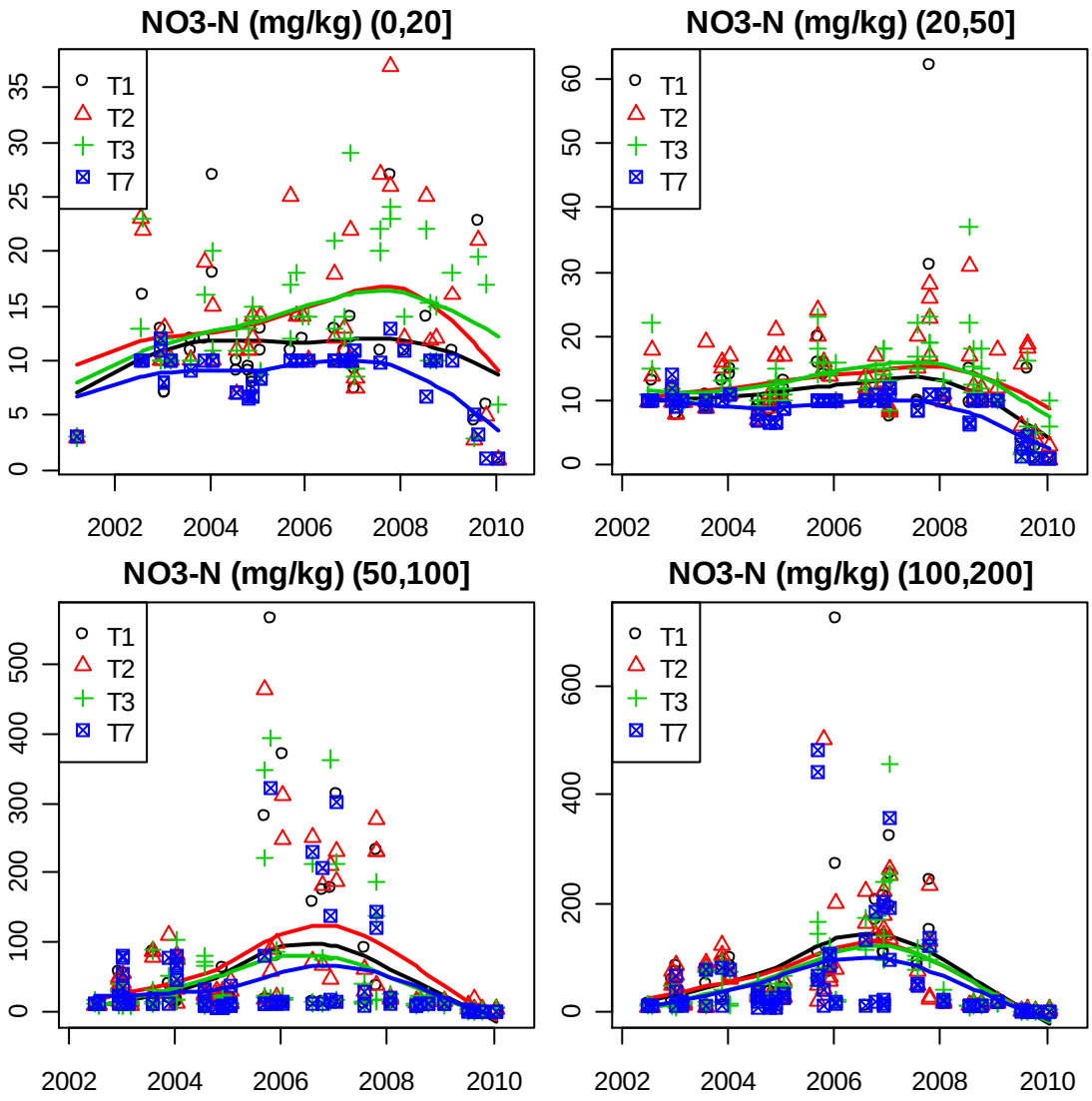

Figure 17: Soil nitrate nitrogen* (mg/kg) of Treatments 1 (240:400), 2 (320:600), 3 (480:800) and 7 (180:87). 0-20cm, 20-50cm, 50-100cm and 100-200cm.

The trend lines shown are smoothing splines.

*1:5 Water Extraction method.

5.3.1.2 Soil Potassium

Soil potassium (K) was assessed as available potassium (mg/kg) and is represented in Figure 18.

The data indicated considerably lower potassium concentrations between T7 (87 kg/ha of K) and T1-3 (400 to 800 kg/ha of K). In addition, below 50cm there appeared to be an increasing concentration of potassium correlated to increasing applications from T1 (400 kg/ha of K), to T3 (800 kg/ha).

Prior to 2006, it would also appear potassium concentrations of T1-3 were declining at 0-50cm, after which concentrations tended to increase throughout the sampling depths.

T7 at all depths had considerably lower potassium concentrations until 2007, after which they began to rise steadily between 0-50cm and rose slightly or remained steady at depths greater than 50cm. This trend may be explained by the relatively low application rate of potassium (87 kg/ha) in T7 until 2007/08, followed by a sharp increase to 400 kg/ha thereafter.

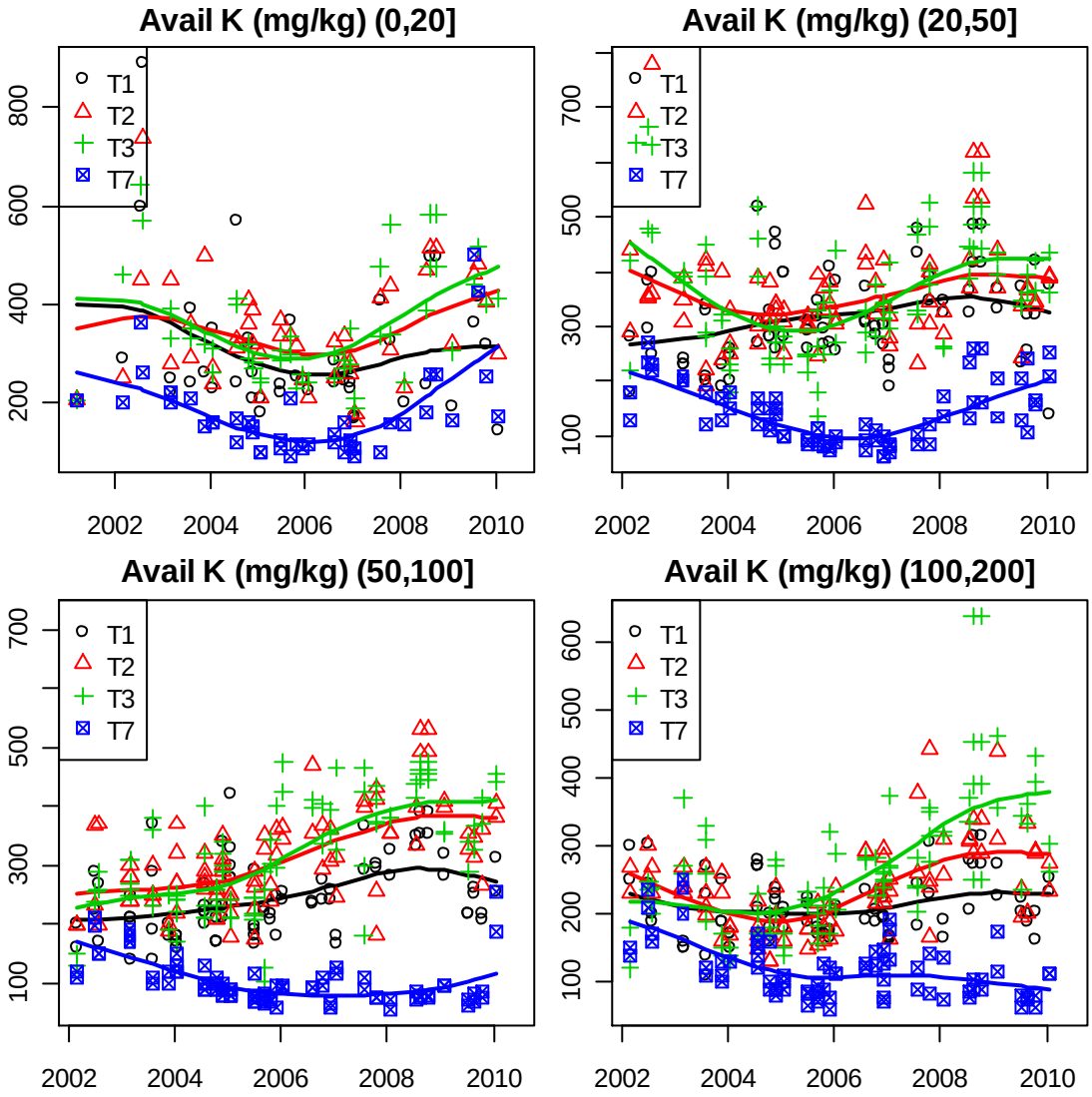

Figure 18: Soil available potassium* (mg/kg) of Treatments 1 (240:400), 2 (320:600), 3 (480:800) and 7 (180:87). 0-20cm, 20-50cm, 50-100cm and 100-200cm.

The trend lines shown are smoothing splines.

*Colwell Bicarbonate Extraction method.

5.3.1.3 Soil Salinity

Soil salinity was assessed using saturation paste extract, electrical conductivity (dS/m) and is represented in Figure 19.

When measuring electrical conductivity there may be salts other than sodium chloride (NaCl) present; nevertheless, the production threshold using traditional Electrical Conductivity Saturation Paste Extract (EC_{SE}) is approximately 1.50 dS/m, after which there may be a decline in yield as EC_{SE} increases (Maas and Hoffman, 1977).

Figure 19 indicated a trend of increasing soil salinity, particularly from 2008-2010, and more apparent at depths from 0-50cm than below 50cm. The trend lines fitted to the data indicated all

treatments mostly remained below the threshold of 1.50 dS/m with T1 and 7 measuring the lowest EC_{SE}, and T3 generally measuring the highest EC_{SE}. Generally EC_{SE} values were indicative of fertiliser rates.

During the summer sampling period EC_{SE} was often found to be greater than 1.50 dS/m in T2 and 3 and often coincided with the extended fertiliser application period of T2 and 3 respectively in January and February. Furthermore, the summer period frequently experienced high evaporation and tree water use, which if inadequately matched with irrigation applications may have resulted in a transient rise in EC_{SE} from fertiliser but also sodium chloride. However, given the higher EC_{SE} generally occurred from 0-50cm, most high readings were more likely due to fertiliser applications than NaCl in the irrigation water.

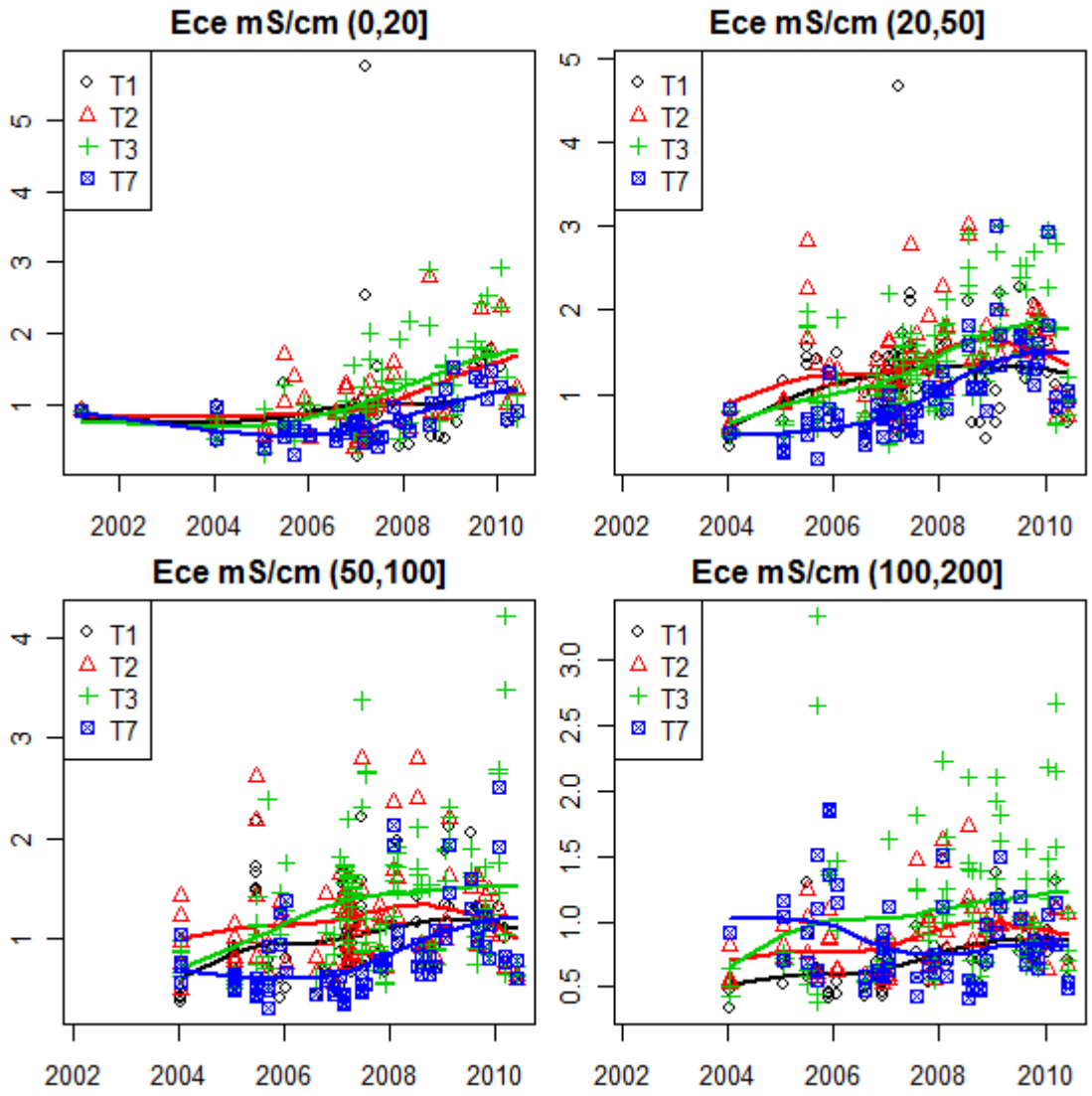

Figure 19: Soil electrical conductivity* (mS/cm or dS/m) of Treatments 1 (240:400), 2 (320:600), 3 (480:800) and 7 (180:87). 0-20cm, 20-50cm, 50-100cm and 100-200cm.

The trend lines shown are smoothing splines.

*Saturation Paste Extract Method.

5.3.1.4 Soil Acidity

Soil acidity was assessed using soil pH_{Ca} and is represented in Figure 20.

The measurement procedure used a 1:5 solution of soil and a weak solution of calcium chloride (pH_{Ca}). It is more commonly used than water based method because it is more reliable and less variable. Its results are approximately 0.8 pH units lower than those from water based methods. Values of pH_{Ca} between 5.5 and 8.0 are considered optimal for nutrient uptake and to ensure sustainably high levels of production. Values for pH_{Ca} less than 5.5 are classified acidic and those greater than 8.0 are classified alkaline and neither are desirable for optimal soil health.

Figure 20 shows a trend of increasing soil acidity (i.e. decreasing pH) at 0-50cm, particularly from 2002-2007. The trend lines indicated the pH went from approximately 8.0 to 6.5 at 0-20cm and from 7.5 to 6.5 at 20-50cm. Although the observed values were still mostly within the desirable pH range, there were concerns with numerous outliers in the highly acidic range from 4.0 to 5.5. The highly acidic readings were mostly correlated with the higher nutrient applications of T1, 2 and 3.

The pH tended to be more stable below 50cm and also more alkaline regardless of treatment. The trend line indicates a lower pH in T1 in comparison to T2 and 3, which is contrary to the acidification potential of the fertiliser programs. T1 and 7 had the least acidifying potential followed by T2 and T3 with approximately and respectively 219, 217, 220 and 383 kg $CaCO_3$ acidification equivalent. The reasons for a lower pH in T1 may be attributed to sampling times, seasonal variability and soil type.

Since 2007, the trend of increasing pH at 0-50cm may be attributed to the change in post harvest fertiliser practices and introduction of lime applications during dormancy. Prior to 2006/07, post harvest nitrogen was applied as ammonium sulphate which has the highest acidification potential of the nitrogenous fertilisers. Approximately 5.4kg of lime ($CaCO_3$) are required to neutralise the acidity of ammonium sulphate, versus 1.8kg of lime to neutralise the acidity of urea or ammonium nitrate. From 2006/07, urea replaced ammonium sulphate and in July 2008 agricultural grade lime at a rate of 4 tonnes/ha was banded above the drip line of all Treatments.

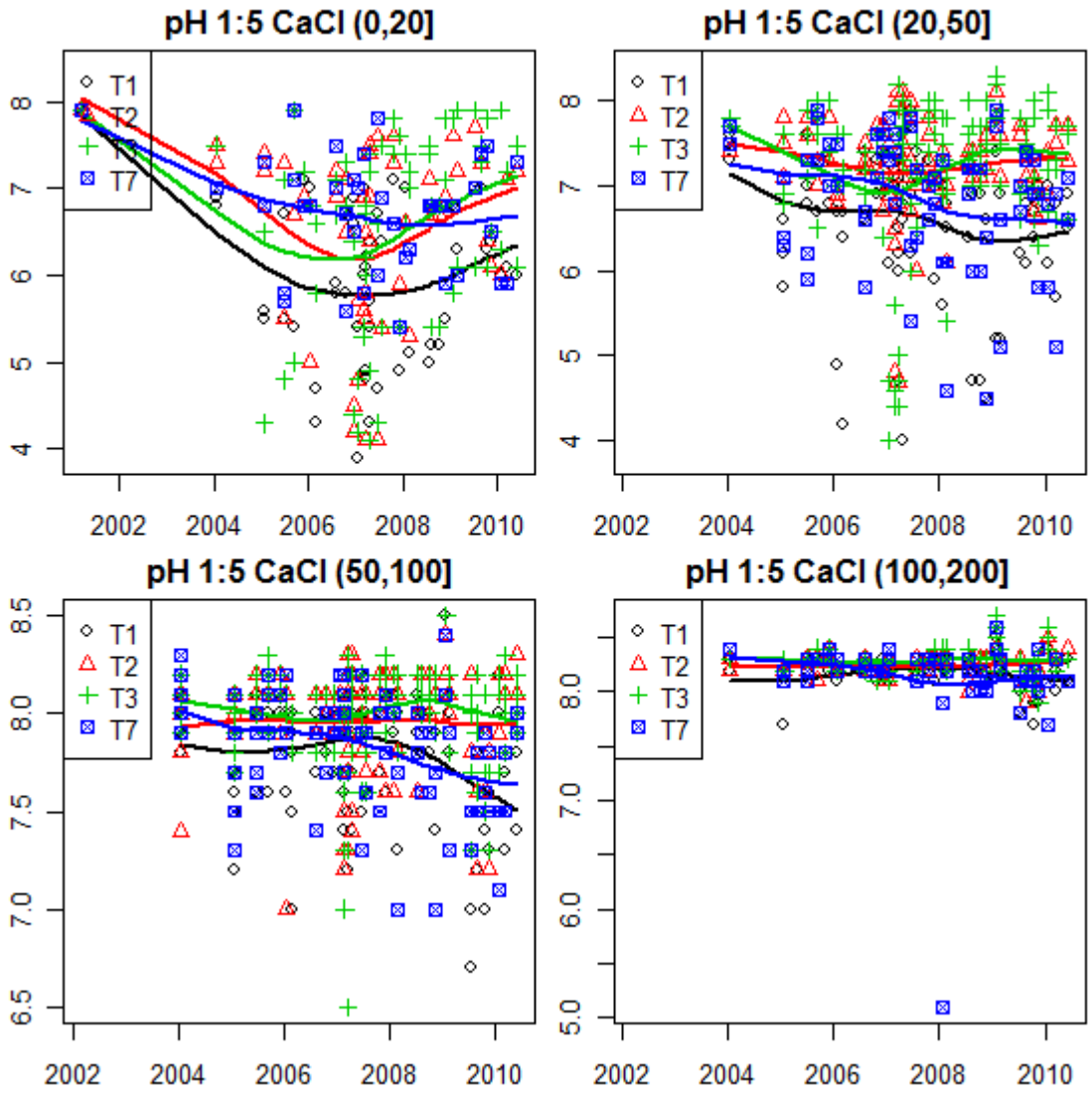

Figure 20: Soil pH_{Ca} of Treatments 1 (240:400), 2 (320:600), 3 (480:800) and 7 (180:87). 0-20cm, 20-50cm, 50-100cm and 100-200cm.
The trend lines shown are smoothing splines.

5.3.2 Soil Solution Monitoring

SoluSAMPLERs suitable for the collection of soil solution were installed in the root zone of T1, T2, T3, T4, T6 and T7 and sampling began in January 2009. The introduction of the soil solution monitoring was to provide a better understanding of the effect of fertiliser applications on the soil solution in the root zone, nutrient uptake and environmental sustainability.

5.3.2.1 Soil Solution Nitrate

Soil solution nitrate concentrations generally decreased with depth across all Treatments; however, there were two periods of large concentration increases in T1-3 at 30cm 60cm and 90cm: 1) the period following profile establishment irrigations and potassium nitrate applications in August 2009, and 2) following post harvest applications of urea in May 2009 and 2010. The increase in concentrations at 90cm was of most concern as this was beyond the most active part of the root system and may suggest an oversupply of nitrogen, inadequate uptake, inappropriate application protocols, and/or excessive irrigation.

There was also a rise in the nitrate concentration of T3 at 30cm, 60cm and 90cm during January and February 2010. This was correlated with the duration of the fertiliser season and the quantity of applied nutrients. T3 continued to receive nitrogen applications until the middle of February 2010, whereas T1 and 2 did not receive any further spring applied nitrogen fertiliser beyond the month of December. This would indicate the application of nitrogen during January and February, and following hull split, was in excess of plant requirements and subject to leaching.

Figure 21 also illustrates the interaction between water applications, nutrient applications and plant uptake. T6 received the same nitrogen applications as T2 but 60% less water and the data indicates this has led to an increase in the nitrogen concentration of T6 at 30cm and 60cm, during November and December. A rise in concentration also increased the osmotic potential of the soil solution and possibly reduced plant uptake.

Nitrate concentrations during September and early October were generally low for T1-3 and likely were either below or well matched to plant requirements.

Low nitrate concentrations for T7 generally indicated no obvious upward trend suggesting, nitrogen applications were either below or well matched to plant requirements.

5.3.2.2 Soil Solution Potassium

Soil solution potassium concentrations followed similar trends to that of nitrate, with potassium concentrations generally decreasing with soil depth.

Two periods of large increases in potassium concentration were evident in T1-3 at 30cm, 60cm and 90cm following the period of profile establishment irrigations and potassium nitrate fertigations in August 2009, and following post harvest fertigations of potassium sulphate in May 2009 and 2010. A rise in concentrations at 90cm was of concern as this was beyond the depths of the most active part of the root system and may suggest an oversupply of potassium, inadequate uptake, inappropriate timing and/or excessive irrigation. Potassium is generally considered relatively immobile, but when in solution and at levels greater than plant requirement, it appeared to be subject to downward movement through the soil profile.

T3 also caused an increase in potassium concentrations at 30cm, 60cm, 90cm and 150cm during January and February 2010. This was correlated to the length of the fertiliser season and amount of nutrient applications. T3 continued to receive potassium applications until the middle of February 2010, whereas T1 and 2 had completed the spring applications of potassium fertiliser by November and December, respectively. This would indicate the application of potassium during January and February, and following hull split, was in excess of plant requirements and subject to leaching.

Figure 22 also illustrates the interaction between water applications, nutrient applications and plant uptake. T6 received the same potassium applications as T2 but 60% less water and the data indicates this had lead to an increase in the potassium concentration of T6 at 30cm and 60cm, during November and December. A rise in the potassium concentration of the soil solution may have increased the osmotic potential around the root zone beyond an optimum level for plant uptake

Potassium concentrations during September and early October were generally low for T1-3 and were either below or well matched to plant requirements.

Low potassium concentrations for T7 generally indicated no obvious upward trend and may also indicate potassium applications were either below or well matched to plant requirements.

5.3.2.3 Soil Solution Salinity

Soil solution salinity also followed similar trends to that of nitrate and potassium.

The production threshold for soil salinity using traditional Electrical Conductivity Saturation Paste Extract (EC_{SE}) is approximately 1.50 dS/m, after which there is a decline in yield as EC_{SE} increases. Comparatively, the equivalent production threshold for soil solution sampled by SoluSAMPLER's™ is approximately double that of soil salinity measurements (i.e. 2 x EC_{SE}), and equivalent to approximately 3.0 dS/m (Biswas *et al*, 2007). Further research into the relationship between EC_{SE} and EC_{SW} continues and indicates 2 x EC_{SE} is not always going to be appropriate for all soil types, EC_{SE} readings, Etc. It is advised orchards conduct their own calibration.

When only the treatments with the same irrigation but different nutrient levels are compared (T1-3), T1 in most instances had the lowest electrical conductivity and this was consistent with the applied fertiliser rates (Figure 23).

The EC_{SW} of T1-3 was generally above the threshold of 3.0 dS/m at 30, 60 and 90cm from May 2009 to the middle of July 2009 and was probably due to the delayed, post harvest fertiliser applications of urea and potassium sulphate.

The high EC_{SW} of T1-3 continued through the winter months and was evident up until the irrigations to the establish the profile began. Following those irrigations, the EC_{SW} generally decreased during the first half of July, except for T2 at 90cm, which could not be explained. The EC_{SW} at 30cm of T1-3, subsequently increased above the threshold in early August and was likely the result of minimal irrigation following profile establishment and drying of the surface soil.

The higher EC_{SW} at 30cm in early August subsided once regular irrigations started and mostly remained below the 3.0 dS/m threshold until the beginning of October for T6 and November for T2 and 3. Subsequently, the EC_{SW} increased above the threshold at 60cm and 90cm at T2, 3 and 6 until March. An earlier rise in EC_{SW} in T6 was likely caused by a 40% reduction in irrigation volume relative to T1-T4 resulting in a lower soil water content (SWC) and an associated rise in the concentration of salts (natural or fertiliser).

T1, for the most part, remained below the threshold at all depths until January, at which point the EC_{SW} at 30, 60 and 90cm increased above the threshold until the end of March.

T7 EC_{SW} generally experienced a similar trend to T1.

In general, the increase in EC_{SW} was closely related to the quantity of applied nutrients, the evaporative demand (i.e. E Pan), and the tree water requirement.

Whilst fertiliser is not made up of sodium or chloride, it is osmotically active and therefore contributes to the overall EC measurement. Fertilisers at high concentrations will increase the osmotic potential of the soil solution, and thus has the potential to reduce plant water and nutrient uptake and increase plant stress (Mass 1996, and Mass & Hoffman 1977). Our results reaffirms the importance of: a) ensuring the SWC of the root zone is adequate prior to, and during any fertiliser application period, b) better understanding the contribution of individual fertilisers to EC, c) applying fertiliser in small amounts but frequently to reduce the ion concentration in the soil solution, and d) applying post harvest fertiliser as soon as possible after harvest when the leaves are still functioning. The aim of these measures is to increase water and nutrient uptake when the trees are still physiologically active, and thus maximise efficiency and environmental sustainability.

5.3.2.4 Soil Solution pH

The relationship between soil solution pH (i.e. pH_{SW}) and soil pH is not well understood, however the data indicates the majority of pH_{SW} change was at 30cm, with little change observed at 60cm and below. This trend was not surprising given the sandier texture, lower buffering capacity, the large concentration of roots (Figure 33), and the frequent water and nutrient fluctuations at 30cm relative to 60cm and below.

At 30cm, two obvious trends were evident across all treatments; 1) a large reduction in pH_{SW} in late April and May 2009, and from November to March, and 2) a recovery in pH_{SW} from July to late October. An explanation for both trends may be associated with the use of ammonium-containing nitrogenous fertilisers (i.e. urea) and its acidifying characteristics. The two periods of pH_{SW} reduction were closely associated with the introduction of urea into the fertigation program (following the 26th October when soils increased in temperature), and the period of pH_{SW} recovery was closely associated with the absence of urea and the use of a more balanced mix of ammonium- and nitrate-containing nitrogenous fertilisers of potassium nitrate, liquid ammonium nitrate and MAP. Fertilisers containing nitrate ions and no ammonium ions (e.g. potassium nitrate and calcium nitrate) are in fact, alkaline. Their inclusion in the fertigation program probably contributed to a more balanced soil solution compared with the exclusive use of urea as a source of nitrogen during the post harvest period and the use of liquid ammonium nitrate in the Spring/Summer.

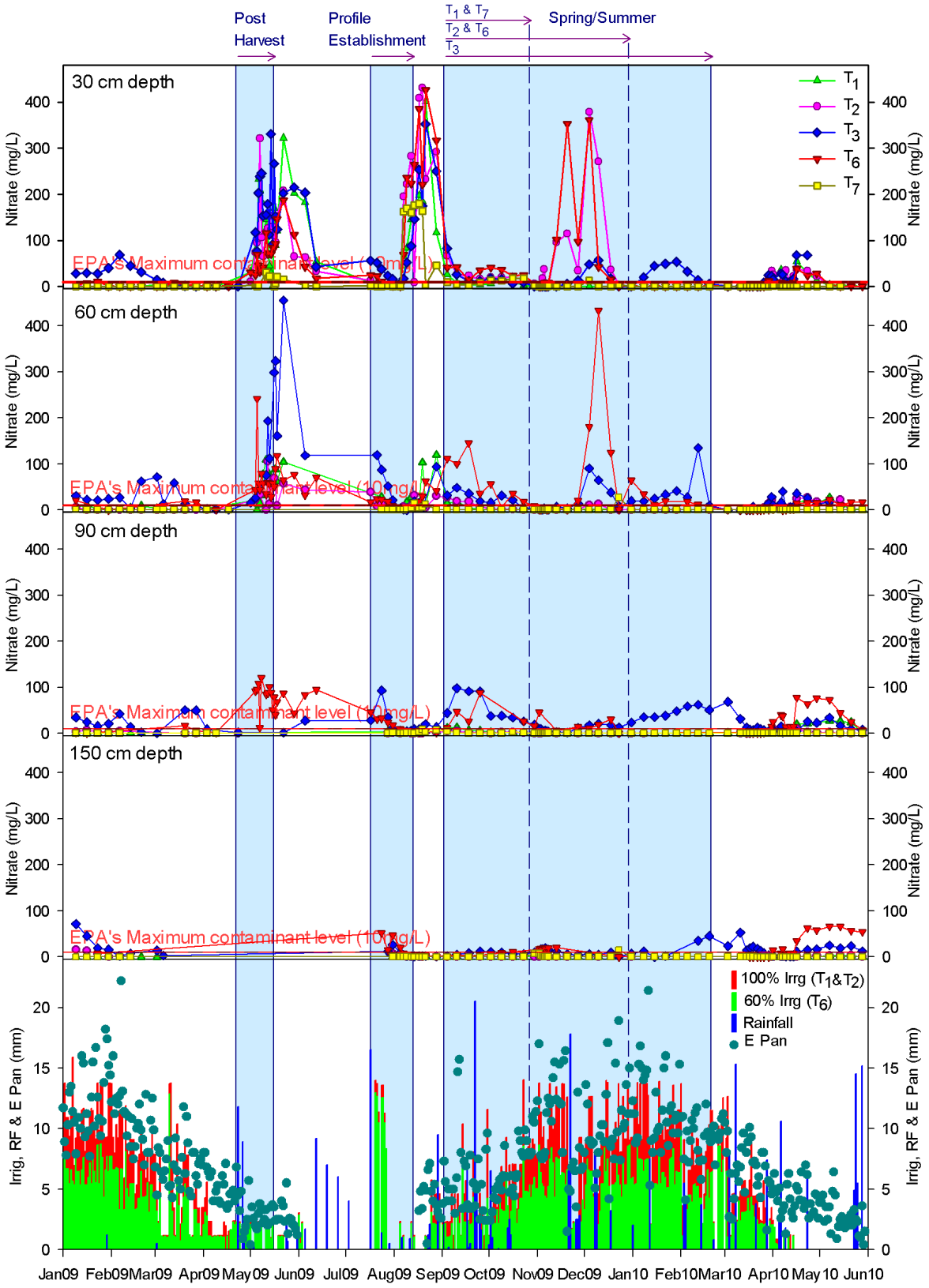

Figure 21: Soil solution nitrate from 2009

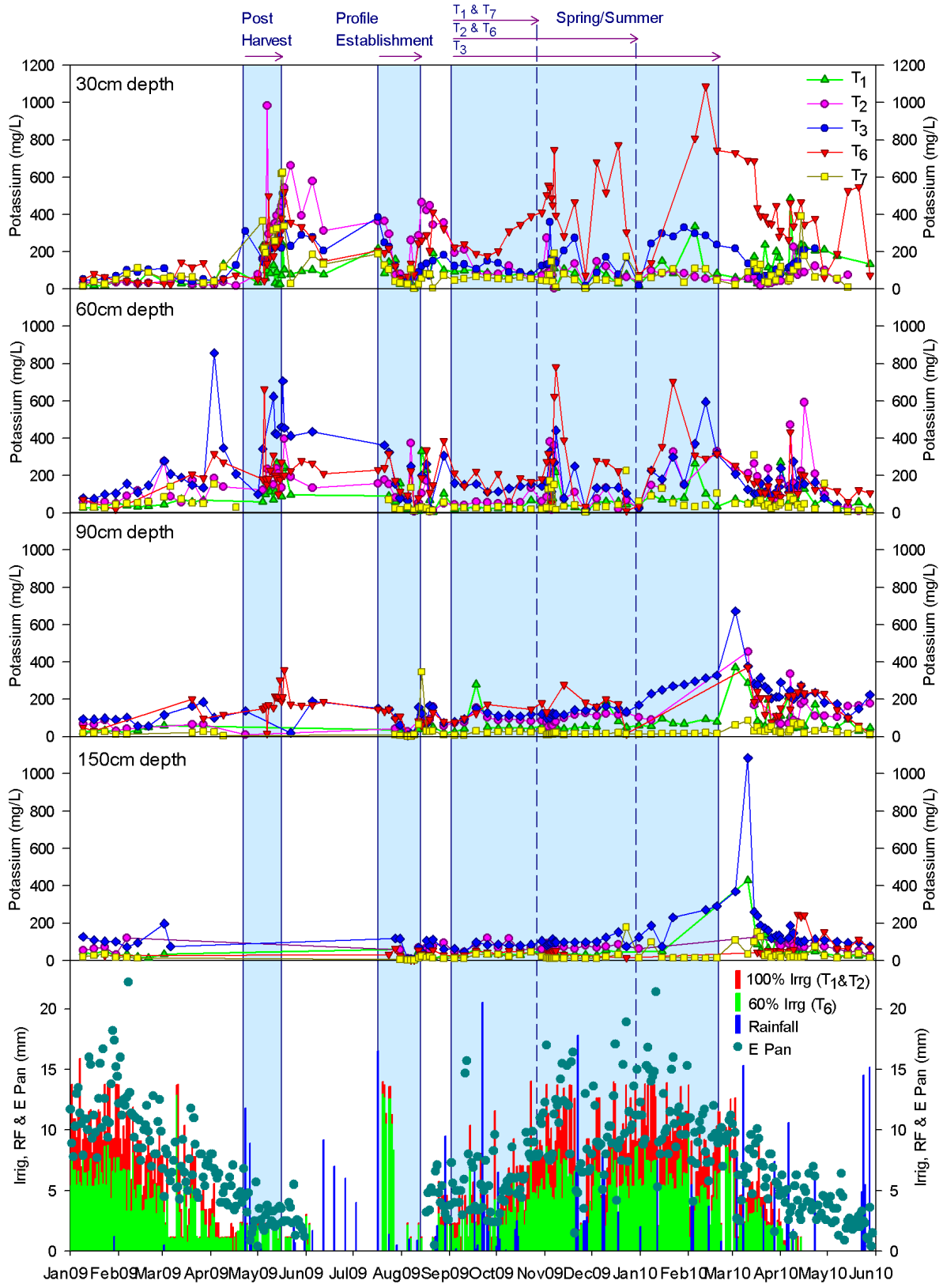

Figure 22: Soil solution potassium from 2009

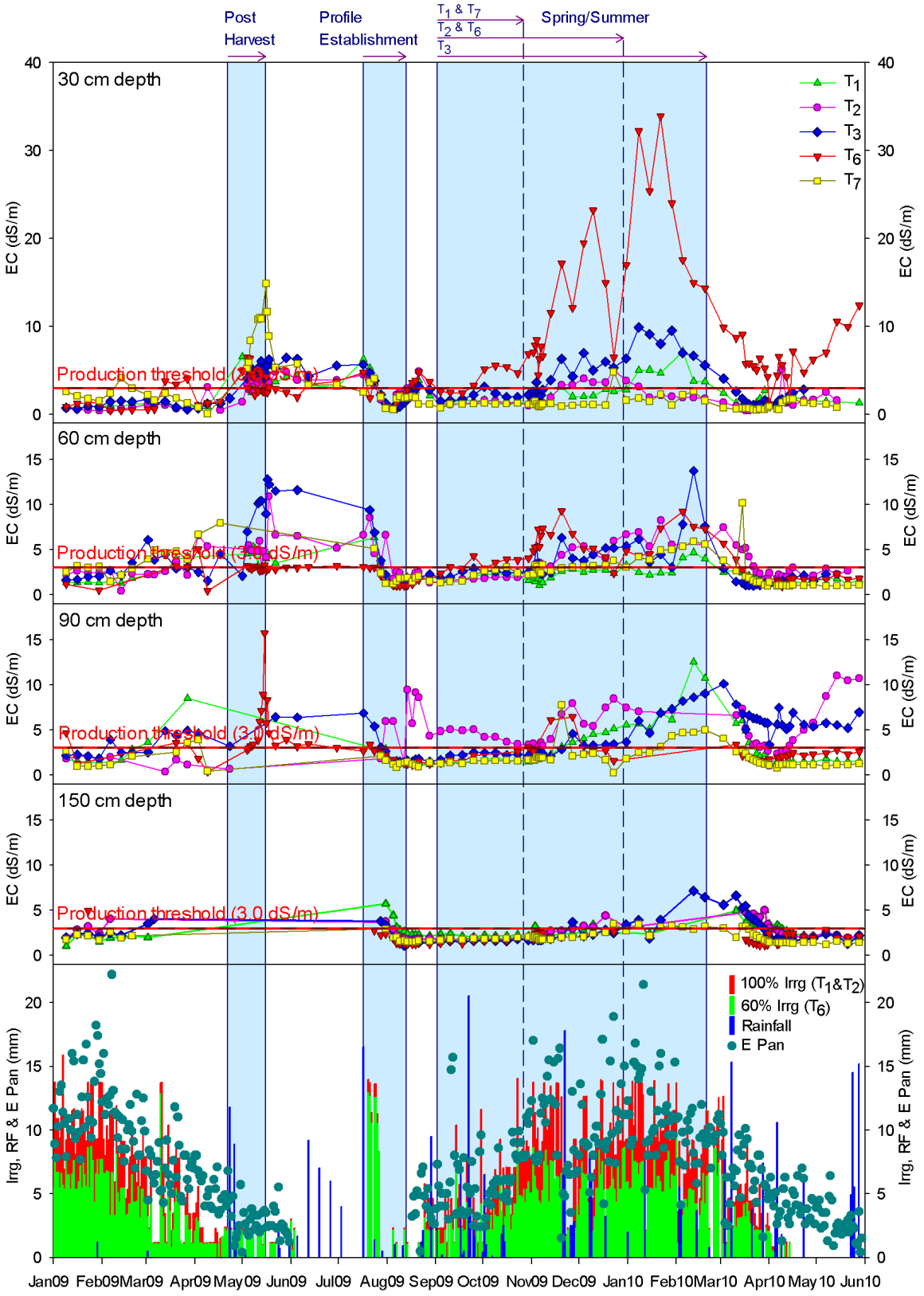

Figure 23: Soil solution electrical conductivity from Jan 2009

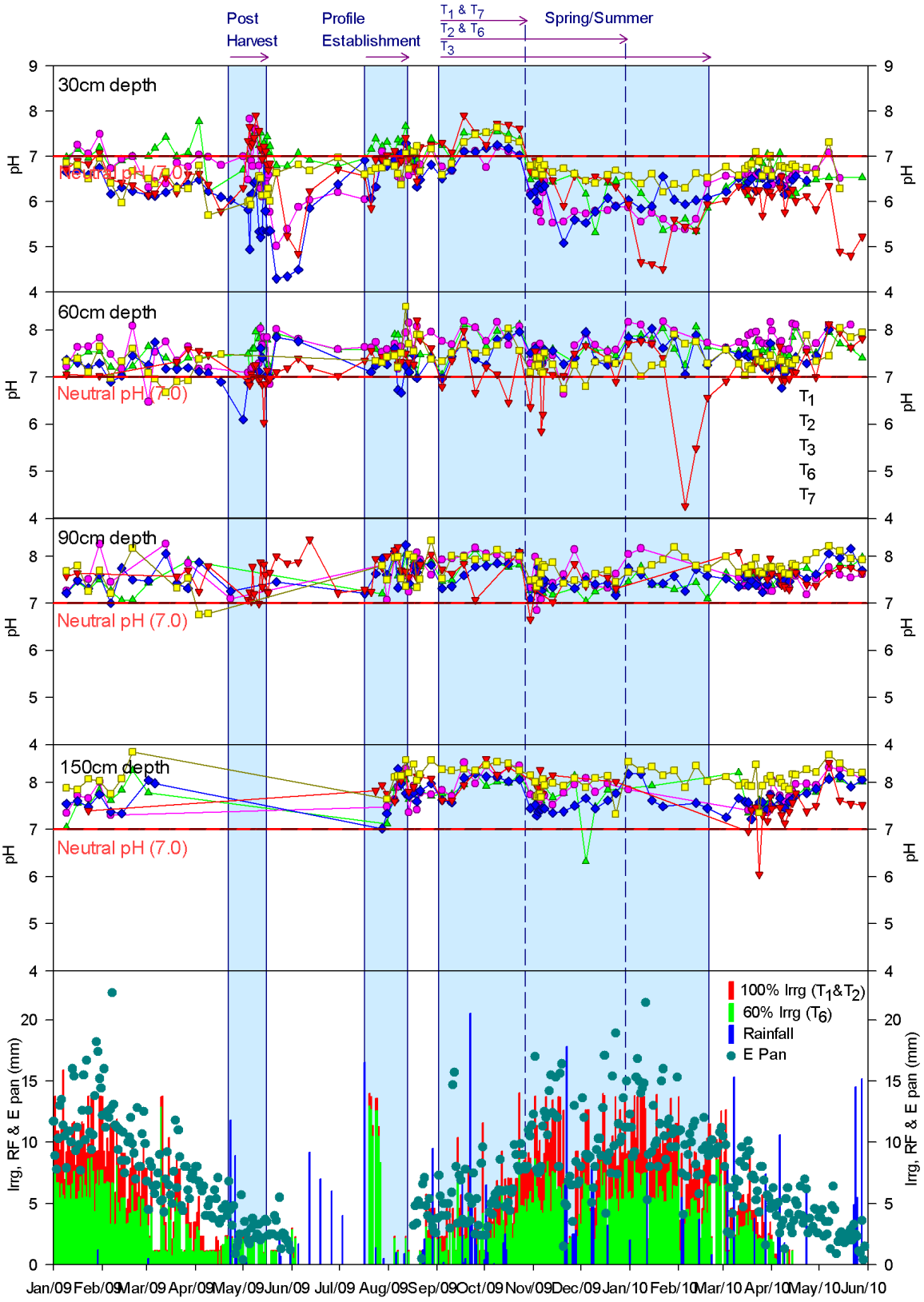

Figure 24: Soil solution pH from Jan 2009

5.3.3 Foliar Data

Table 7 illustrates the comprehensive foliar nutrient program undertaken at the Trial. The program was the same for T1-6 with each spray designed to ensure non-limiting supplies of macro and micro nutrients, in particular zinc. There were some minor variations in the number and timing of sprays applied in each season; Table 7 provides an example of a typical spray schedule used in 2008/09.

All treatments received the same nutrient spray program and nutrient sprays were neither combined with those of pesticides nor fungicides.

Table 7: Foliar nutrient summary for Treatments 1-6.

Date	Variety	Tank Mixture	Chemical Rate (/1000L)	Purpose
21 Jul, 2008	Carmel	KNO_3	50	Dormancy breaking
25 Jul, 2008	Nonpareil	KNO_3	30	Dormancy breaking
1 Aug, 2008	Carmel	KNO_3	30	Dormancy breaking
14 Aug, 2008	All	Boric Acid	0.1	Pollination/fruit set
18 Aug, 2008	All	Boric Acid	0.1	Pollination/fruit set
22 Sep, 2008	All	NZn, KNO_3, lo-bi Urea	1.5, 2.5, 2.5	Leaf size/shoot extension
26 Sep, 2008	All	NZn, KNO_3, lo-bi Urea	1.5, 2.5, 2.5	Leaf size/shoot extension
29 Sep, 2008	All	NZn, KNO_3	1.5, 2.5	Leaf size/shoot extension
3 Oct, 2008	All	NZn, KNO_3, lo-bi Urea	1.5, 2.5, 2.5	Leaf size/shoot extension
7 Oct, 2008	All	NZn, KNO_3, Solubor	2, 5, 2	Leaf size/shoot extension/fruit set
10 Oct, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
13 Oct, 2008	All	NZn, KNO_3, Solubor	2, 5, 2	Leaf size/shoot extension/fruit set
17 Oct, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
20 Oct, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
24 Oct, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
27 Oct, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
31 Oct, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
3 Nov, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
7 Nov, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
10 Nov, 2008	All	NZn, KNO_3	2, 5	Leaf size/shoot extension
27 Apr, 2009	All	lo-bi Urea	10	Bud building
1 May, 2009	All	lo-bi Urea	10	Bud building
4 May, 2009	All	lo-bi Urea	10	Bud building
8 May, 2009	All	lo-bi Urea	10	Bud building
2 Jun, 2009	All	Urea (1.5% biuret)	70	Defoliation

Table 8: Mean nutrient concentrations within almond leaf tissue.

Sampling Period /Treatment No.		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	B (mg/kg)	S (%)
Oct	**1**	4.10	0.21	3.14	1.57	0.42	0.07	0.27	265.95	150.27	83.35	8.98	52.43	0.22
	2	4.04	0.20	3.11	1.40	0.39	0.08	0.43	266.23	165.83	87.73	7.26	49.22	0.23
	3	4.03	0.20	3.31	1.42	0.37	0.07	0.33	286.21	225.64	85.33	7.12	52.41	0.24
	7	3.14	0.22	2.50	2.46	0.63	0.05	0.23	81.78	144.00	68.86	8.58	37.66	0.09
Nov	**1**	3.51	0.17	2.88	1.91	0.45	0.07	0.29	398.05	164.11	85.98	6.16	40.05	0.20
	2	3.50	0.15	2.64	1.74	0.35	0.08	0.41	325.71	153.85	88.92	5.66	39.76	0.20
	3	3.64	0.17	2.93	1.72	0.39	0.07	0.32	370.88	209.54	83.31	5.69	38.66	0.21
	7	2.92	0.18	2.07	2.93	0.66	0.04	0.28	100.01	152.99	83.45	4.24	34.68	0.18
Dec	**1**	2.92	0.14	3.37	2.63	0.50	0.08	0.45	407.12	136.40	103.27	5.81	42.30	0.18
	2	3.17	0.14	3.27	2.24	0.43	0.08	0.57	413.84	162.10	107.30	5.03	40.50	0.19
	3	3.13	0.14	3.49	2.29	0.39	0.08	0.45	416.41	217.23	104.33	5.44	40.70	0.20
	7	2.48	0.14	2.40	3.63	0.77	0.05	0.35	161.03	168.43	77.57	4.73	36.30	0.16
Jan	**1**	2.94	0.14	2.71	2.58	0.49	0.07	0.33	323.43	154.54	84.74	5.77	40.56	0.16
	2	3.04	0.14	2.81	2.26	0.43	0.07	0.49	346.96	171.11	92.78	5.53	39.95	0.17
	3	3.16	0.14	2.83	2.26	0.41	0.06	0.36	327.16	188.09	91.34	5.11	38.87	0.18
	7	2.33	0.14	1.88	3.49	0.72	0.04	0.36	79.94	143.84	88.60	4.93	36.40	0.15
Aust/USA January Standard		2.5	>0.1	1.7	>2	>0.25	<0.25	<0.3	30	>20	ND	>4	25-65	ND

Results of the leaf tissue analysis indicated there was very little difference between T1, 2 and 3, despite the different application rates in nitrogen and potassium. In comparison to T7; T1-3 were all consistently higher in nitrogen, potassium and zinc, but lower in calcium and magnesium.

The content of nitrogen, phosphorus and potassium across all treatments decreased from October to January as the leaves matured but that of calcium and magnesium increased.

The data also indicated nitrogen, potassium and zinc levels were well above the conventional Australian and USA standards. The high rates of potassium and zinc may be partly attributed to surface contamination of the leaves following the comprehensive foliar program of potassium nitrate and NZn. Whilst the leaves were acid washed prior to analysis, research into leaf sampling and surface contamination indicates acid washing or other cleaning methods are not totally effective. The high potassium levels could further be attributed to the increased applications of potassium in the fertiliser program, particularly in comparison to historical potassium rates of 87kg/ha in T7.

5.3.4 Fruit Data

Analysis of the dry weight nutrient values of whole almond fruit at harvest (Table 9) indicated potassium had the highest content, followed by nitrogen, phosphorus, calcium and magnesium, across all treatments. In comparison to T1 and 2, T3 generally had a higher content of all elements, particularly nitrogen and potassium and was probably caused by the higher application rates of nitrogen and potassium; however, the content was not directly proportional, indicating the limit of nutrient uptake may have been exceeded.

With respect to nitrogen, the data indicated T7 was considerably lower (approximately 40%) in nitrogen concentration. This suggested that an increase in nitrogen rate from 180 kg/ha to 240 kg/ha corresponded to an increased nitrogen concentration within almond fruit, while the increase in the nitrogen rate from 240 kg/ha to 480 kg/ha resulted in a minimal increase in nitrogen content. Yield followed a similar trend, it was greater in T1-3 in comparison to T7, but no significant difference was seen between T1, 2 and 3 (Figure 25 and Figure 26).

Potassium, content of fruit from T7 was approximately 15% lower than that of other treatments. This suggested that a rate increase from 87 kg/ha to 400 kg/ha resulted in a small increase in potassium content of fruit, while a rate increase from 400 kg/ha to 800 kg/ha resulted in a minimal rise in fruit potassium content. Yield performance followed a similar trend, it was greater in T1-3 than in T7, but no significant difference in yield was apparent between T1, 2 and 3 (Figure 25 and Figure 26). Approximately 20-25% more potassium was removed from T1-3 in comparison to nitrogen and approximately 50% more potassium in T7.

Table 9: Mean (2008-2010) dry weight nutrient concentrations of whole almond fruit sampled at harvest.

Treatment No.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Cu (mg/kg)	B (mg/kg)	S (%)
1	2.13	0.22	2.67	0.20	0.15	0.02	0.11	65.16	19.71	103.58	5.56	77.33	0.08
2	2.19	0.21	2.64	0.17	0.14	0.02	0.15	55.93	20.33	107.44	4.57	62.20	0.07
3	2.37	0.23	2.92	0.18	0.15	0.02	0.13	87.77	28.25	140.00	5.25	82.11	0.08
7	1.52	0.26	2.34	0.20	0.14	0.02	0.10	27.78	16.93	101.38	4.80	59.01	0.06

Higher nutrient concentrations in the leaves (Table 8) and fruit (Table 9), combined with higher yields (Figure 25 and Figure 26) resulted in considerably larger nitrogen and potassium removal (Table 10) from T1-3 in comparison to T7, but there was minimal difference between T1-3. This would suggest the positive plant response was mostly due to a rate increase from 180 to 240 kg/ha for nitrogen and from 87 to 400kg of potassium but a further rise in either nitrogen or potassium did not translate in a corresponding yield gain.

The data also indicated yield was the main factor in determining the quantity of nutrient removal, rather than the elemental concentrations within the tree.

Table 10: Mean (2007/08-2009/10) nutrient export quantities (kg/ha) at harvest of whole almond fruit.

Treatment No.	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	Fe	Cu	B	S
1	268.81	29.38	338.09	27.04	19.06	2.86	16.46	0.75	0.26	1.44	0.07	0.95	9.94
2	285.61	28.00	345.23	22.40	18.48	2.60	21.41	0.68	0.27	1.54	0.06	0.79	9.69
3	291.42	28.77	359.60	23.65	19.09	2.83	18.49	0.95	0.34	1.82	0.06	0.94	10.03
7*	155.39	25.41	232.16	20.80	13.97	1.76	11.59	0.28	0.17	1.10	0.05	0.57	5.60

*From 2008/09, T7 was modified from irregular watering and 180:87 to consider more current best practice, i.e. T1 and 100% Etc, 240:400

When assessing the nutrient use efficiency of the two major elements nitrogen and potassium (Table 11), T1 was the most and T3 was the least efficient. However, an application rate of 240 kg/ha of nitrogen in T1 is unlikely to be sustainable in the long term because approximately 12% more nitrogen was removed with the fruit than was applied as fertiliser.

The data indicates T2 represents an optimal nitrogen application rate (320 kg/ha), and an optimal application for potassium is that of T1 (400 kg/ha). The combined rates would also more closely match the nitrogen to potassium ratio of approximately 1.00 : 1.20.

Table 11: Mean (2007/08-2009/10) nitrogen and potassium use efficiency using nutrient export quantities (kg/ha) of harvested whole almond fruit.

	Nitrogen			Potassium		
Treatment No.	**Applied**	**Exported**	**Efficiency**	**Applied**	**Exported**	**Efficiency**
1	240	269	112%	400	338	85%
2	320	286	89%	600	345	58%
3	400	291	73%	800	360	45%
7*	220	155	70%	296	232	78%

*From 2008/09, T7 was modified from irregular watering and 180:87 to consider more current best practice, i.e. T1 (100% Etc, 240:400)

5.3.5 Yield Response to Nutrition

Yield increased from 2002 (3 year old, first harvest) to 2005 (6 year old, fourth harvest) as the trees became mature, thereafter the yield tended to plateau with variations more likely attributable to seasonal differences.

No significant difference in Nonpareil (Figure 25) or Carmel (Figure 26) yield were apparent between nutrition T1, 2 and 3, indicating that when mean annual applications totalled approximately 18 ML/ha of water, 240 kg/ha of nitrogen and 400 kg/ha of potassium were adequate to achieve a high yield. Whether 240 kg/ha of nitrogen and 400 kg/ha of potassium would be adequate when annual water applications totalled less than 18 ML/ha could not be assessed because it was not included as an experimental treatment. There was however, approximately a 60% increase in yield between T1 - 3 in comparison to T7.

The data also indicated Carmel yield was more consistent between seasons and marginally higher from one season to the next, in comparison to Nonpareil.

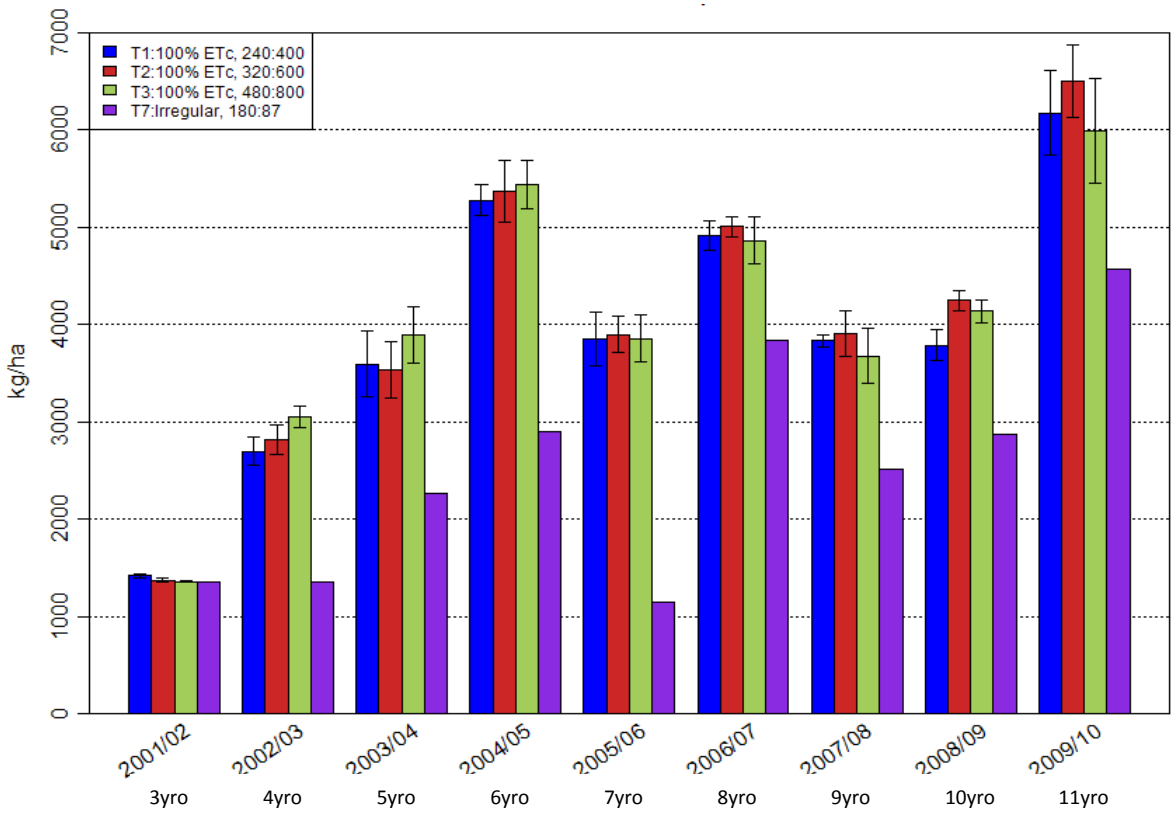

Figure 25: Nutrition treatment effects on Nonpareil yield.

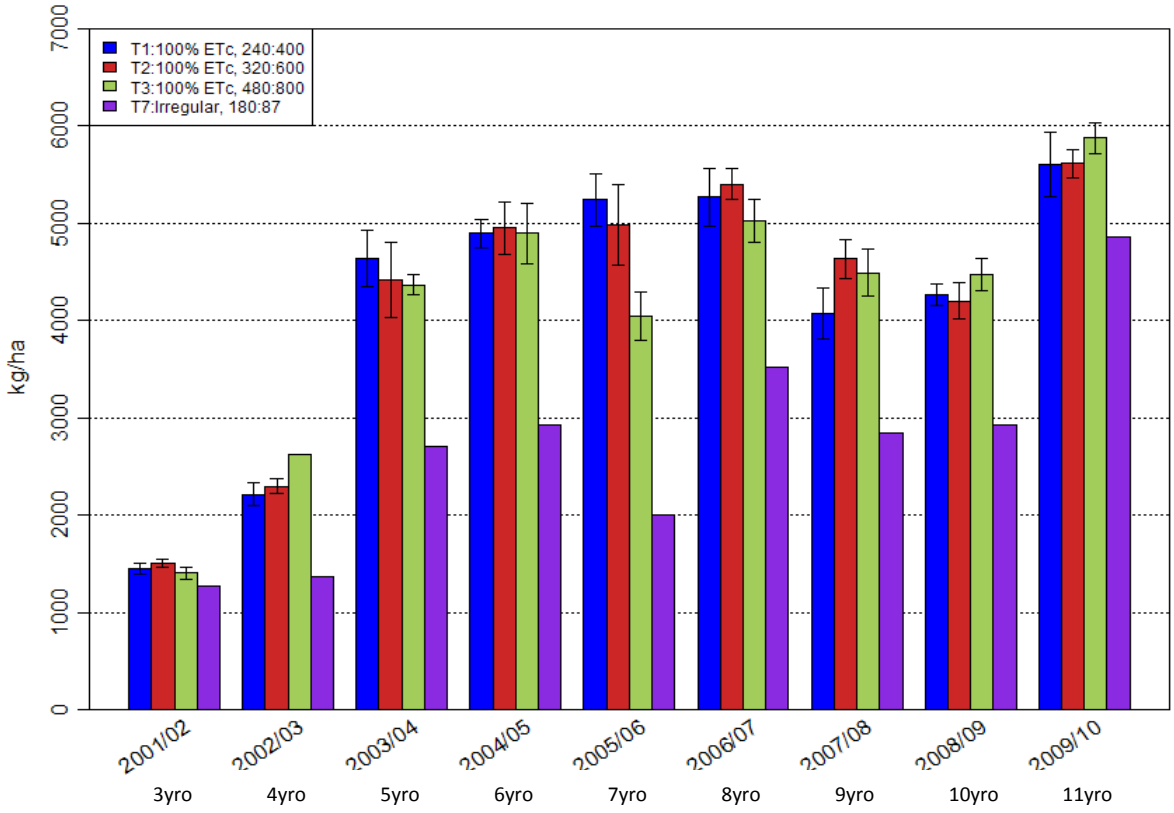

Figure 26: Nutrition treatment effects on Carmel yield.

The bars shown are 2 x standard errors (1 up, 1 down). Statistical significance exists between treatments where the means differ by three standard errors.

5.4 Varietal Characteristics

5.4.1 Yield

Carmel (Table 13) yield, for the most part was marginally higher and more consistent between seasons in comparison to Nonpareil (Table 12). The only exception was T6 (40% less water) with marginally lower Carmel yield.

Carmel also tended to achieve a marginally higher crackout % and fruit numbers per tree, but had lower kernel weights than Nonpareil.

Table 12: Mean yield data of Nonpareil.

Treatment No.	Yield (kg/ha)	Yield (kg/tree)	Fruit No. /Tree	Kernel Weight (g)	Kernel Crackout (%)
1	3,947[a]	16.11	11,590	1.39	31.07
2	3,998[a]	16.59	11,935	1.39	31.24
3	4,027[a]	16.44	11,743	1.40	31.36
4	3,896[a]	14.92	10,657	1.40	31.45
5	3,986[a]	15.08	10,771	1.40	31.61
6	3,690[a]	15.06	11,074	1.36	30.08
7	2,533	10.34	7,893	1.31	28.00

Significant differences exist where initials differ.

Table 13: Mean yield data of Carmel.

Treatment No.	Yield (kg/ha)	Yield (kg/tree)	Fruit No. /Tree	Kernel Weight (g)	Kernel Crackout (%)
1	4,180[a]	17.29	12,903	1.34	33.10
2	4,270[a]	17.45	13,022	1.34	33.35
3	4,130[a]	17.09	12,754	1.34	32.80
4	4,093[a]	16.22	12,015	1.35	32.18
5	4,118[a]	15.85	11,569	1.37	32.42
6	3,597[a]	14.16	10,892	1.30	32.51
7	2,711	11.06	8,641	1.28	30.89

Significant differences exist where initials differ.

5.4.2 Trunk Growth

Yield efficiency assessed as total yield (kg/tree) per gain in trunk cross sectional area (cm^2) is represented in Figure 27. The data indicates T6 (60% Etc) was the most efficient, producing approximately 0.32 kg/cm^2 and 0.39 kg/cm^2 in Nonpareil and Carmel, respectively. Differences in nutrient applications (i.e. T1-3) did not correspond to gains in yield efficiency. However, there was a gain in yield efficiency corresponding to decreasing water applications. This indicated more water produced a larger tree (Figure 28) but that did not equate to a proportionally larger yield. In fact, a 40% increase in water applications between T6 and T2 only equated to a significantly greater yield in three out of nine seasons and five out of nine seasons for Nonpareil and Carmel, respectively (Figure 12 and Figure 13). Cumulative yield differences between 60% Etc and 100% Etc indicated there was no significance yield difference across the duration of the Trial. In addition, visual observations of fruiting density indicated T6 was more productive per square meter of canopy. It was therefore thought there was an optimum figure of light interception which promoted bud numbers and bud health, but once the light interception threshold was exceeded, bud health deteriorated and canopy

productivity declined. Figure 29 illustrates the differences of light interception between T2 (100% Etc) and T6 (60% Etc). In addition, Carmel was more efficient than Nonpareil across all treatments and likely to be related to Carmel's more compact growth habit.

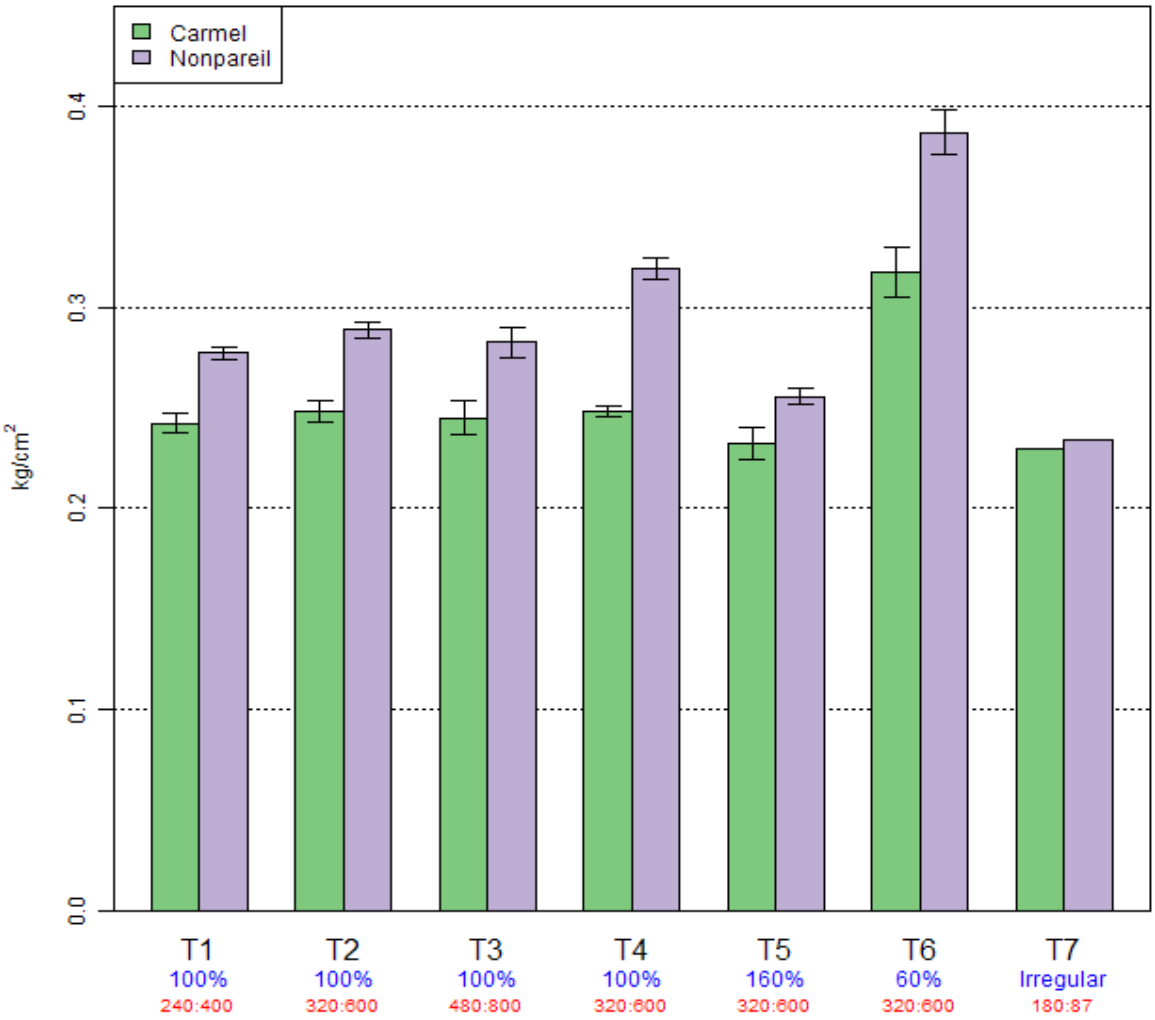

Figure 27: Nonpareil and Carmel yield per gain in tree trunk cross sectional area (kg/cm^2) from 2002-2010.

The bars shown are 2 x standard errors (1 up, 1 down). Statistical significance exists between treatments where the means differ by three standard errors.

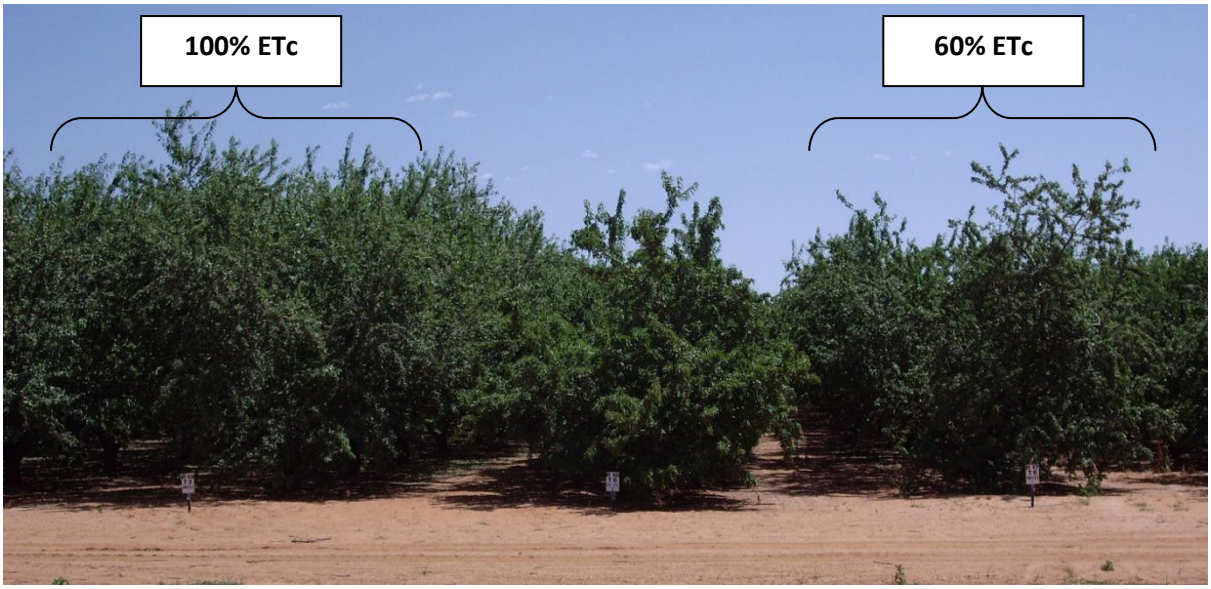

Figure 28: Nonpareil canopy size of T2 (100% Etc) versus T6 (60% Etc)

Figure 29: Light interception of 100% Etc (a) versus 60% Etc (b)

5.5 Canopy Management

Canopy management, pruning and tree architecture were investigated; however, the same management program occurred across all treatments. The canopy management program comprised two steps: 1) young tree training, and 2) mature canopy management.

5.5.1 Young Tree Training

Trees were first trained at the age of four years at the beginning of 2002. The aim was to create a "Y" shape and thereby optimise the surface area and hence light interception and fruiting potential of previously vertical, vegetative limbs. The "Y" shape was achieved by tying down limbs using tree tape and stakes (Figure 30).

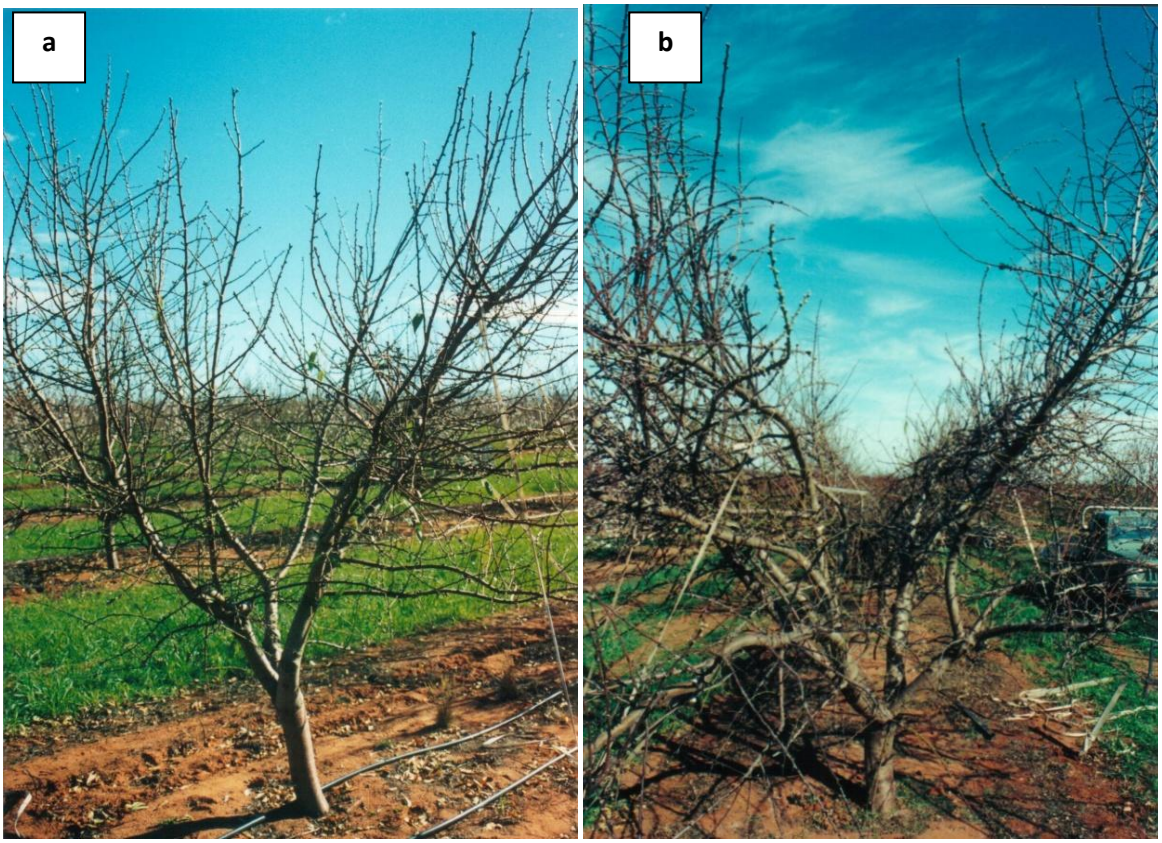

Figure 30: Young almond tree before (a) and after (b) training.

5.5.2 Mature Canopy Management

Aims of the mature canopy management program were to develop a tree structure capable of minimising fungal inoculums, optimising light interception, promoting air flow and supporting the long term sustainability of the significantly increased yields achieved in the Trial.

The pruning process involved the following steps:

1. Prune and remove all dead wood from the tree. The dead wood was commonly a result of excessive shading or hull rot infections.
2. Remove water shoots and vertically dominant limbs from the centre of the tree to create a "Y" shape.
3. Remove cross over limbs and/or limbs resulting in dense, shaded, fruiting walls.
4. Obtain a one metre wide gap, free of wood between tree rows.

The mature canopy management program was conducted as required after evaluating the orchard each winter. The most comprehensive pruning program involving all four steps was undertaken in winter 2007 (Figure 31).

Following the 2007 pruning, there were two noticeable effects: 1) a decrease in 2007/08 yield, particularly in T6 (60% Etc), and 2) the re-generation and health of the lower canopy was considerably enhanced (Figure 32) leading to increased productivity and fruiting throughout the canopy, not just at the canopy top. T6 (60% Etc) was pruned less severely than the other 100% water treatments, but may have resulted in proportionally greater wood removal due to the comparatively smaller canopy. Nonpareil and Carmel seasonal yield results (Figure 12, Figure 13, Figure 25 and Figure 26) show that it took approximately two seasons for the yield to recover following the June 2007 pruning.

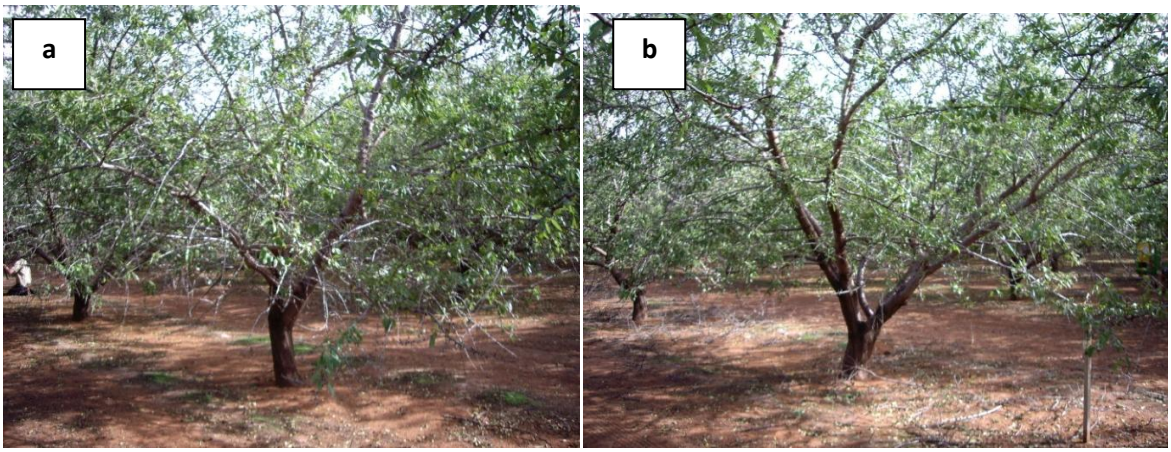

Figure 31: Mature T6 (60 Etc), Nonpareil tree before (a) and after (b) pruning.

Figure 32: Spring vegetative growth of lower canopy following pruning.

Figure 33: Nemaguard root system development.

6 Discussion

The Sustainable Optimisation of Australian Almond Production trial has produced a number of very beneficial results that have gone a long way to achieving its aims:

- Assess the effectiveness of water and nutrient programs for seven experimental treatments.
- Determine the consumptive use of water and nutrients by almonds.
- Determine the optimal rate of water and nutrient uptake of almonds.
- Investigate the possibilities of saving water and increasing yield efficiency.
- Double the commercial yields of almond orchards and their profitability.

Assess the effectiveness of water and nutrient programs for seven experimental treatments

The Trial was a complex trial, incorporating both water and nutrient treatments in the same design. Results from the watering treatments proved to be most insightful.

The main aims of the trial were to double the commercial yield but also to determine the optimal rate of orchard water and nutrient use. Water and fertiliser were considered the main determinants of production and therefore should be the main factors in the experimental design. Three levels for each factor were included in the experiment but it fell short of combining these in a complete

factorial design where every watering level is combined with every fertiliser level. The shortcoming was due to a lack of funds and sufficient third party orchard area. In hindsight it would have been interesting to also include an additional water level at below the 60% Etc and the 240:400 nutrient rate. This is particularly true given the increased scarcity and expense of water and fertiliser that evolved following the inception of the Trial and the wish of the industry to become more environmentally sustainable. It would also have been interesting to evaluate all possible interactions between nutrient and watering levels. Nevertheless, the Trial succeeded in many areas, both in its original aims and particularly with regard to some of the incidental benefits which were implicit within the Trial.

For example, one of the main benefits to come out the Trial, aside from the experimental results, was a much better understanding of the skills required for the successful management of drip irrigated almond orchards on coarse textured soils low in water and nutrient storage and dominated by a climate with very high evaporation rates during a large part of the growth period. Following the rapid expansion that was occurring in parallel to the Trial, the Australian almond industry is now largely (94%) located within the southern Murray Darling Basin, a dry inland environment with evaporation rates well in excess of 2,000mm. 90% of all commercial orchards are now irrigated with drip irrigation, and are planted on coarse textured soils. Many of these conditions are in complete contrast to those found in California or Spain, traditionally the major sources of R&D and technology advances. It was therefore important for the local almond industry to establish the Trial and set up its own research base suitable for the soil and climatic conditions specific to irrigated inland Australia.

Another benefit of the Trial was the recognition of the importance of a systematic foliar nutrient program. Historically, most Australian almond orchards included the key nutrients that were used in the Trial in their foliar nutrient programs, but most were somewhat ad hoc with regard to nutrient composition, date and rate of application. Zinc for example was recognised as an important nutrient but because of a concern regarding the phytotoxicity of existing formulations insufficient zinc was applied, particularly in spring. Instead, zinc sulphate was routinely applied in autumn mainly with the aim to defoliate trees but also to provide them with supplementary zinc. Potassium wasn't given a high priority as a nutrient and consequently it was infrequently applied. Boron was known to be important but was not routinely applied, particularly throughout the bloom period when the plant requires it most.

It was beyond the scope of the Trial to assess the many possible combinations of different nutrient programs but the benefits of the regular and systematic use of NZn, potassium nitrate, boric acid and urea were observed, documented and immediately communicated to industry.

Given the unique physical environment of the Australian almond industry and with 75% of young orchards still to reach full maturity, the incidental benefits of the Trial have been invaluable.

Determine the consumptive use of water and nutrients by almonds

and,

Determine the optimal rate of water and nutrient uptake of almonds

Determining the consumptive use of water and nutrients would allow the determination of the optimal rate of water and nutrients.

Water

The watering treatments gave an important insight into the yield response of a modern almond orchard in an environment that is typical for much of the Australian industry.

The high watering level (160% Etc, 2,764mm) did not convey any additional yield benefit over the medium level (100% Etc, 1,814mm) and was therefore discontinued following the 2006/07 season. In fact four of the six seasons recorded a lower yield in the high relative to the medium level. The medium level 100% Etc (1,814mm) in three of nine seasons achieved a significant yield benefit over the low level 60% Etc (1,132mm) in three of nine seasons, but no significant benefit was achieved in consecutive seasons. One of those seasons followed a considerable winter prune when probably a greater proportion of viable wood was removed in 60% Etc compared to the 100% Etc. The observed yield benefit therefore was inconsistent and 60% Etc was considered too little water and 100% Etc was considered too much water. A model was devised that related yield to water applications and thus was able to determine the watering level with the greatest optimum economic return. The variables are listed in Equation 1 and include, w as the optimum amount of water (ML/ha), C_w is the value of water ($/ML), C_k is the value of kernels ($/kg), k is a shape parameter, m is the maximum potential yield, and w_o is an estimate of the amount of water required to keep the trees alive without any commercial yield (3 ML/ha). This model did not estimate profitability as no account was taken of other growing costs. The model was rather an assessment of diminishing returns and whether an investment in leased water was going to produce a 100% return in yield (kg) and therefore return ($/kg).

$$w = \frac{ln\left(\frac{C_w}{C_k k m}\right)}{k} + w_0$$

Equation 1: Optimum amount of water (ML/ha).

The results of the model using Equation 1 for Nonpareil and Carmel are provided in Table 14 and Table 15, respectively. This model was released in December 2008 and consequently in 2007/08 when River Murray high security water licences were under severe water restrictions with seasonal allocations ranging from 25% to 43%, it was a very useful tool for growers to make an informed decision about leased water purchases. For example, the average leased water purchase in 2007/08 was approximately $545/ML (Waterfind "Australia's National Waterbroker"), which according to Table 14, suggested almond orchards could potentially justify 12.6ML/ha of leased water assuming $5.00/kg kernel value following the completion of harvest.

Regardless of whether leased water purchases and water restrictions are an ongoing feature of almond orchards, a value still needs to be attached to water and a return on investment is necessary. If the average value of water purchased in 2007/08 (i.e. $545/ML) is used in conjunction with the kernel value assumed by Pocock, 2007 (i.e. $5.70/kg), the results of the Nonpareil model indicate the most appropriate water application is approximately 13 ML/ha (or 72% of Assaf *et al* Etc). In fact, there were very few scenarios where the equivalent of 100% Etc (1,814mm) could be justified with the majority of the results indicating <15 ML/ha (or <83% Etc).

The mean daily and weekly crop factors for 72% Etc are illustrated in Figure 34 and Table 16, respectively.

Table 14: Optimal water use (ML/ha) for different kernel ($/kg) and water values ($/ML) for Nonpareil.

	Water Cost or Value ($/ML)									
Kernel Value ($/kg)	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**800**	**1000**	**1500**
2.50	12.3	11.6	11.1	10.6	10.1	9.7	9.4	8.2	7.2	5.6
3.00	13.0	12.4	11.8	11.3	10.9	10.5	10.1	8.9	8.0	6.3
3.50	13.7	13.0	12.5	12.0	11.5	11.1	10.8	9.6	8.7	7.0
4.00	14.2	13.6	13.0	12.5	12.1	11.7	11.3	10.1	9.2	7.5
4.50	14.7	14.1	13.5	13.0	12.6	12.2	11.8	10.6	9.7	8.0
5.00	15.2	14.5	14.0	13.5	13.0	12.6	12.3	11.1	10.1	8.4
5.50	15.5	14.9	14.4	13.9	13.4	13.0	12.7	11.5	10.5	8.8
6.00	15.9	15.3	14.7	14.2	13.8	13.4	13.0	11.8	10.9	9.2
6.50	16.2	15.6	15.0	14.6	14.1	13.7	13.4	12.2	11.2	9.5
7.00	16.6	15.9	15.4	14.9	14.4	14.0	13.7	12.5	11.5	9.8
7.50	16.8	16.2	15.6	15.2	14.7	14.3	14.0	12.8	11.8	10.1
8.00	17.1	16.5	15.9	15.4	15.0	14.6	14.2	13.0	12.1	10.4
8.50	17.4	16.7	16.2	15.7	15.2	14.8	14.5	13.3	12.3	10.7
9.00	17.6	17.0	16.4	15.9	15.5	15.1	14.7	13.5	12.6	10.9
9.50	17.8	17.2	16.6	16.1	15.7	15.3	14.9	13.7	12.8	11.1
10.00	18.0	17.4	16.8	16.4	15.9	15.5	15.2	14.0	13.0	11.3
10.50	18.2	17.6	17.0	16.6	16.1	15.7	15.4	14.2	13.2	11.5

Table 15: Optimal water use (ML/ha) for different kernel ($/kg) and water values ($/ML) for Carmel.

	Water Cost / or Value ($/ML)									
Kernel Value ($/kg)	**300**	**350**	**400**	**450**	**500**	**550**	**600**	**800**	**1000**	**1500**
2.50	13.6	12.8	12.1	11.5	11.0	10.5	10.1	8.6	7.5	5.5
3.00	14.5	13.7	13.0	12.4	11.9	11.4	11.0	9.5	8.4	6.4
3.50	15.3	14.5	13.8	13.2	12.7	12.2	11.8	10.3	9.2	7.1
4.00	15.9	15.2	14.5	13.9	13.4	12.9	12.4	11.0	9.9	7.8
4.50	16.5	15.8	15.1	14.5	14.0	13.5	13.0	11.6	10.5	8.4
5.00	17.1	16.3	15.6	15.0	14.5	14.0	13.6	12.1	11.0	8.9
5.50	17.5	16.8	16.1	15.5	15.0	14.5	14.0	12.6	11.5	9.4
6.00	18.0	17.2	16.5	15.9	15.4	14.9	14.5	13.0	11.9	9.9
6.50	18.4	17.6	16.9	16.3	15.8	15.3	14.9	13.4	12.3	10.3
7.00	18.8	18.0	17.3	16.7	16.2	15.7	15.3	13.8	12.7	10.6
7.50	19.1	18.3	17.7	17.1	16.5	16.0	15.6	14.2	13.0	11.0
8.00	19.4	18.7	18.0	17.4	16.9	16.4	15.9	14.5	13.4	11.3
8.50	19.7	19.0	18.3	17.7	17.2	16.7	16.2	14.8	13.7	11.6
9.00	20.0	19.2	18.6	18.0	17.4	17.0	16.5	15.1	14.0	11.9
9.50	20.3	19.5	18.8	18.2	17.7	17.2	16.8	15.3	14.2	12.2
10.00	20.6	19.8	19.1	18.5	18.0	17.5	17.1	15.6	14.5	12.4
10.50	20.8	20.0	19.3	18.8	18.2	17.7	17.3	15.9	14.7	12.7

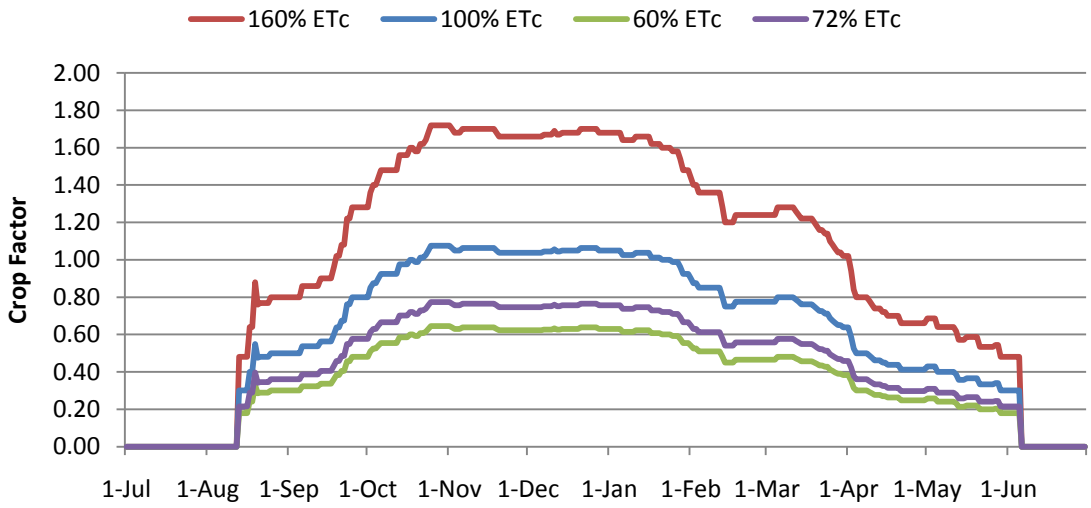

Figure 34: Mean daily crop factors of 72% Etc versus 160% Etc, 100% Etc and 60% Etc.

Table 16: Mean weekly crop factors for 72% Etc* Assaf *et al.*

MONTH	WEEK #	PHENOLOGICAL STAGE #					CROP FACTOR
JUL	1						0.00
	2						0.00
	3	PE					0.00
	4	PE					0.00
	5	PE					0.00
AUG	6		S1a				0.00
	7		S1a				0.24
	8		S1a	S1b			0.35
SEP	9			S1b			0.36
	10			S1b			0.37
	11			S1b			0.39
	12			S1b			0.45
	13			S1b			0.57
	14			S1b			0.62
OCT	15			S1b			0.67
	16			S1b	S2a		0.71
	17				S2a		0.75
	18				S2a		0.77
	19				S2a		0.76
NOV	20				S2a		0.77
	21				S2a		0.75
	22				S2a		0.75
	23				S2a		0.75
DEC	24				S2a		0.75
	25				S2a		0.76
	26				S2a		0.76
	27				S2a		0.76
JAN	28				S2a	S2b	0.74
	29					S2b	0.74
	30					S2b	0.72
	31					S2b	0.67
FEB	32					S2b	0.61
	33					S2b	0.58
	34					S2b	0.56
	35					S2b	0.56
	36					S2b	0.57
MAR	37					S2b	0.56
	38					S2b	0.54
	39					S2b	S3 0.49
	40						S3 0.41
	41						S3 0.35
APR	42						S3 0.32
	43						S3 0.30
	44						S3 0.30
	45						S3 0.29
MAY	46						S3 0.27
	47						S3 0.25
	48						S3 0.23
	49						S3 0.22
JUN	50						0.00
	51						0.00
	52						0.00

*** Warning:**

- These crop factors assume the soil profile begins the season at field capacity and has a readily available water (RAW) figure of approximately 118mm and consequently a profile establishment irrigation of approximately 118mm. The 118mm is applied in July prior to the beginning of the irrigation season. If 118mm is not applied, or a figure less than 118mm is applied, the irrigation program would require adjustment. This adjustment could involve an earlier start to the irrigation season (i.e. earlier than week 7), and/or an increase to the crop factors at the beginning of the irrigation season (e.g. weeks 7-16).
- Water is valued at approx $545/ML/pa.
- Kernel value is valued at approx $5.70/kg.

The significantly greater water use efficiency of 60% Etc further signified it was closest to the most appropriate water application with 0.32kg/cm^2 (Figure 27) and 3.6 kg/mm (Figure 15) achieved.

There are number of reasons why an additional 40% water in T2 (100%) resulted in only a marginal 10% increase in yield relative to T6 (60%).

Firstly, water supply during the early stages of the season (i.e. S1a, S1b and S2a) was critical in achieving optimum yield in the current and the following season. Both, T2 and T6 received similar and sizable irrigation depths of 118 and 109mm respectively for profile establishment in July. In the first eight to ten weeks after flowering this water provided T6 with a very good buffer and reservoir to maximise fruit (pericarp) growth and consequently, the "chamber" in which the kernel would grow and fill in the subsequent stages (Figure 35). That is, the larger the pericarp, the larger the potential for kernel size. Once pit hardening occurred in mid October, the ability to change the potential fruit size, and ultimately kernel size, was lost.

Therefore, one of the most crucial, site specific decisions growers need to take is how much water to apply in July in order to establish a sufficiently high SWC. This required watering depth is largely dependent on the soil type and in particular the topsoil depth and effective rooting depth. Those irrigation valves within orchards with shallow topsoil and root zone will require smaller quantities of water in the profile establishment period in order to minimise drainage beyond the root zone. Irrigation valves with deep topsoil and deep root zones may apply more water. For those orchards applying smaller quantities (<60-80mm) of water at profile establishment, they will have to re-assess their irrigation schedule and crop factors for the August and September period as the original program assumes a depletion of SWC before re-establishment in October. Orchards applying small quantities of water at profile establishment may need to marginally increase their crop factors in order to make up for the shortfall.

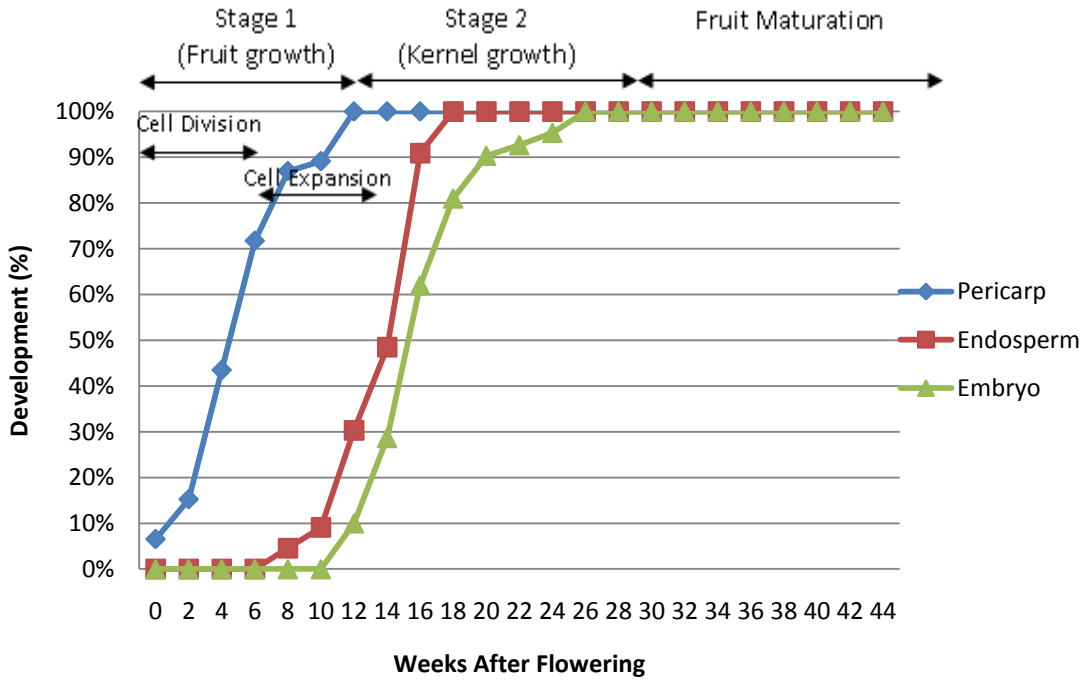

Figure 35: Almond fruit development (adapted from Hawker and Buttrose, 1980).

Secondly, in some cases plant based indicators of water status may complement soil water monitoring in achieving an optimum tree water supply. Stem water potential (SWP) is a plant based indicator, its measurements was introduced to the Trial from October 2009 to February 2010. SWP readings for T6 until the end of December indicated that trees were well watered (<-1.0 MPa) and readings were similar to those of T2 trees despite the fact that neutron probe readings were suggesting a lower and declining SWC from October at 0-30cm and 0-80cm for T6 relative to T2. More research is required to obtain a more thorough understanding of the relations between SWC and SWP.

Thirdly, results from sap flow sensors suggest there may be a plant water use threshold in certain climatic conditions and high watering rates particularly when applied using a daily, surface emitting, drip irrigated system may be result in increased and disproportionate evaporative losses. Sap flow measurements were introduced to the Trial from late December 2009 to early February 2009. The results indicated water applications in both treatments were in excess of plant uptake (i.e. sap flow). In parallel to this, the SWC as measured by the neutron probe was well below field capacity and at some of the lowest values recorded through the 2009/10 season. With approximately a 50% discrepancy between water applied and plant uptake, sap flow is either a poor indicator of water uptake or the losses from the drip system have been under estimated. More research is required to obtain a more thorough understanding of the relations between SWC, sap flow and evaporation from daily, surface emitting, drip irrigation orchards.

Nutrients

The nutrient treatments, 240:400, 320:600 and 480:800 achieved no significant difference in yield throughout the nine seasons with mean yields of 3,947 kg/ha, 3,998 kg/ha and 4,027 kg/ha, respectively. The absence of any statistical significance between the T1-3 was difficult to explain given crop removal calculations suggested a negative balance of approximately 12% between nitrogen applications and nitrogen removals. One possible explanation may have been the build up of nitrogen reserves when trees were still juvenile (3 years) during the establishment phase of the Trial and application rates were in excess of requirement.

Aside from the yield results there also were no clear differences in dry matter accumulation of nutrients in either the fruit or leaf. Soil sampling data indicated a trend of increased nitrate concentrations below 50cm until 2008, and a trend of increasing potassium concentrations below 50cm until 2010. Soil solution sampling indicated plant uptake well matched nutrient applications from September to November but periods of increased nutrient concentrations were seen deeper in the soil following the profile establishment irrigations in July and after post harvest nutrient applications in May.

The impact of potassium nitrate fertigations in July/August following the profile establishment irrigations is unclear and due to its association with relatively large irrigation volumes, needs to be monitored carefully to avoid possible nutrient loss due to drainage of nutrient solution beyond the root zone. Fertigation rates may have to be reduced or reapportioned from September to November. The period of nutrient application following post harvest was generally considered critical to building nutrient reserves for the following season, but uptake is probably more effective if the fertigation is applied earlier when growing conditions are still favourable. It should be noted that all three nutrient treatments received 100% of nominal water requirements and the interaction between lower nutrient applications and lower water applications was not investigated.

The Trial results indicated the plant requirement for nitrogen was greater than 240 kg/ha due to the 112% efficiency obtained from crop removal calculations and thus was approximately 269 to

320kg/ha. Potassium requirement was estimated at approximately 338 to 400 kg/ha. As with the water treatments, the most critical period of nutrient application appears to be from the beginning of the season to end of embryo (i.e. kernel) growth – approximately 18 to 20 weeks following the beginning of flowering.

It is proposed to adopt new critical values for routine leaf tissue analysis and they should be between those values of T1 and T2 for October, November, December and January (Table 8).

Investigate the possibilities of saving water and increasing yield efficiency

If the optimum water figure from the Trial is 13 ML/ha and the industry currently uses between 12.8 and 15.0 ML/Ha (Pocock, 2007 and Ratna and Pollock, 2011), the Trial did not indicate a significant water saving was achievable. The Trial did however; produce considerable improvements in water use efficiency. T6 produced a water use efficiency of 360 kg/ML, where as Pocock (2007) and Ratna and Pollock (2011) indicated the benchmark almond water use efficiency was 213 kg/ML and 240 kg/ML, respectively.

Double the commercial yields of almond orchards and their profitability

Doubling the commercial yields and profitability was not achieved, but considerable improvements were made. Pocock (1999 and 2007) assessed the benchmark almond yield and financial performance indicators of commercial almond orchards and the Trial (Pocock, 2007). A summary is provided in Table 17.

The extension of the Trial results since 2002 coincided with a considerable increase in the industry's benchmark yield, from >2.45 t/ha in 1999 to 3.2 t/ha in 2007 and an increase in gross margin from >$8,000/ha to >$10,000/ha.

Table 17: Primary yield and financial performance indicators of commercial almond orchards and the Sustainable Optimisation of Australian Almond Production trial.

Performance Indicator	1999 Benchmark	2007 Benchmark	T1 (to 2006)	T2 (to 2006)	T6 (to 2006)
Best average 3-year yields	>2.45 t/ha	>3.2 t/ha	4.58 t/ha	4.55 t/ha	3.99 t/ha
Years to first return (0.25 t/ha)	Three	Three	Three	Three	Three
Years to mature return (t/ha)	Six	Six	Four	Four	Four
Gross margin	>$8,000/ha	>$10,000/ha	$11,003/ha	$10,416/ha	$7,812/ha
Cash costs/kg of kernel	<40ha = <$2.20/kg >100ha = <$1.60/kg	<$2.01/kg	$3.28/kg	$3.39/kg	$3.73/kg

7 Technology Transfer

In many instances, R&D is adopted with – "I'll believe when I see it", in mind, and the Sustainable Optimisation of Australian Almond Production trial was an obvious example of this. Technology transfer of the Trial more or less began following the visual observations and success of the first season with easy comparisons made between neighbouring patches of CT Farms and with producers' own orchards in mind. Industry's demand for information about the most relevant water and nutrient programs was very strong, and those that were sceptical waited for further results from subsequent seasons. The Optimisation of Australian Almond Production trial is one of the most significant R&D projects the industry has undertaken.

Formal means of technology transfer included regional demonstration sites minimum of one field day per season at the Trial site, annual almond conference presentations, workshops, articles written for the Australian Nutgrower, regular Fact Sheets, and automated excel spreadsheet providing the actual and up to date Trial fertigation and irrigation protocols and the ability to vary these where appropriate.

The majority of the technology transfer has occurred through industry development projects such as AL05001, AL07008 and AL09021. The most appropriate outputs to include in this report were the Fact Sheets (Appendix 2) and automated excel spreadsheet (Appendix 3) providing the actual and up to date Trial fertigation and irrigation protocols. It should be noted some of the Fact Sheets were published throughout the Trial and will now require revisions following additional season's data.

8 Recommendations

8.1 Scientific

As with many R&D projects, more questions are generated than are solved. The key scientific recommendations of the Trial are:

- As all water and fertiliser treatments were clustered close to, or on the plateau of the yield response curve, there is a need to more accurately research the shape of the curve in response to water and nutrient inputs and to determine the point of inflexion where yield begins to fall strongly.
- Further investigate the nutrient requirements of almond orchards given the absence of significant differences across T1-3.
- Better understand the interaction between different nutrient levels at relatively low water applications (i.e. <75% Etc).
- Understand the importance of concentration based fertigation as compared to area based fertiliser rates. This would provide more relevance to those regions with lower water application rates or those using reclaimed water already rich in various elements.
- Research the validity of irrigation scheduling programs that target specific phenological stages of the tree to maximise water use efficiency. Can we successfully adopt a regulated deficit irrigation (R.D.I) program? A new HAL research project (AL08009 – Deficit Irrigation of Almonds) has commenced to research this and expand on the work completed by Goldhamer *et al*, 2005.
- Assess the quantity of evaporative losses from daily, drip irrigated orchards.
- Explore relationships between soil water monitoring and plant based monitoring.

- Research the effects of efficiency and performance of peach x almond hybrids and other rootstocks with the same or lower inputs of water and fertiliser.
- Research the effects of increased tree densities on improving water and nutrient use efficiencies.
- Research the effects of intensive water and fertiliser management programs on soil acidification around dripper emitters.
- Research the intensive foliar nutrient program implemented by the Trial. For example, does boric acid assist pollination and fruit set or is boron (solubor) better applied post harvest as Californian research suggests, what is the minimum number of NZn sprays required, Etc?
- Combine the critical values from the Trial with a survey of commercial orchards to obtain more up to date critical values for leaf tissue analysis.
- Research pruning regimes to maximise light interception and high yields.
- Research the pest and disease levels within high yielding orchards, particularly the incidence and severity of carob moth and hull rot.

8.2 Industry

Of the management programs researched in the Trial, the key industry recommendations are:

- Daily (or regularly if not practical) apply water and nutrient applications via drip irrigation, matched to phenology and changing climatic conditions.
- Optimum water applications are approximately 72% Etc of Assaf *et al* (Table 16) or approximately 66% of irrigation season Epan readings. This equated to approximately 13 ML/Ha in Berri, South Australia.
- Optimum nitrogen applications are between 240 kg/ha and 320 kg/ha.
- Optimum potassium applications are between 338 to 400 kg/ha of potassium.
- Regular foliar applications of NZn, lo-bi urea and potassium nitrate from fruit set to the end of embryo (kernel) growth.
- Foliar applications of boron to aid fruit set.
- Regular fertigation of micro nutrients.
- If practicing pulsed, daily, drip irrigation, ensure orchard elevations are carefully considered in the irrigation design to avoid leakage in low lying areas and long “fill-up” times for the piping infrastructure.
- If the existing drip irrigation system experiences drainage, avoid multiple irrigation pulses per day. One, daily event may be the most appropriate.
- If implementing the profile establishment irrigations, calculate site specific water quantities based on soil characteristics and winter rainfall. If the water applied does not fill the profile to field capacity then irrigations may need to begin earlier than the Trial schedule as a buffer will not exist. Crop factors may also need adjusting upwards.
- If orchards practice profile establishment irrigations and begin the season with a high SWC, carefully monitor the subsequent water and fertiliser applications during the spring period with the aim to avoid over irrigation that will lead to drainage and nutrient loss.
- When managing high inputs and high yields, regularly sample and analyse soils to assess changes in chemical and physical properties.
- To optimise nutrient uptake of post harvest fertiliser, it should be applied as close to fruit maturity as possible (e.g. March), not when harvest is finished (i.e. April or May). Waiting until harvest is finished commonly results in poor water and fertiliser uptake because trees are partly defoliated and ambient and soil temperatures are below optimal.

A general recommendation to industry following the Trial is when investing in applied research which is expensive and time consuming, ensure an adequate number of experimental treatments are implemented to maximise the results obtained.

9 Acknowledgements

The project team would like to acknowledge the efforts, guidance, critical review, goods and services provided by the many people and organisations involved in AL07005, its preceding projects, and the original research conducted in Israel.

Specifically, a special thanks to the technical officers, the late Phil Watters, John Kennedy and Brett Rosenzweig whose diligent work kept the Trial operational. We acknowledge Professor Raphael Assaf and his Israeli associates, especially the late Levin, I. and Bravdo, B, Agriculture Research Organisation Volcani Centre Beth-Dagan of Israel, the Institute of Horticulture and the Israeli Ministry of Agriculture for their co-operation with Australia and use of their previous research results.

We acknowledge the role and financial assistance of the Australian Federal Government facilitated through Horticulture Australia Limited (HAL), South Australian Research and Development Institute (SARDI) and the support from the directors and staff of Clark-Taylor Farms and Jubilee Almonds.

Special thanks must also go to the Almond Board of Australia, the Almond Industry Advisory Committee (IAC), the Production Committee, and the critical review and input of Dr Ben Robinson and Dr Karl Sommer.

We also acknowledge the co-operation and goods and services supplied from other service providers such as Sentek and Agri-exchange.

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12 Appendices

12.1 Appendix 1 - Neutron Probe Calibration

Analysis of Water Retention & Water Content Profiles for ABA Experimental Plots

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Background

Ben Brown (Industry Liaison Manager, Almond Board of Australia) contacted me in late June 2008 to discuss the irrigation strategies being used at an ABA experimental site where the almond trees were being irrigated to 'field capacity' on the basis of water retention data I supplied in 2003 (cf. Grant, 2003). To check the efficiency of the irrigation strategy, the ABA staff measured the volumetric water content of the soil down the profile at the site using a neutron probe[1]. On the basis of the neutron count rates (which were not converted to volumetric water contents), Ben believed that too much water was being applied and that the water use efficiency was too low. He therefore asked me to re-examine my water retention data in light of the neutron probe results so a more conservative irrigation strategy could be identified.

Ben supplied me with three confidential reports (ABA 2006, ABA 2008, and Dowley 2006) plus an Excel spreadsheet containing the neutron count rates for the calibration sites. I met with Ben Brown and Brett Rosenbzweig on 26 August 2008 to discuss the neutron count rates and to clarify the data available to me. On the basis of our discussions and the Dowley (2006) report, we agreed the data from Pit 2 of Grant (2003) was most relevant to the ABA sites. Furthermore, we determined that the calibration of the neutron probe (conducted by B Rosenbzweig) could only be used as a rough guide because the soil samples were not oven dried – they were simply 'air dried' in a hot shed. This was considered acceptable for the very sandy soils (Sites 1-4 & 9-12), but less acceptable for the heavier textured soils at Sites 5-8 below about 45 cm.

We also agreed the following information was required to make effective use of the neutron probe data:

- The texture of each soil horizon down the profile was needed (to determine how many different calibrations were required to calculate water contents from the raw neutron count rates). Ben agreed to perform hand-textures on new soil samples taken every 10 cm down the profile and to identify other soil features that would differentiate horizons at the relevant sites (Table 1).
- The following raw neutron counts rates, C, are required to convert the raw neutron count rates in the soil to volumetric water contents:
    - C_{std}, the standard count rate for the probe inside the shield (B Brown stated this information was not available).
    - C_{air}, the alternative standard count rate in air if the standard in-shield count rate is unknown for the probe. (B Rosenbzweig measured this to be 50 in a 4 sec count).
    - C_w, the count rate in water (B Rosenbzweig measured this to be 23,680 in a 4 sec count).
- We needed to determine the feasibility of repeating the calibrations at all the sites in the event that the present analysis proved to be inadequate. Ideally the repeat-calibration was to occur at the same location as before, so B Rozenbzweig agreed to determine whether there was sufficient space around each neutron access tube at the original site to facilitate a second set of soil cores being taken at the same site. In the end a repeat calibration was not considered to be feasible – there were simply too many previous holes.

[1] CPN Hydroprobe with source of Am/Be 50 mCi.

Equipped with the above information I was commissioned to work up the data to obtain a reliable set of volumetric water contents. Using the profile water content data, I was to make a suitable link between it and the water retention data so that a 'best-estimate' could be obtained for the water content and matric head at which irrigation water should be turned off.

Methods

Calibration of neutron probe

Data to calibrate the neutron probe were collected by staff in the ABA during August 2006. Procedures and neutron count rate data are reported in ABA (2006), and I was provided with an electronic copy, which included raw neutron count rates plus gravimetric water contents determined on soil cores taken in the immediate vicinity of the neutron access tubes. I found three problems with the data supplied to me:

1. The gravimetric water contents, θ_m, of the calibration soil samples were determined incorrectly (the soil samples were not oven dried – just air dried). As indicated above, this may be roughly acceptable for very coarse textured sands but would be less reliable for the loams and clay loams at 5-8 (the gradational soil) below about 45 cm.

2. The gravimetric water content of the soil samples was calculated incorrectly (the wet mass, $M_{moist\ soil}$, was used in the denominator instead of the dry mass, $M_{oven\text{-}dry\ soil}$). The correct way to calculate a gravimetric water content is:

$$\theta_m = \frac{M_{moist\,soil} - M_{oven-dry\,soil}}{M_{oven-dry\,soil}} \qquad [1]$$

3. The gravimetric water contents were not converted to volumetric water contents – for the calibration to be meaningful this conversion must be done because the neutron probe measures water contents on a volumetric basis. Conversion of the gravimetric water contents to volumetric water contents, θ_v, can be done with knowledge of the dry bulk density of the soil:

$$\theta_v = \theta_m \frac{\rho_b}{\rho_{water}} \ , \qquad [2]$$

where ρ_b is the dry bulk density of the soil, and ρ_{water} is the specific gravity of water, usually taken to be 1.0 g/cm^3.

With no oven-dry masses available (only air-dry masses), I re-calculated the gravimetric water contents using **Eqn [1]** with the air-dry soil masses, $M_{air\text{-}dry\ soil}$ in place of the oven-dry soil masses. I then converted all gravimetric water contents to volumetric water contents using **Eqn [2]** with the relevant dry bulk density data taken from Grant (2003) for Pit 2.

(I must warn here that because of the inaccuracies in the gravimetric water contents, the accuracy of the volumetric water contents is compromised, and thus the neutron probe calibrations are also somewhat compromised, particularly for the loams and clay loams. This risk was considered to be acceptable for the sands (because the soil samples were dried in a very hot shed for several weeks, and there would not have been much water left in them). A greater risk of error was thought to be present in the loams and clay loams, but we decided that the amount of work required to get another complete set of soil samples and neutron count rates down the profiles was too great to justify at present, so we accepted the potential error. If critically precise information is required at

some stage in the future, the calibration must be repeated, and this should be conducted under supervision of a qualified soil scientist (i.e. CPSS accredited).

The raw neutron count rates in the soil, C_{soil}, were converted to relative neutron count rates, RCR, using procedures outlined in Greacen (1981) and Hignett (1980). The values of C_{soil} were divided by the raw neutron count rate measured in rain water, C_{water}, determined by B Rosenbzweig to be 23,680, as shown below:

$$RCR = C_{soil}/C_{water} \ , \qquad [3]$$

The values of RCR were then correlated with the volumetric water contents at all relevant depths and times to produce calibration equations of the following form:

$$\theta_v = a + b\, RCR \ , \qquad [4]$$

where a and b are fitting parameters for the linear relation between water content and relative count rate. The correlations were conducted for the 4 different soil horizons outlined in **Table 1**. In the case of the heavier textured clay loam soil at the bottom of the gradational soil (Sites 4-8), the linear relation shown above produced a relatively poor fit, so I applied an exponential model (with fitting parameters, α and β), which marginally improved the fit. In this case, the choice of the calibration equation will only influence the outcome in very dry and very wet soils. The results may have been influenced by differences in bulk density (Holmes 1966) but the differences in density down the soil profiles were relatively minor (Grant, 2003) and other problems with the data made correction for density seem unimportant (Greacen and Hignett 1979).

Interpretation of the water retention data

I applied the water retention model of Groenevelt & Grant (2004) to the six sets of water retention data that I collected in 2003 for Pit 2. The water retention model describes the relation between the volumetric water content, θ_v (cm/cm) and the soil matric head, h (cm):

$$\theta(h) = \theta_s - k_1 \exp\left[-\left(\frac{k_0}{h}\right)^n\right] \ , \qquad [5]$$

where θ_s is the saturated volumetric water content, n, k_0 and k_1 are freely adjustable fitting parameters, the values for which are determined by a procedure that minimises the sum of squared errors.

The values for the saturated water content, θ_s, and the fitting parameters, n, k_0 and k_1, were determined for all the available water retention data. On the basis of the soil textures provided by Ben Brown (**Table 1**), I grouped the water retention data into three distinct textural classes: sands, loams, and clay loams. The average values for the different textural classes are given in **Table 2.**

The water capacity, $C(h)$ was then determined as the first derivative of **Eqn [5]** with respect to the matric head, h:

$$C(h) = -n{k_0}^n k_1 h^{-(n+1)} \exp\left[-\left(\frac{k_0}{h}\right)^n\right] \qquad [6]$$

While the water capacity can identify clear differences between soils, a better estimate of the matric head at which irrigation should be turned off can be obtained from the points of curvature and inflection determined from the 2nd and 3rd derivatives of **Eqn [5].** At the risk of boring you with mathematics in this report, the relevant equations for the curvature and inflection are:

Curvature curve:

$$\kappa(h) = \left[k_0{}^{n}\ k_1\ \left(n^2+n\right) h^{-(n+2)} - k_0{}^{2n}\ k_1\ n^2\ h^{-2n-2}\right] \exp\left[-\left(\frac{k_0}{h}\right)^{n}\right] \qquad [7]$$

Inflection curve:

$$\iota(h) = \exp\left[-\left(\frac{k_0}{h}\right)^{n}\right] \left[\frac{k_0{}^{2n}\ k_1\ n^2(2n+2)}{h^{2n+3}} - \frac{k_0{}^{n}\ k_1\ \left(n^2+n\right)(n+2)}{h^{n+3}} - \frac{k_0{}^{n}\ n\ h^{1-n}\left(\frac{k_0{}^{2n}\ k_1\ n^2}{h^{2n+2}} - \frac{k_0{}^{n}\ k_1\ \left(n^2+n\right)}{h^{n+2}}\right)}{h^2}\right]$$

[8]

The peak in the water capacity curve locates the greatest ease of water extraction. The minimum in the curvature curve at the dry end identifies the matric head where the rate of drainage begins to slow down. The minimum in the inflection curve at the dry end identifies the matric head up to which water can be added during irrigation without experiencing too much drainage.

Results and discussion

Volumetric water contents from neutron moisture meter data

The calibration data and regression lines for the neutron probe are shown in **Figures 1, 2, 3** and **4** respectively for the three horizons in the gradational soil plus the single horizon in the deep, uniform sand. The two parameters, a and b (or α and β), for each correlation are summarized in **Table 3**; the number of points, n, in each correlation is indicated beside the regression coefficient, R^2. The low R^2 value for the deep, uniform sand (R^2 = 0.36) reflects a huge variation in the data of **Figure 4** and suggests the calibration may need to be repeated at some stage in the future. Again, this should be conducted by a qualified (CPSS accredited) soil scientist.

Interpretation of water retention curves for irrigation

The water retention curves are plotted in **Figure 5** for the gradational soil at Sites 5-8, and in **Figure 6** for the deep, uniformly textured sandy soils at both Sites 1-4 and 9-12. The mean water retention curve applicable to each depth at each site is coloured in **Table 1** as yellow (sands), brown (loams), and blue (clay loams). It can be seen that a single water retention curve applies to the deep, uniform sandy soil at Sites 1-4 & 9-12, while three different water retention curves apply to the gradational soil profile at Sites 5-8 because the soil texture gradually becomes heavier with depth. (The reaction to carbonates shown in **Table 2** was not taken into account in this analysis because carbonates do not influence water retention in the way soil texture does).

The water capacity curves are shown in **Figure 7**. The area under each curve in **Figure 7** indicates the total amount of water held in the soil. As you might expect, this shows that the water capacity for the lighter textured (sandy) soil is smaller than that for the loam-textured and the clay loam textured soils. What is perhaps not expected is that the loam-textured soil contains more water than the clay-loam textured soil. The reason for this is that the clay particles in the clay loam are unstable (dispersive) so most of the water is held in very small pores, from which plants cannot extract water.

The peak of each curve in **Figure 7** shows the matric head at which the greatest amount of water is released per unit matric head. In a crude way, this identifies an absolute maximum point of wetting that should not be exceeded during any irrigation. If you wet the soil beyond this matric head, an excessive amount of water will be lost due to leaching. This should be avoided.

The water curvature curves are shown in **Figure 8**. The peak in each of these curves identifies the matric head at which further irrigation will lead to increasing rates of water loss to drainage. Again, these matric heads should be avoided.

The water inflection curves are shown in **Figure 9** and their right-hand minima identify the matric heads to which irrigation should ideally be brought to and maintained. That is, irrigation should be shut off as soon as these points are reached – that will ensure minimal water is lost to drainage.

The matric heads and water contents corresponding to the peak in the water capacity curve, the peak in the water curvature curve, and the right-hand minima in the inflection curve are summarized in **Table 4**. These should act as a guide to monitor tensiometer readings during irrigation. Of the three choices given in **Table 4**, the matric heads associated with the inflection curves represent the ideal points at which irrigation should be shut off. These ideal matric heads are shown in **Table 5** along with the corresponding volumetric water contents, relative neutron count rates, and the soil neutron count rates. You can choose from **Table 5** whichever numbers correspond to the monitoring tool you have available (tensiometer, neutron probe, etc).

Conclusion and recommendations for irrigation practices

With the available information my analysis suggests that **Table 5** should be used as the best guide for monitoring irrigation using either tensiometers (for the critical matric heads, h_i) or neutron probes (for the raw soil neutron count rates, C_{soil}). If dielectric methods are used to monitor volumetric water contents, these will need to be calibrated.

The soil moisture in the deep, uniform sands at Sites 1-4 and 9-12 should be monitored throughout the soil profile during the irrigation cycle to ensure that at any depth the matric head (on tensiometer) and the raw neutron count rate (from neutron probe reading) never become wetter than the critical values shown in **Table 5** for the sands.

The soil moisture in the gradational soil at Sites 5-8 should also be monitored in each of the three horizons during the irrigation cycle to ensure the values in **Table 5** are not reached. Having said this, there is some flexibility in these gradational soils for the critical values in the surface horizon to be exceeded because the lower horizons can be wetted to a greater extent than the surface horizon. Thus if too much water is applied to the surface horizon, a certain amount of leaching will simply transfer the water to the lower two horizons, which can accept more water without

leaching. The difference in matric heads between 213 cm and 126 cm is not large and can be reached very quickly, however, so careful monitoring is important to prevent this.

At all sites, irrigation should be applied as slowly as possible (say < 2 mm/h) so that there is maximum opportunity for water to spread out as much as possible before the critical matric heads are reached. To achieve this, small amounts of irrigation applied at regular intervals would be more effective than larger amounts applied less frequently.

As indicated above, the neutron probe calibration conducted for the ABA Sites was compromised by poor procedures, so the recommendations above must be used with caution and must be used only for the ABA Sites. In the long term I recommend the calibration be repeated.

Table 1. Textural analysis (by hand texturing) and reaction to acid (presence of carbonates) estimated by Ben Brown for the ABA sites corresponding to the water retention data of Pit 2 (Grant 2003). Textural classes: LS = loamy sand, SL = sandy loam, LSCL = light sandy clay loam, SCL = sandy clay loam, CL = clay loam, SC = sandy clay. Reaction of soil carbonates to acid: S = slight, M = moderate, H = high, V = very high).

Horizon boundaries		Row 17 (Sites 5-8)		Row 11N (Sites 1-4)		Row 31N (Sites 9-12)	
Upper (cm)	Lower (cm)	Texture	Reaction to Acid	Texture	Reaction to Acid	Texture	Reaction to Acid
0	40	LS	N	LS	N	LS	N
			S				
		SL	M				
40	50	SL	M		H		
50	60	LSCL	H				S
60	70	LSCL	H		V		M
70	80	LSCL	H				
80	90	SCL	H				H
90	100	SCL	V				V
100	110	CL	V				
110	120						
120	130						
130	140						
140	150						
150	160	SC					
Colour scheme to indicate the mean water retention curve that applies:							
Mean of curves from 5-10, 25-30 & 45-50 cm							
Mean of curves from 65-70, 85-90, 105-110 & 125-130 cm							
Mean of curves from 145-150 & 165-170 cm							

Table 2. Average values for the parameters in the water retention model of Groenevelt & Grant (2004) for the horizons considered to be texturally distinctive at the ABA sites.

Water retention model of Groenevelt & Grant (2004): $\theta(h) = \theta_s - k_1 \exp[-(k_0/h)^n]$								
Depth Range (cm)	Mean θ_s	Std dev'θ_s	Mean k_0	Std dev' k_0	Mean k_1	Std dev' k_1	Mean n	Std dev'n
Row 17 (Sites 5-8)								
0-45	0.376	0.006273	167.1233	3.56374	0.3214	0.008514	1.3369	0.38086
45-100	0.396	0.007293755	117.6646	7.59255	0.3354	0.003703938	1.0034	0.06762
100-160	0.382	0.003291302	129.07358	21.89153097	0.31402	0.001018234	0.928355	0.061270803
Row 11N (Sites 1-4) and Row 31N (Sites 9-12)								
0-160	0.376	0.006273	167.1233	3.56374	0.3214	0.008514	1.3369	0.38086

Table 3. Results of the correlation between the neutron probe relative count rates and the volumetric water content of samples collected around the neutron access tube.

Calibration parameters for neutron probe using Eqn [4], Y = a + b RCR			
Depth (cm)	a	b	R^2
Gradational soil (Sites 5-8)			
Sands 0-45	-0.0403	0.5275	0.8081, n = 409 pts
Loams 45-100	-0.0562	0.5264	0.8262, n = 619 pts
Clay loams 100-160	-0.0854	0.6584	0.7717, n = 608 pts
Deep, uniform sand (Sites 1-4 and 9-12)			
Sands 0-160	-0.0057	0.2864	0.3629, n = 3379 pts
	*α = 0.0147**	*β = -5.8938**	*0.4232, n = 3379 points*

* *parameters for the exponential model, Y = α exp(-β RCR)*

Table 4. Matric heads at critical points in the water retention function, grouped by texture and in order of merit from the worst situation to the ideal situation.

Texture	Worst case	Acceptable case	Ideal case
	h at peak water capacity (cm)	h at peak curvature (cm)	h at right-hand minimum inflection (cm)
Sands	110	163	**213**
Loams	59	93	**126**
Clay loams	59	94	**129**

Table 5. Link between critical matric head, h_i, and corresponding values for the volumetric water content, $\theta_v(h_i)$, plus ideal relative neutron count rate, RCR_i, and raw neutron count rate in soil, C_{soil}.

Texture	Ideal matric head, h_i, cm	Ideal volumetric water content, $\theta_v(h_i)$	Ideal RCR_i $RCR_i = (\theta_v - a)/b$	Ideal C_{soil} $C_{soil} = RCR_i \times C_w$
Sands	**213**	0.220	0.493459716	**11685**
Loams	**126**	0.264	0.608282675	**14404**
Clay loams	**129**	0.266	0.533718104	**12638**

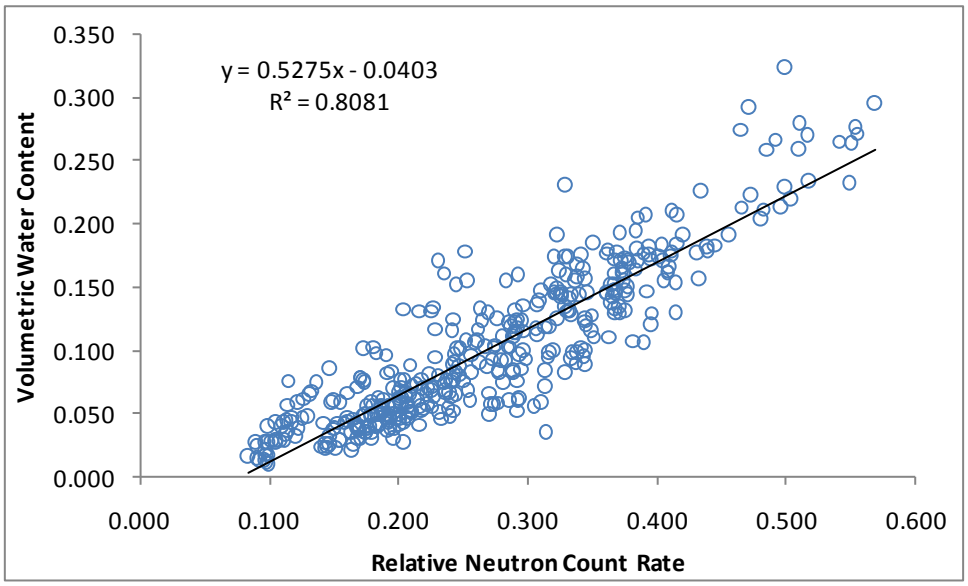

Figure 1. Neutron moisture meter calibration for sandy surface horizon in gradational soil.

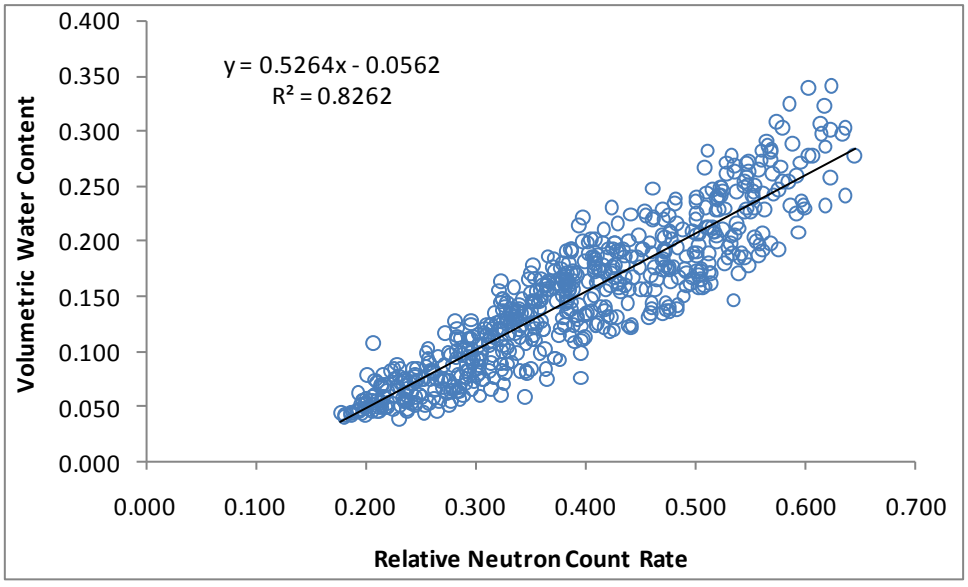

Figure 2. Neutron moisture meter calibration for loamy horizon in gradational soil.

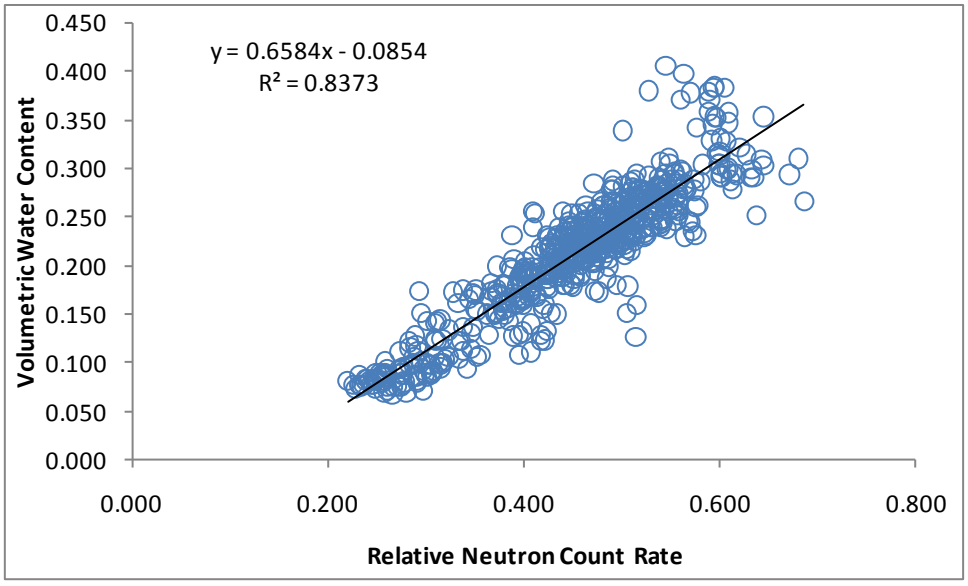

Figure 3. Neutron moisture meter calibration for clay loam horizon in gradational soil.

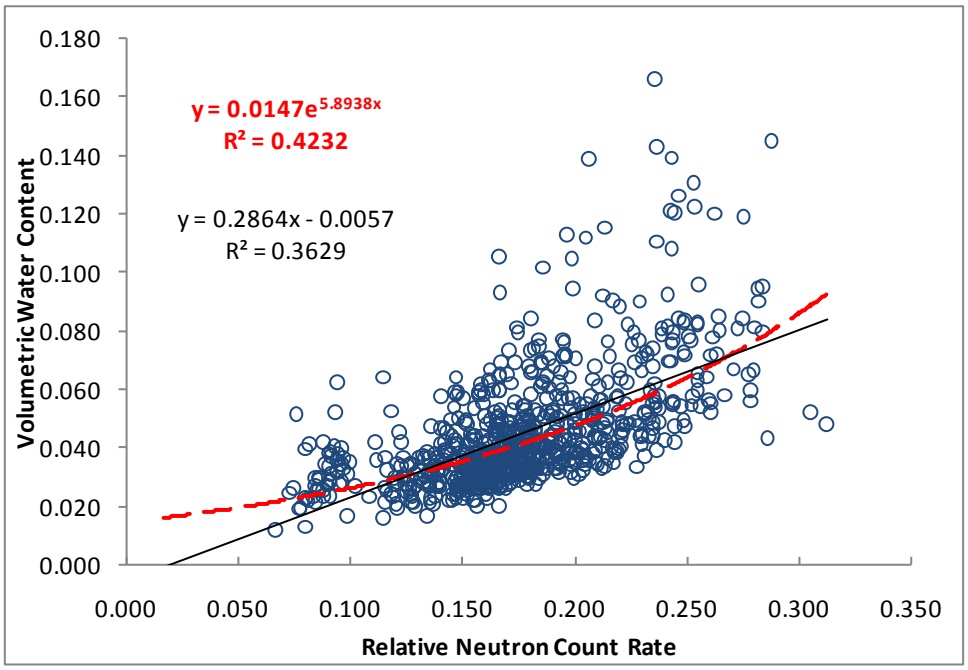

Figure 4. Neutron moisture meter calibration for full profile of deep, uniform sand.

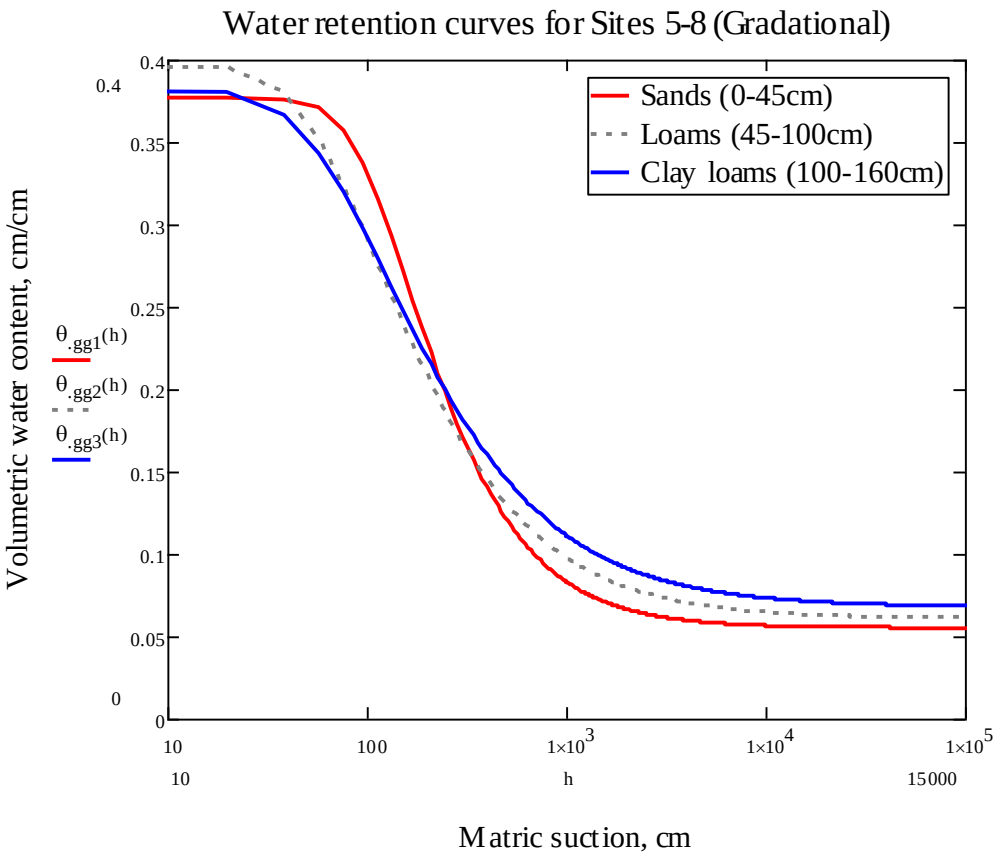

Figure 5. Water retention curves for Sites 5-8.

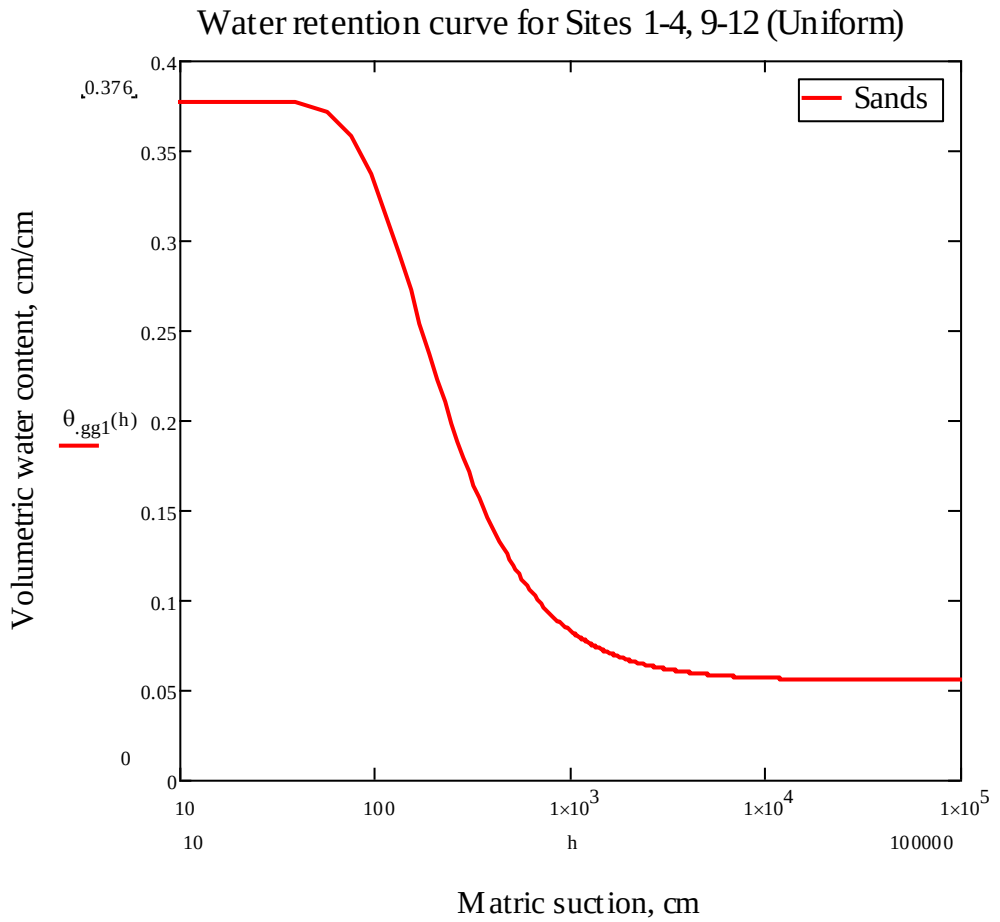

Figure 6. Water retention curve for Sites 1-4 & 9-12.

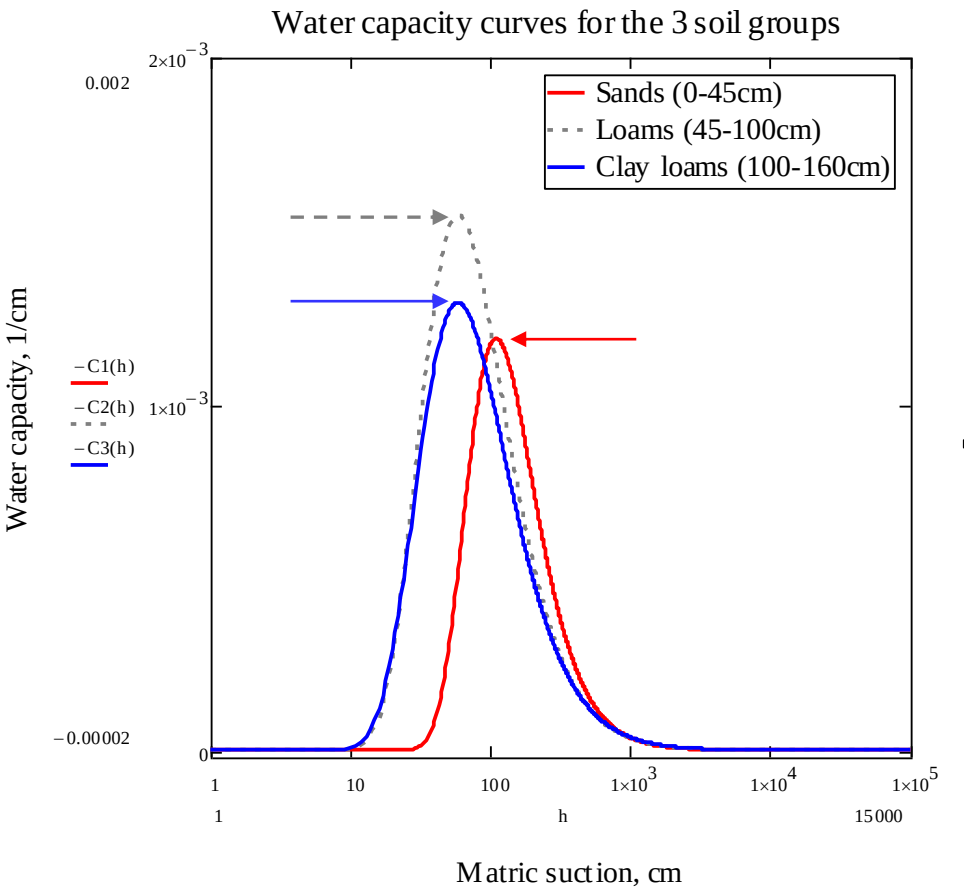

Figure 7. Water capacities for the three soil-texture groups. Arrows indicate critical points.

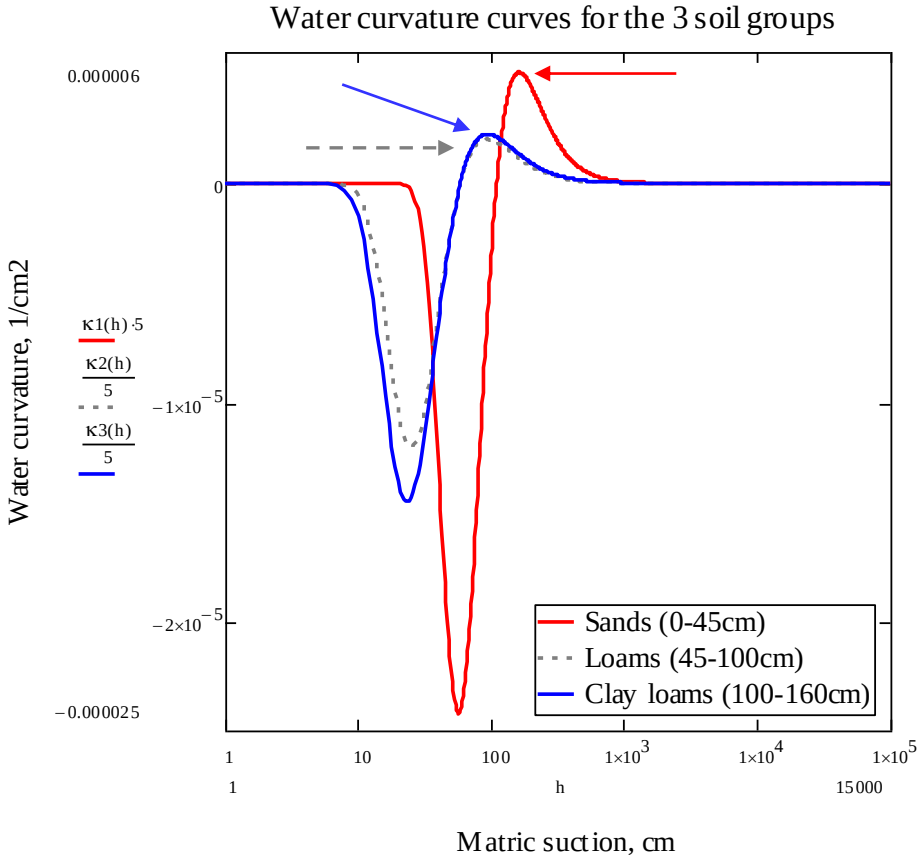

Figure 8. Curvatures of the water retention for the three soil-texture groups. Arrows indicate critical points.

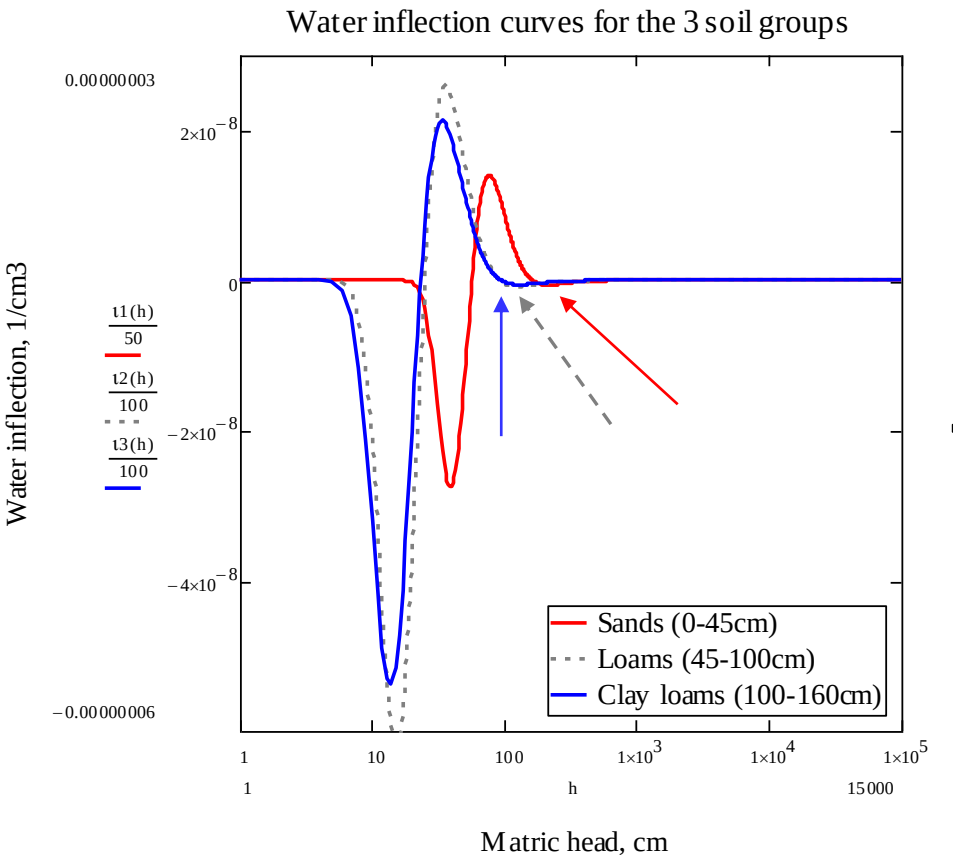

Figure 9. Inflection points in the water retention curves for the three soil-texture groups. Arrows indicate critical points.

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Dr Cameron Grant, CPSS-3

31 October 2008

12.2 Appendix 2 – Fact Sheets

All About Almonds

Fact Sheet 01 – Leaf Analysis

Welcome to the first edition of "All About Almonds", Fact Sheet 01. We aim to distribute various fact sheets throughout the seasons to briefly outline technical concepts, principles and potential outcomes of traditional almond growing required to manage an almond orchard, and to informally communicate concepts and results coming out of the industry's research and development program. Fact sheets will be issued on an ad-hoc basis covering topical information relevant to the specific time of the year. Fact sheets will be distributed to almond growers via email and fax, in addition to being made available for downloading from the levy payers' access page on the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

A lot of what is discussed below will not be new information for those growers who currently practice leaf sampling as a part of their annual property management. However, the aim will be to revisit the basics of leaf sampling, as well as list the January leaf standards achieved at the CT Farms Optimisation Trial, thereby enabling comparison against data from regular January samples.

Over the years there have been many advances in technology and other methodologies to both optimally grow plants and assess the plant nutrient status. New methodologies now include practices such as sap analysis and soil solution extraction and analysis, however plant leaf tissue analysis still remains a very useful and common method to quickly, easily and cheaply assess the plant nutrient status of a horticultural crop.

Methods

Primarily, leaf analysis is undertaken for two reasons, either to **diagnose** a nutrient deficiency or to **monitor** nutritional concentrations within the plant tissue. As with any assessment method involving sampling, the success, reliability and repeatability of the data will depend on accurately using the standard sampling techniques and laboratory protocols. A brief summary of both approaches is provided below.

Diagnostic Approach

The diagnostic approach is commonly employed to assess a "once-off" nutritional disorder where one or a combination of elements are either deficient or toxic or to confirm a soil assessment or visual observation. This method is quite simple. Separate samples of 100 leaves from both "good" trees and "bad" trees are normally adequate for analysis. Leaves for the "good" and "bad" patches should, represent each area and be taken from the same variety, rootstock, soil type, age, etc, this way a direct comparison will be possible. Sometimes, there may be standards available for the particular time of the season that the sample was taken but not always.

Monitoring Approach

The monitoring approach is commonly employed to assess the success of the past and current season's nutritional management. Monitoring samples are commonly taken at a specified time in the crop's growth cycle, where the nutrient composition is at its most stable and for which calibrated standards have been developed. As with all sampling techniques the methodology has to be kept standard from one sample to the next and from one season to the next to enable direct comparison.

For almonds, 100 leaves are taken to represent a particular patch using the following sampling protocols:

- **Young almonds and non-spur bearing cultivars** – collect a normal sized leaf midway along new season's shoot. See Figure 1.

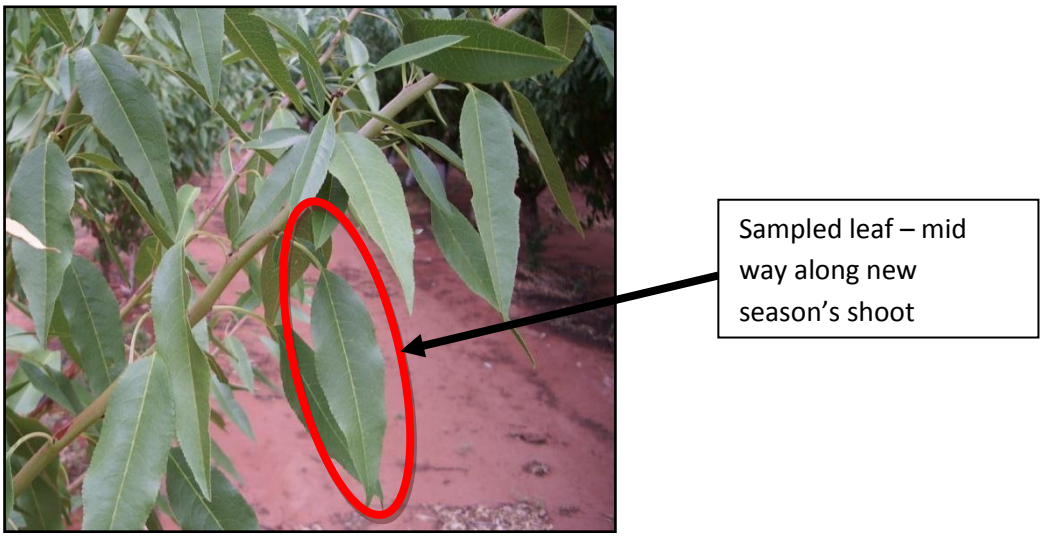

Figure 1. Leaf to be sampled for young trees.

- **Cropping, spur bearing cultivars** – see below.

INSTRUCTION	TRADITIONAL SAMPLING METHOD	CT TRIAL SAMPLING METHOD
When	Mid to Late January	Mid to Late January but also can be taken monthly in October, November and December.
Which Leaf	Fully expanded, healthy leaves from non-fruiting spurs. See Figure 2.	Fully expanded, healthy leaves from midway along new season's side branches. Ideally there should be nuts located "upstream" of the extension lateral shoot from which the leaves are taken. Do not sample apical extension growth. If the side branches are not available refer to the traditional sampling method. See Figure 3.

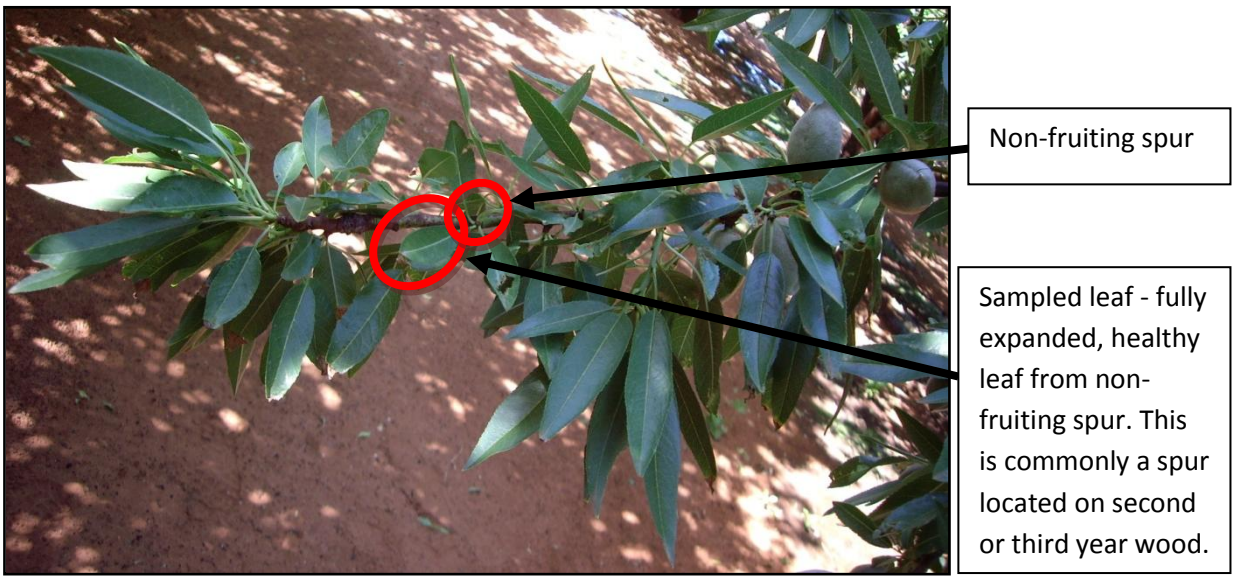

Figure 2. Leaf to be sampled using traditional sampling method.

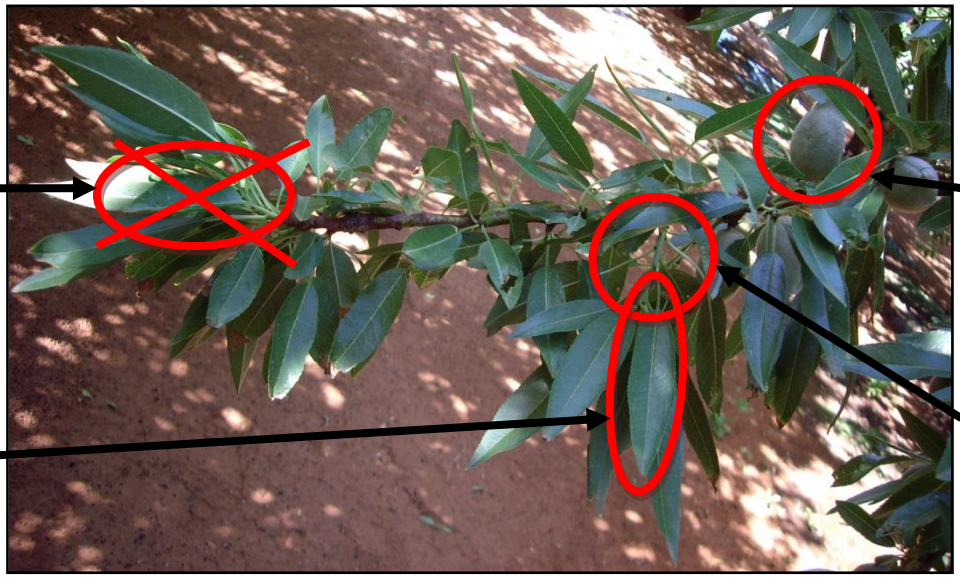

Figure 3. Leaf to be sampled using CT Trial sampling method.

- **Small to medium sized trees** - if good light interception is present around the whole tree, the sample should include four leaves (one from each of the north, east, south and west side of the tree) from twenty to twenty five trees at shoulder height.
- **Large trees or hedged rows** - the sample should include two leaves (one from each side of the tree) from forty to fifty trees at shoulder height.
- **A representative area** - Regardless of the situation, the sample should take into account variety (commonly Non-Pareil is the only variety sampled in newer orchards), rootstock, age, soil type, topography, etc and avoid diseased, damaged, irregular sized, water stressed leaves, and end trees and rows. Commonly a diagonal transect is taken from one corner of the patch to the opposite corner. The sampling track should be recorded so that the same trees can be sampled each year.

All samples should be taken early in the week to avoid delays in transport and deterioration of the product. In the field the leaves should be placed in an ice box (not on the dash board of the ute) in well labelled paper bags. They should be delivered to the laboratory within 24 hrs of sampling, if possible (e.g. by courier not in the mail). The same laboratory should be used each year but for quality control additional sub-samples may be sent to another laboratory for cross checking.

Ideally, the leaves should be washed of any impurities or contaminates that may affect the analysis. For the CT Trial we ask the laboratory to undertake the following method:

- Wash leaf samples fresh and prior to wilting.
- Wash in de-ionised water. Do not let leaves stand in water.
- Wash four times in hydrochloric acid (0.1N) plus de-ionised water solution.
- Washed in de-ionised water (preferably three changes).
- Dried in blotting paper.

Commonly used laboratories:

Analytical Crop Management Laboratory
PIRSA Loxton Centre
Bookpurnong Road or PO BOX 411
Loxton, SA, 5333
Phone: (08) 8595 9125

Geoff Proudfoot
CSBP Soil & Plant Laboratory
2 Altona Street
Bibra Lake, WA, 6163
Phone: (08) 9434 4600

Results

Analysis is to include Nitrogen (N), Phosphorus (P), Potassium (K), Sulphur (S), Calcium (Ca), Magnesium (Mg), Sodium (Na), Chloride (Cl), Copper (Cu), Zinc (Zn), Manganese (Mn), Iron (Fe) and Boron (B).

Interpretation

Laboratory data are usually provided within a few days. The data can be compared with standard values appropriate to the sampling procedure used.

Specialist help in interpreting leaf analysis data can often be very helpful. There can be many reasons why the data from a particular patch varies from the standard values other than inappropriate fertiliser use. For example, a shortage of irrigation can also lead to low nitrogen values, low soil pH can affect the levels of a range of nutrients in different ways. Some fungal protectant residues and foliar nutrient sprays are difficult to wash off and may lead to erroneous conclusions.

Two sets of standards are provided below. The first set has been used in Australia for many years and refer to trees grown in the conventional way. The second set is derived from the data collected at the CT Farms trial site. Clearly the observed values from the CT Farms Trial site are higher for both macro-nutrients and micronutrients. One of the benefits hoped for from the On Farm Trials which started this year will be a clearer picture of which of these differences are critical in the achievement of high yielding trees

Almond Leaf Standards – South Australian survey work by Robinson and Glenn (1981) based on the Californian method (e.g. Beutel *et al*.1976).

NUTRIENT	Deficient	Marginal	Adequate	Toxic or Excessive
N(%)	<1.8	1.8-1.9	2.0-2.5	
P(%)	<0.1		>0.1	
K(%)	<1.0	1.0-1.3	1.4-1.7	
S(%)				
Ca(%)			>2.0	
Mg(%)			>0.25	
Na(%)			<0.25	>0.25
Cl(%)			<0.3	>0.3
Cu(mg/kg)			>4	
Zn(mg/kg)	<15	15-24	25-30	
Mn(mg/kg)			>20	
Fe(mg/kg)				
B(mg/kg)	<12	12-24	25-65	>85

Almond Leaf Results (Average of Jan samples, 2005-2007) –Optimisation of Almond Growing in Australia (CT Farm Trial)

NUTRIENT	CT Trial Results
N(%)	3.1
P(%)	0.1
K(%)	2.4
S(%)	
Ca(%)	2.4
Mg(%)	0.48
Na(%)	0.05
Cl(%)	0.36
Cu(mg/kg)	5.0
Zn(mg/kg)	299*
Mn(mg/kg)	210
Fe(mg/kg)	73
B(mg/kg)	37

Note, if you are to use the CT leaf results the leaves need to be acid washed.

*Zinc levels are significantly higher in the CT Trial results because of the high number of foliar sprays which occur through the season, approximately 16 sprays of zinc nitrate. This is unlikely to be achieved by most growers.

For further information contact Ben Brown, Industry Liaison Manager

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Telephone (08) 8582 2055 Facsimile (08) 8582 3503

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Robinson, J.B., Treeby, M.T. and Stephenson, R.A. (1997). Fruits, Vines and Nuts. In 'Plant Analysis: an interpretation manual', 2nd ed. (Eds D.J. Reuter and J.B. Robinson). pg350. (CSIRO Publishing: Melbourne).

All About Almonds

Fact Sheet 02 – Post Harvest Nutrition

Welcome to the second edition of "All About Almonds", Post Harvest Nutrition. Fact sheets will be distributed to almond growers via email and fax, in addition to being made available for download from the levy payers' access page on the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

The idea of post harvest application of fertilisers and the issues discussed below will not be new information for most growers; however the aim will be to revisit the basics. In addition it is a good time as well to consider whether there is a place for the bud-building foliar sprays used to improve bud strength at the ABA's Almond Optimisation Trial located at CT Farms ("CT Trial").

Post Harvest Fertiliser

Post harvest fertiliser applications have long been a management practice in deciduous crops to:

- ensure good bud initiation and differentiation in autumn;
- ensure adequate nutrient storage over dormancy and into the following spring; and
- enhance the new season activities of root, leaf, shoot and fruit growth and blossom.

Almonds are quite unique in that they begin their new season by initiating their first root flush in the middle of winter (mid to late July), followed by blossom towards the end of winter (August), all of which with little or no presence of foliage. Transpiration which "pulls" nutrients from the soil into the tree does not start until the trees leaf out. What little "pulling" of nutrients may occur is further minimised by cool soil temperatures and further minimised again by the slow conversion of urea based fertilisers which are not directly taken up by the roots. This is why nitrate based fertilisers such as potassium nitrate are used in early spring.

A commonly used "rule of thumb" for the post harvest fertilising of deciduous trees is to apply approximately 25% of the whole season's fertiliser. This is very similar to what occurs at the CT Trial, but with one subtle difference: the two fertiliser treatments in the Trial that seem to be commercially relevant, Treatment 1 (240:50:400) and Treatment 2 (320:50:600) receive the same amounts of nitrogen (approximately 75Kg/Ha of actual N) and potassium (approximately 130Kg/Ha of actual K) post harvest, independent of the seasonal total. This equates to a post harvest application of 31% nitrogen and 33% potassium for Treatment 1 and 23% nitrogen and 22% potassium for Treatment 2.

What fertiliser?

When the CT Trial began, nitrogen and potassium were applied as ammonium sulphate and potassium chloride, respectively. Over the life of the Trial soil acidification and soil salinity, have built up and consequently the post harvest fertilisers have been changed to urea and potassium sulphate which are less acidifying and contribute less salinity. Note however that urea can also contribute to soil acidification.

How much fertiliser?

While the forms of fertilisers have changed, the amounts of actual nitrogen and potassium applied have not. Approximately 165Kg/Ha of urea and 310Kg/Ha of potassium sulphate are now applied.

When to apply?

As the name suggests, post harvest fertilisers are normally applied after harvest is finished, but there has to be some flexibility depending on the season and the situation. The fertilisers should not be applied too early as ripening of the fruit may slow, nor too late as defoliation will be near and the uptake of the fertiliser my be inefficient. At the CT Trial, the post harvest fertiliser is applied over a four week period between the middle of March and middle of April. It is injected for an hour each day, five out of every seven days through each week of this period, and in the second last pulse of each day.

Those growers who try to apply fertiliser after the harvest of the last pollinator but find the leaves have deteriorated too much, could safely apply their fertiliser after the completion of the Non-Pareil harvest.

Warnings and thoughts in years of drought and water restrictions

In the current season of low water allocations there has been less opportunity to apply adequate amounts of water and consequently, a diminished ability to maintain rootzone and subsoil moisture levels and leach salt from the soil profile. These issues will be even more difficult to deal with as irrigation scheduling is juggled through the harvest period. Early defoliation is a strong possibility this year.

With this possibility in mind, a strategy is needed to minimise either the risk of causing further toxicity or stimulating re-growth of stressed trees. The following approach to post harvest fertiliser application could be considered:

- Soil salinity test – collect samples at say 15 cm depth intervals through the rootzone both within the wetted profile and on the margins (for drip irrigators) or at 2-3 positions within the sprinkler pattern (for sprinkler irrigators).

- Determine the effect of salt build up - use the critical threshold of about 2dS/m to decide if there is a potential salinity problem.
- If water allocations allow, re-establish a satisfactorily wetted profile straight after harvest and **prior** to post harvest fertilising. This should help leach salt from the profile.
- Begin to apply post harvest fertiliser on top of the "wet" profile. Use the strategy of **little amounts but more often**. For those who irrigate every day, as a minimum requirement, inject fertiliser five out of every seven days and over at least one hour each day. If salinity is a problem it would be safest to inject over the whole irrigation event at a lower rate per hour (same or slightly lower daily amount) and over five to seven days every week. This approach should assist in keeping the salinity of the mainline solution low (<1.0dS/m), uptake efficient and the risk of toxicity low.
- For those who irrigate less frequently (e.g. with sprinklers of micro-jets) inject the fertilisers over the last one third of the irrigation. That way the fertiliser will be placed in the root zone, but the concentration in the soil solution will not be too high.

Bud-Building

The use of post harvest, foliar nutrient sprays, in particular lo-bi (low biuret) urea, has been researched across numerous crops such as citrus and apples. The results of this research have varied. However, there is a strong suggestion based on some of the successful research trials in deciduous crops such as apples (Fallahli *et al.* 2002 and Guak *et al*. 2001) and the visual observations on the almond trees at the CT Trial, that post harvest, foliar applications of lo-bi urea provide a benefit in improving the nitrogen content of the buds and consequently bud strength and flower development in the following spring. For those who would like to try the program as used in the trial, or a modification of it, the bud-building sprays used on the CT Farms trial have involved two different spray routines:

1. *30th April to 10th May – 3 to 4 sprays of lo-bi urea (0.45% biuret) at 1% (10Kg/1000L).*

   Once again, there is an opportunity to apply the sprays earlier in March/April for maximum uptake; however spray coverage could marginally be better once the fruit is off the tree.

2. *3rd Week in June – 2 sprays of urea (1.5% biuret -fertiliser grade urea) at 4% (40Kg/1000L).*
   This spray may also assist in defoliation. The impurity biuret, is quite toxic to plants, so the use of fertiliser grade urea as a foliar spray has some risk. To date no problems have been encountered when it has been applied to the trial trees at this rate.

Note; the use of urea (1.5% biuret) as a defoliation spray at 5-7% (50-70Kg/1000L) in place of zinc sulphate could also be helpful in "bud-building". This is also a spray routine on the CT Farms trial.

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ACKNOWLEDGEMENTS
The input and knowledge of Dr Ben Robinson, John Kennedy and Brett Rosenzweig.

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All About Almonds

Fact Sheet 03 – Dormancy Breaking

Welcome to the third edition of "All About Almonds", Dormancy Breaking. Fact sheets are distributed to almond growers via email and fax, in addition to being made available for download from the levy payers' access page on the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

International and domestic research into the artificial control of budbreak has been quite extensive over the years with research into products such as oils, dinitro-o-cyclohexylphenol (DNOC), hydrogen cyanamide, gibberellic acid, cytokinins, paclobutrazol, potassium nitrate and fatty amines. The research has primarily been brought about by the commercial growing of deciduous fruit trees in warmer climates where there is the potential for insufficient chilling. Insufficient chilling of deciduous trees causes three effects of varying intensity depending on the level of deficiency: a) poor budbreak, poor foliage development, sparse bloom and abnormal flowers, b) delayed foliation and bloom and uneven budbreak; and c) poor fruit set, reduced leaf area due to a lack of growing points, and early growth cessation due to secondary dormancy (Erez, 1987).

The use of chemicals to artificially break dormancy is generally reliant of dosage and timing with the higher the dose and the later the treatment, the stronger the effect. However, this practice also brings about a greater risk of phytotoxicty and significant damage. Flower buds and flower parts are more sensitive than vegetative buds and species such as stonefruit are more sensitive than grapes. It should also be noted that the result of using such chemicals can further be influenced by other factors such as the climatic conditions around the time of application, the level of bud development at the time of application and previous management practices such as irrigation, fertiliser and pruning. Furthermore, it should be noted that no chemical will compensate for the total absence of the chilling requirement (Erez, 1987).

The main concern for almond growers is the lack of chilling may cause a lack in flowering overlap needed for cross pollination and successful fruit set. It has been reported that in an average year, only 30% of almond flowers result in a nut, however, this can range between 20% and 40% depending on the seasonal variations in flower numbers per tree, pollination conditions, etc (Polito *et al*, 1996). Consequently, to maximise cross pollination all almond orchards have been planted with two criteria in mind: 1) plant at least two pollen compatible varieties (e.g. Non-Pareil and Carmel) but more commonly orchards have three to four (e.g. Non-Pareil, Carmel, Price and Peerless/Ne Plus) pollen compatible varieties, and 2) each of the pollen compatible varieties have flowering times which generally overlap each other.

CT Optimisation Trial

The CT Trial is planted to three varieties: 50% Non-Pareil, 33% Carmel and 17% Ne-Plus. This particular planting pattern was reasonably common in the past but less so recently. This planting pattern is particularly limiting because: a) Ne-Plus generally flowers too early with a peak flowering time approximately 5 days earlier than Non-Pareil and to a lesser degree, b) the percentage of early flowers are minimal because of the low percentage of Ne-Plus rows, and c) Carmel is approximately 3 days later than the peak flowering of Non-Pareil. Consequently, at the CT Trial it was decided that the best chance of obtaining an optimum fruit set was to use a foliar program of Potassium Nitrate, which when used by itself, has been mildly successful on other deciduous crops such as peaches (Erez, 1987 and Erez et al., 1971). Research has shown the specific effect of Potassium Nitrate has been the enhancement of flower budbreak (Erez et al., 1971) with two to three, sequential applications the most effective (George and Nissen, 1993).

The aim of the Potassium Nitrate program in the CT Trial was to not only provide two macro-elements to the trees, but to primarily advance the flowering of Carmel and to promote a more intensive and more uniform break of flowering buds across ALL varieties. Indirectly, this program is also thought to have also promoted a more intense and even break of the vegetative buds, which has in turn promoted greater leaf area, more shoots, and potentially a greater number of flowering buds in the following season.

Dormant Oil which was already used to control Bryobia mite and San Jose scale in the CT Trial can also indirectly have the same benefits mentioned above. It is thought the oil affects budbreak by influencing bud respiration, where as Potassium Nitrate provides a nitrate ion which influences some of the chemical compounds which promote flowering (George and Nissen, 1993).

1. **Dormant Oil**

Spraying of dormant trees with Winter Oil or Summer Oil occurs on the CT Trial at the traditional Winter Oil or Summer Oil concentrations of 2% (i.e. 20L/1000L).

2. **Potassium Nitrate**

The general, specific timing is based on a visual assessment of the Non-Pareil flowering buds. The first application (i.e. 50Kg/1000L) is ideally applied to Carmel only, when the Non-Pareil flower buds have moderately, advanced swelling and prior to budbreak. The second application (i.e. 50Kg/1000L) is applied approximately 5 days later to Non-Pareil only, and also prior to budbreak of

both varieties. The third spray (i.e. 30Kg/1000L) is applied at a lower concentration due to the more advanced bud swell and risk of phytotoxicity. The fourth spray (i.e. 30Kg/1000L) has been an optional spray, depending on whether the Carmel needs more assistance to break and coincide with Non-Pareil flowering.

SEASON	DATE APPLIED	VARIETY	CHEMICAL	RATE	PURPOSE
2005/2006	20th July	Carmel	Potassium Nitrate	50 Kg/1000L	Initiate budbreak
	25th July	Non-Pareil	Potassium Nitrate	50 Kg/1000L	Initiate budbreak
	26th July	Carmel	Potassium Nitrate	30 Kg/1000L	Advance budbreak
	1st August	Carmel, Non-Pareil	Potassium Nitrate	30 Kg/1000L	Advance budbreak
2006/2007	17th July	Carmel	Potassium Nitrate	50 Kg/1000L	Initiate budbreak
	21st July	Non-Pareil	Potassium Nitrate	50 Kg/1000L	Initiate budbreak
	24th July	Carmel, Non-Pareil	Potassium Nitrate	30 Kg/1000L	Advance budbreak
2007/2008	19th July	Carmel	Potassium Nitrate	50 Kg/1000L	Initiate budbreak
	25th July	Non-Pareil	Potassium Nitrate	30 Kg/1000L	Advance budbreak
	2nd August	Carmel	Potassium Nitrate	30 Kg/1000L	Advance budbreak

The primary aim of the 50Kg/1000L rate is to **initiate** budbreak of both varieties while the primary aim of the 30Kg/1000L rate is to further **advance** budbreak of both varieties. Each season is slightly different and can require a different number of sprays dependent on the effort necessary to firstly initiate budbreak, secondly assist budbreak and thirdly assist flowering coincidence of the two varieties.

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ACKNOWLEDGEMENTS
The input and knowledge of Dr Ben Robinson, John Kennedy and Brett Rosenzweig.

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All About Almonds

Fact Sheet 04 – Profile Establishment

Welcome to the fourth edition of "All About Almonds", Profile Establishment. Fact sheets are distributed to almond growers via email and fax, in addition to being made available for download from the levy payers' access page on the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

Most horticultural regions, in particular those areas containing almond orchards, have recently experienced a combination of two scenarios:

1. less rainfall than the already low, average, annual rainfall (e.g. Loxton Research Centre mean annual rainfall from 1984-2008 was 264mm compared with 172mm in 2008), and
2. a recent increase in the use of drip irrigation systems.

If not managed appropriately, the combination of these two scenarios has the potential to greatly affect tree performance and yield.

There is an increasing awareness this scenario could cause and in some cases is causing:

a) a reduction in root growth due to a lack of soil water content in July, the beginning of the first root flush and the almond season,
b) a reduction in soil exploration by the rootzone and consequently a restricted root mass and impaired ability to cope with peak, plant water requirements during unexpected or excessive heatwaves,
c) inconsistent rootzone development and root biomass due to the variable soil water status within differing soil layers, and
d) an increase in soil salinity within the rootzone and on the margins of the rootzone.

Rectification of these issues can be achieved with drip irrigation through good lateral spread of water and the successful establishment of field capacity within the majority of the rootzone, prior to the first root flush in July. This requires a drip irrigation system which produces minimal or more preferably, no drainage, and ultimately an understanding of:

- soil textures
- soil hydraulic movement
- potential soil water holding capacity
- rootzone depth
- pre-existing soil water status, and
- the average readily available water figure of each irrigation shift.

It is imperative that each grower recognises their individual soil variability and manages it accordingly. Too little water could moderate the result or more importantly, too much water could cause a decline in tree performance through the stimulation of drainage water and waterlogged, anaerobic conditions.

The most successful strategy to achieve lateral spread in a drip irrigation system is to apply water via an on/off cycle. This cycle commonly involves one hour on, one hour off, but this may not always be possible, particularly on heavier soil types and/or high output drippers. Water ponding, a lack of vertical penetration, water runoff down rows or mounds, and orchard access are some of the issues which could be faced if the dripper outputs are too great for the soil infiltration rate. Consequently, there may be some trial and error involved.

Profile establishment to field capacity obviously involves an early allocation of water or an announcement of a carryover allocation and in these current times, this is difficult to achieve. Nonetheless, if the decision has been to irrigate your almond orchard, this practice should be considered as part of a drip irrigation management strategy for the year – or at the very least, a moderated version.

CT Optimisation Trial

The practice of profile establishment has occurred every season at the CT Optimisation Trial. The total amount of water applied has varied each season depending on the pre-existing soil water status, soil salinity levels and in this last season – water availability.

The procedure normally occurs around the later half of July, in time for the first root flush, and involves the following steps:

1. Measure the soil water content of the various sites with the calibrated, neutron probe.
2. Assess and make a decision on the pre-existing soil water status.
3. Begin the one hour on, one hour off cycle with no more than 40mm applied in any one cycle.
4. Once the first 40mm has been applied, allow 24-48 hours for the water to equalise through the soil profile.
5. Reassess the soil water status with the calibrated, neutron probe.
6. If required, begin another cycle of one hour on, one hour off cycle. Again, if necessary, ensure no more than 40mm is applied.
7. This process is repeated until the rootzone has established field capacity.

The effect of this procedure on the soil water content is depicted in the following figures.

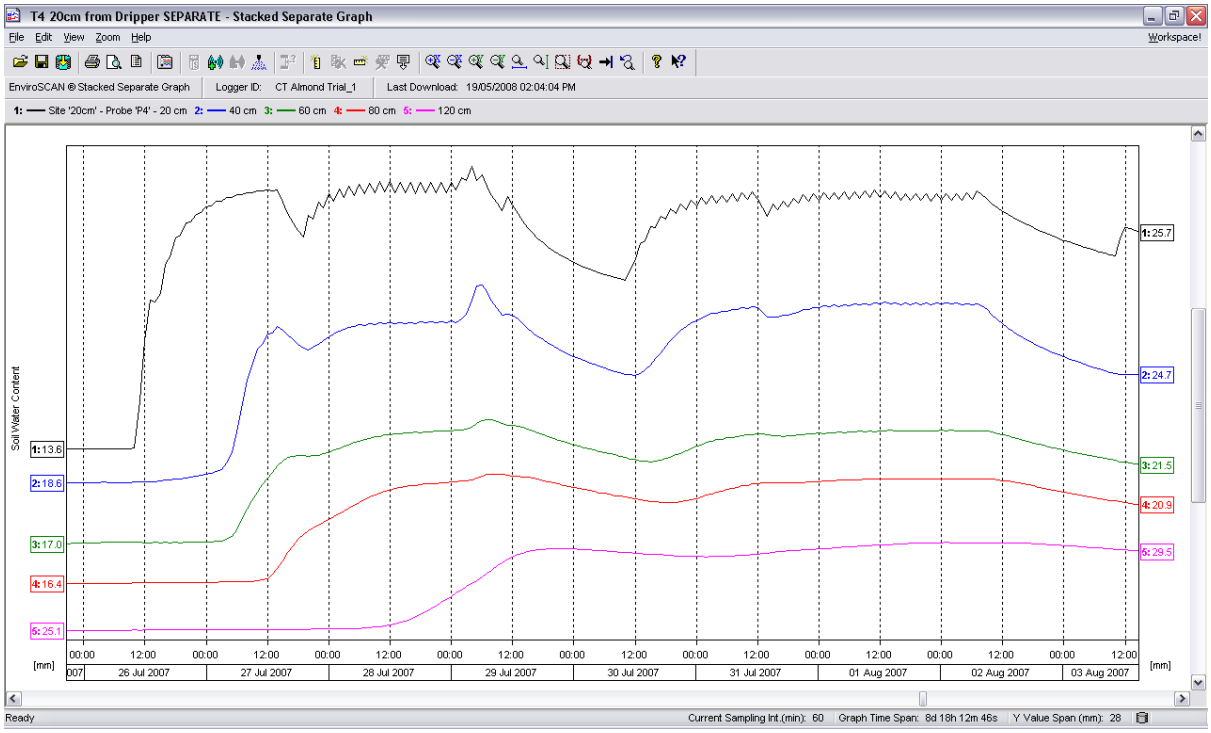

Figure 1. Soil Water Graph for depths 20cm, 40cm, 60cm, 80cm and 120cm – 20cm out from the dripper emitter.

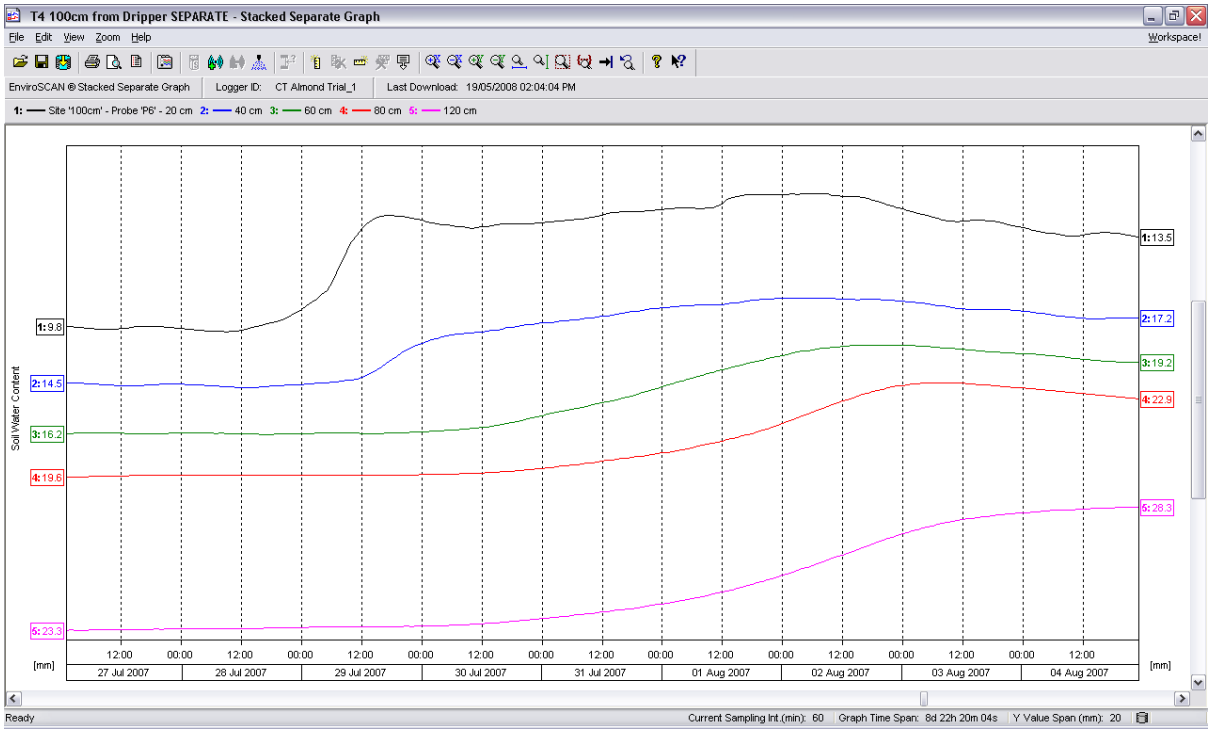

Figure 2. Soil Water Graph for depths 20cm, 40cm, 60cm, 80cm and 120cm – 100cm out from the dripper emitter.

It should be noted that this procedure is highly site specific and each site needs to be managed individually. Not all orchards and soil types will require the same amount of water applied at the CT Optimisation Trial and consequently won't require or achieve the same vertical and lateral spread.

Following the soil profile establishment to field capacity, the first application of fertiliser can take place. Fertiliser must not be applied prior to the irrigation event because of two, quite obvious reasons:

1. avoid the risk of leaching the fertiliser past the rootzone, and
2. avoid the risk of toxicating the rootzone with excessive fertiliser (i.e. another form of salt), which may occur if fertiliser is applied to a dry soil and rootzone.

Following the establishment of the rootzone to field capacity, the procedure from July to September is to apply only supplementary irrigations and to allow for a slight "mining" of the soil water content, and consequently, highly aerated/oxygenated conditions for the remainder of the root flush (Figure 3). From the end of September, the aim is then to re-establish your soil water content in time for pit hardening, shoot extension growth and consequently, the period of peak water use. For more detail, please refer to the crop factors and irrigation and fertiliser spreadsheet on the industry website (login section).

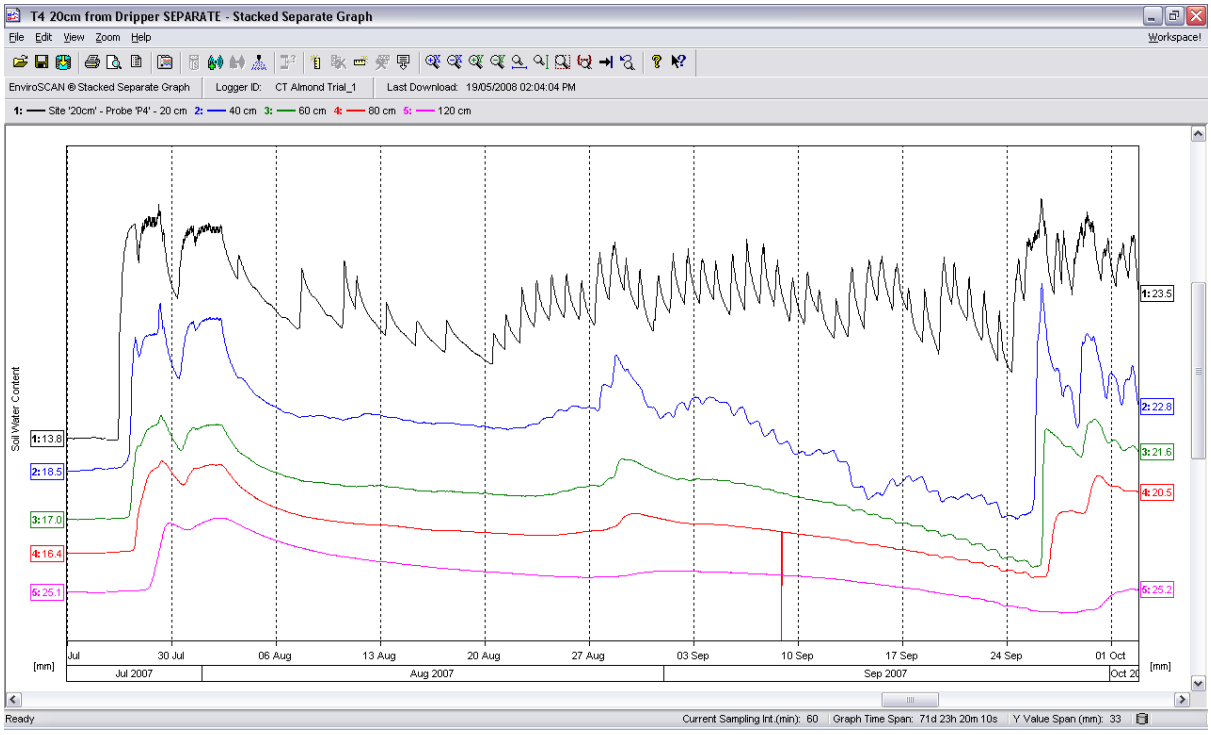

Figure 3. Soil Water Graph for depths 20cm, 40cm, 60cm, 80cm and 120cm – 20cm out from the dripper emitter, end of July to early October.

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ACKNOWLEDGEMENTS

The input and knowledge of Dr Ben Robinson, John Kennedy and Brett Rosenzweig.

All About Almonds
Fact Sheet 05 – Pit Hardening

Welcome to the fifth edition of "All About Almonds", Pit Hardening. Fact sheets are distributed to almond growers via email and fax, in addition to being made available for download from the levy payers' access page on the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

The almond fruit is classified as a drupe (or stonefruit) where the hard, lignified stone or pit is derived from the ovary wall of the flower. Unlike most drupes, the outside fleshy mesocarp (husk) is dry and leathery, not for human consumption, and does not increase in size following pit hardening. The absence of any increase in fruit size after pit hardening results in an exponential fruit growth curve (Figure 2) rather than the sigmoid curve of a traditional stonefruit variety such as an apricot.

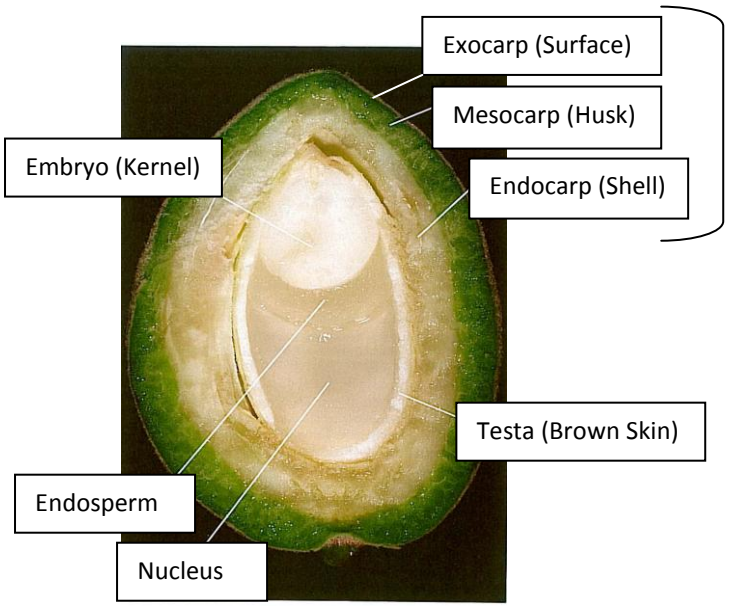

Figure 1. Developing almond fruit (adapted form Ohlendorf, 2002).

Following pollination, fertilisation and fruit set, the early stages of almond fruit and shoot growth occur. The two processes almost occur simultaneously and compete for water, applied nutrients and stored tree reserves. Consequently, it is important to have an understanding of the anatomy of an almond fruit (Figure 1), the various fruit development stages, the interpretation and assessment of the fruit stages and how to correctly manage irrigation and fertiliser applications to achieve the optimum result.

Almond Fruit Development

The development of the almond fruit can be divided into as many or few stages as you like, depending on how complex you make it. In general, the almond fruit has two stages of growth (Figure 2):

- **Stage 1** – Fruit growth where the seed and hull reaches its full size. The majority of cell division and cell expansion normally occurs from 0 to 6 weeks and 6 to 12 weeks after flowering, respectively (Hawker & Buttrose, 1980).

- **Stage 2** – Kernel growth where within the fruit, the embryo (edible kernel) grows and reaches its full size. Following which, the embryo looses moisture and dry weight increases.

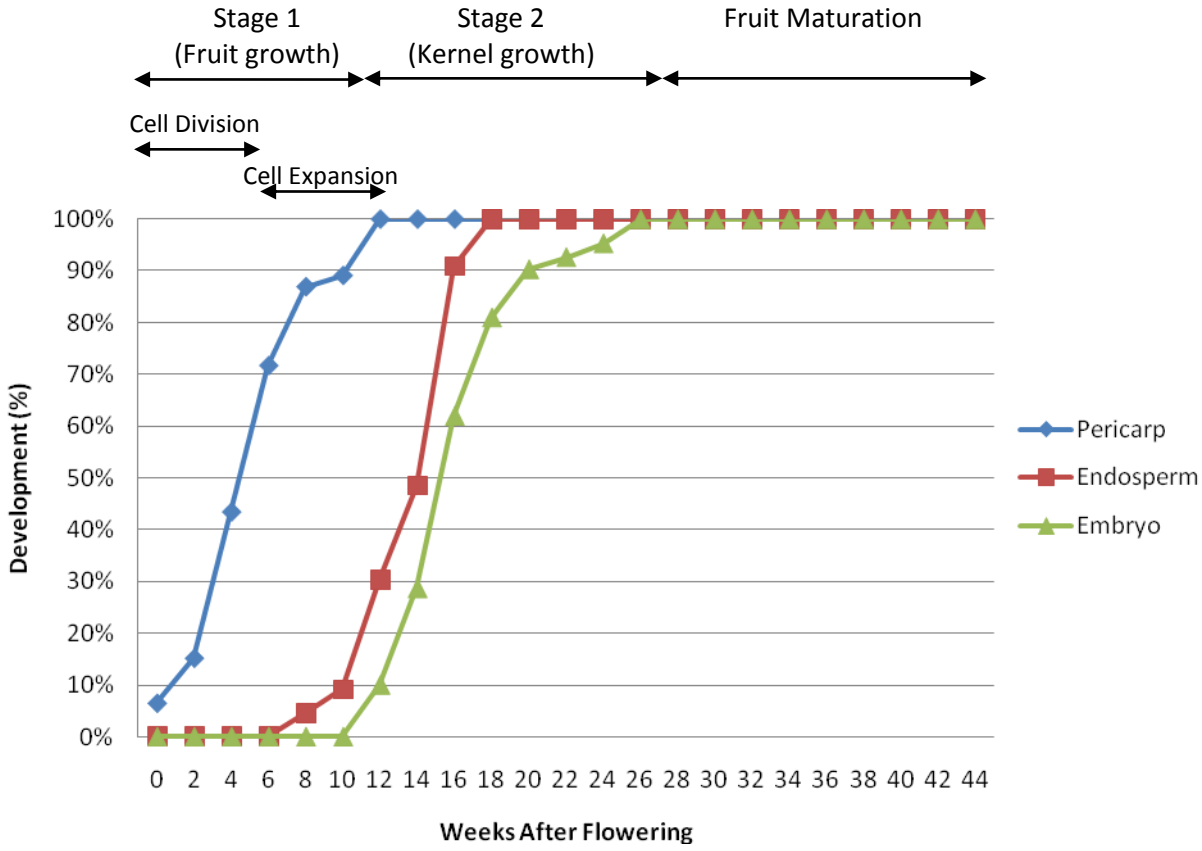

Figure 2. Almond fruit development (adapted from Hawker & Buttrose, 1980).

Pit Hardening

The transition between Stage 1 and 2 is critical and commonly referred to as pit hardening. By definition, pit hardening is the lignification and hardening of the endocarp (shell), the inside layer which surrounds the seed (kernel). Pit hardening begins on the inner surface of the shell cavity and at the end opposite to the stem attachment (Kester *et al*, 1996).

In the field, pit hardening is best assessed with the use of a sharp knife or razor blade and cutting the fruit either length or across ways. To assess the very early stages of pit hardening it is best to cut the fruit longitudinally starting from the opposite end of the stem and finishing with a fruit like that in Figure 1. Due to the lignification process that has begun, the operator should feel a slight

resistance at the endocarp (shell) once passing the blade from the mesocarp (husk) through to the endosperm (translucent gell).

The period following the early beginnings of pit hardening is critical in optimising the potential of the developing kernel. The theoretical potential has been established following the completion of cell division and expansion. However, whether this potential is accomplished is yet to be determined. Water and fertiliser management must be precise as not only are you developing the fruit but also new shoot growth and creation of fruiting positions for next seasons crop. Failure to do so will result in small, pinched and shrivelled kernels and lack of vegetative growth, fruiting positions and lower yield for the following season. In combination with these critical phenological periods, the increase in temperature and evaporative demand also occurs. Consequently, heading into early pit hardening of Non-Pareil (normally the second week in October at the CT Trial), the irrigation program undergoes a two staged increase in crop factor from the last week in September. That is, a 60% increase in crop factor initially, followed by a further 20% increase in crop factor.

If pit hardening is missed in the field, it will usually be highlighted with the monitoring of crop water use with irrigation scheduling equipment. This period will normally show a significant increase in water use. The increase in crop factor leading into pit hardening also coincides with the increase in soil temperatures, subsequent introduction of urea and increase in fertiliser applications.

Early pit hardening till the completion of embryo growth must be given maximum attention as it consists of approximately 33% of seasonal water applications and approximately 50% and 30% of nitrogen and potassium applications respectively.

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ACKNOWLEDGEMENTS
The input and knowledge of Dr Michelle Wirthensohn, Dr Ben Robinson, John Kennedy and Brett Rosenzweig.

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All About Almonds
Fact Sheet 06 – Statistical Analysis of Data from the Almond Optimisation Trial

Welcome to the sixth edition of "All About Almonds", Statistical Analysis of Data from the Almond Optimisation Trial. Fact sheets are distributed to almond growers via email and fax, in addition to being made available for download from the levy payers' access page on the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

The Almond Board of Australia with the assistance of Horticulture Australia Ltd has undertaken a production based, research and development project entitled "Developing Optimal Nutritional and Irrigation Requirements for Almonds" or "the CT Trial" over the last 7 years. Over that time a large amount of data has been collected. To date only the production data have been discussed in detail. The Project management team has recently engaged a statistician to undertake an analysis of the water, soil chemistry and yield data to provide a **preliminary** summary of the trends over time which will provide the industry with **guidance as** to **the likely effects of the innovative nutritional and irrigation approaches that have been incorporated into the trial,** and which have caused such interest within the Australian almond industry. Due to the nature of the trial, the difficulty in making sense of results obtained with younger trees and the need for several seasons of repeatable data on older trees, it has not been possible to develop "optimum" requirements for a mature almond orchard which can be applied widely. However, the results to date do provide some food for thought and emphasise the sorts of monitoring that will be necessary if the CT Trial management techniques are to be successfully adapted/adopted by the Australian almond industry.

Soil chemistry data were not collected from all treatments so the data presented later were drawn from the three fertiliser treatments listed in Table 1.

The yield data were taken over the production years 2004/2005, 2005/2006, 2006/2007 and 2007/2008 from the following treatments:

		Irrigation Applications	Fertiliser Applications (N:K)
Fertiliser Treatments	1	100% (approx 15-18 ML/Ha)	240kg/ha : 400kg/ha
	2	100% (approx 15-18 ML/Ha)	320kg/ha : 600kg/ha
	3	100% (approx 15-18 ML/Ha)	480kg/ha : 800kg/ha
Irrigation Treatments	4	100% (approx 15-18 ML/Ha)	320kg/ha : 600kg/ha
	5	160% (approx 25-28 ML/Ha)	320kg/ha : 600kg/ha
	6	60% (approx 11-12 ML/Ha)	320kg/ha : 600kg/ha

Table 1. Almond Optimisation Scientific Treatments as of 2007/2008.

Irrigation – Yield responses to increasing application of water

The statistical analysis indicated the economical, optimal water application where the cost of an additional megalitre of water would provide a 100% return on investment in that megalitre of water for the CT Trial was between 13.6ML/Ha and 13.8ML/Ha (Figure 1). The analysis was based on the following assumptions:

- A minimum, seasonal water use figure somewhere between 6ML/Ha would be required to "just" grow a commercial crop and justify harvest,
- 100% value placed on water by assuming 0% water allocation,
- The value of water would be $500/ML,
- Kernel value set at $5.70/kg,
- No consideration of any possible effect of restricted applications on next seasons harvest or other aspects of tree growth or performance, and
- Only considering the theory of diminishing returns of an investment in water and **not** profitability. That is, based on the yields achieved at the CT Trial an estimation of what the Trial could afford to pay for water before the return from yield could not account for 100% of the value placed or spent on water.

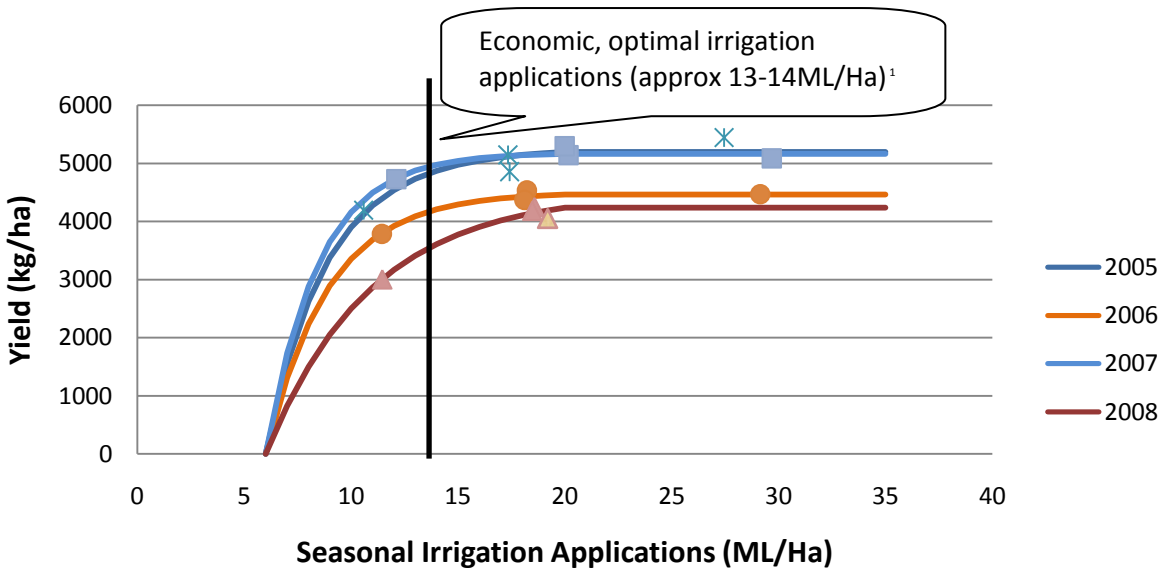

Figure 1. Yield response to varying, seasonal irrigation quantities.

[1] Economic, optimal irrigation application of 13-14 ML/Ha based on the above assumptions. For a more detailed analysis refer to Table 2.

The following sensitivity analysis (Table 2) was also produced. It shows the sensitivity of economic, optimal irrigation rates (these numbers are expressed in the body of the table by a colour scaling) to changes in cost of water and kernel returns. As with Figure 1, Table 2 also considers the theory of diminishing returns of an investment in water, it does **not** take into account profitability. Profitability of each individual property has its own defining circumstances based on interest and principle, depreciation, operational expenses, etc. As an example, if the CT Trial budgeted its long term average yield of approximately 4.5 tonnes/ha and wished to investigate what would the economic optimal irrigation rate be if the budgeted kernel value was $5.00/Kg and the leased water price started at $500/ML and moved to $600/ML. Using Table 2 and its assumptions, $500/ML would suggest 14-16ML/Ha would be the most economic optimal irrigation rate. That is, every dollar spent per megalitre of water would be replaced by the amount of money received ($/Kg) from the orchard and processor. However, using the above scenario, if the price of water increased to $600/ML, the entire cost of 14-16ML/Ha would not be 100% replaced by the money received ($/Kg) from the orchard and processor – but an investment in a water rate of 12-14ML/Ha would be 100% replaced.

	Cost/Value of Water ($/ML)							
Kernel Value ($/kg)	**$300**	**$400**	**$500**	**$550**	**$600**	**$700**	**$800**	**$1,000**
$0.50							<6ML/Ha	<6ML/Ha
$1.00								
$1.50								
$2.00								
$2.50								
$3.00								
$3.50								
$4.00								
$4.50								
$5.00								
$5.50								
$6.00								

6 to 8 ML/Ha economic, optimal water use application
8 to 10 ML/Ha economic, optimal water use application
10 to 12 ML/Ha economic, optimal water use application
12 to 14 ML/Ha economic, optimal water use application
14 to 16 ML/Ha economic, optimal water use application

Table 2. Sensitivity of water use figures in relation to changes in water and kernel value. Assumes the long term average yield at the Trial of approximately 4.5 T/Ha, maintenance water of between 3 and 7 ML/Ha to "just" grow a commercial crop and justify harvest, and 100% value placed in water based on 0% allocation.

Soil Chemistry

A first look at the impact of different management strategies on the chemistry of the soil (sampling position of 20cm from the dripper) indicated the following trends. The graphs depicted below are examples which best illustrated the trends in soil chemistry. Whilst the graphs are only of an individual treatment and depth range, the trends were consistent across all water and fertiliser treatments involved in the sampling procedure.

Soil pH

Firstly, significant soil acidification has occurred in the topsoil during the life of the Trial (Figure 2). Acidification is expected when nitrogen fertilisers which contain ammonium or urea are applied, particularly where there may be loss of nitrogen through the rootzone to drainage. It can be more serious where "point source" irrigation or intensive, drip irrigation systems are used. The acidification has predominantly occurred in the last two seasons where despite applications of lime to the soil surface, the soil pH has continued to decrease (become more acid). The likely cause of the sudden drop in soil pH depicted in Figure 2 is the exhaustion of the soil buffering capacity. This will occur faster in a sandy soil than in one that contains a higher percentage of clay and soil buffering capacity.

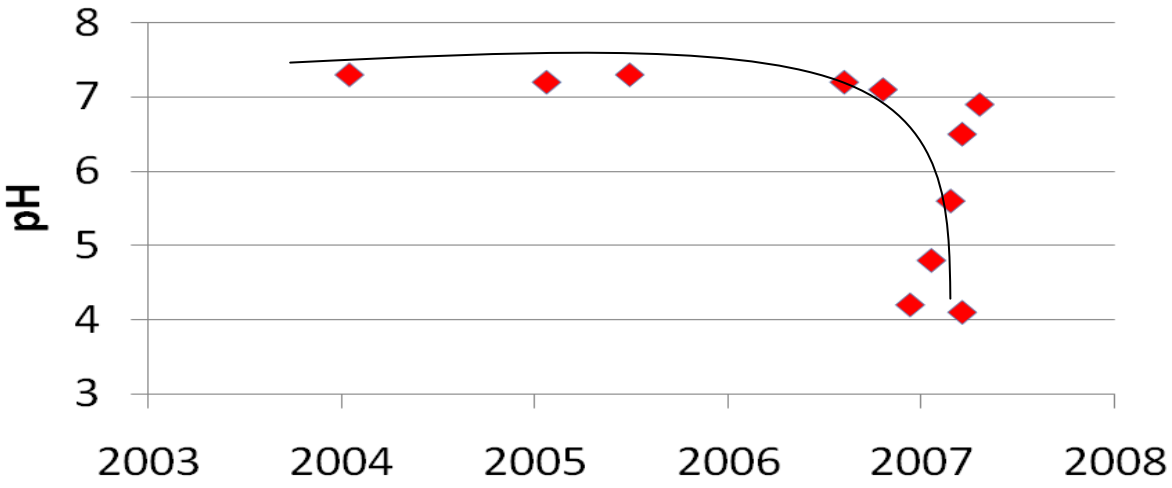

Figure 2. Treatment 2, 12.5-20cm.

Soil Salinity

Secondly, there has been an increase in soil salinity levels below 50cm (Figure 3) – this is a common feature of drip irrigation in low rainfall areas and with water sources that contain natural salts. To keep the rootzone free of damaging salinity it is necessary to build in a "leaching fraction" to move the salinity past the root zone.

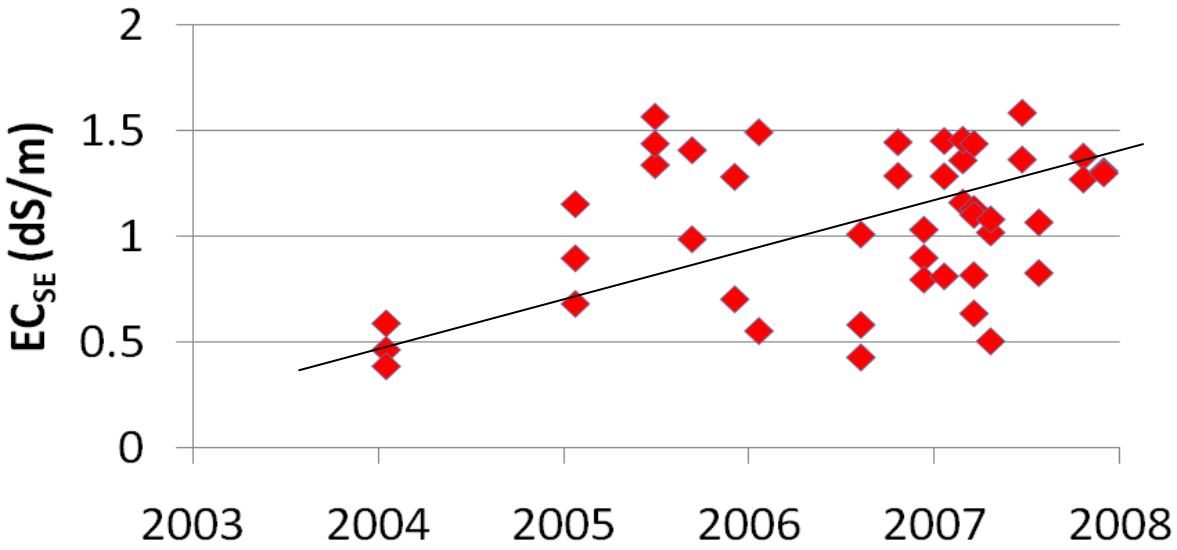

Figure 3. Treatment 1, 20-51cm.

Soil Nitrate Nitrogen

Thirdly, there has been a significant increase in the concentration of nitrate nitrogen below 50cm (Figure 4) – this is of concern to an orchard manager as it represents a waste of a resource and an unnecessary cost. In addition, it poses a risk to the environment and may mean that such a management system is unsustainable.

The movement of nitrate nitrogen through the soil profile is often a feature of irrigated horticulture. Nitrate nitrogen has a negative charge, urea is neutral and consequently neither are held up by the negatively charged exchange sites of the soil. The movement may also be attributed to an imbalance between the amount of nitrogen-containing fertilisers **applied** and the amount **required** by the trees. However, an analysis of the inputs (i.e. fertiliser quantities) in comparison to the outputs (i.e. crop removal of nitrogen) suggests a neutral to slightly negative nitrogen balance in the Trial. Consequently, the movement of nitrate nitrogen is more likely to be due to leaching rather than excessive applications of nitrogen fertilisers.

It is worth noting however, that a perfect nitrogen balance is very difficult to achieve and often only a 50% nitrogen use efficiency is achieved.

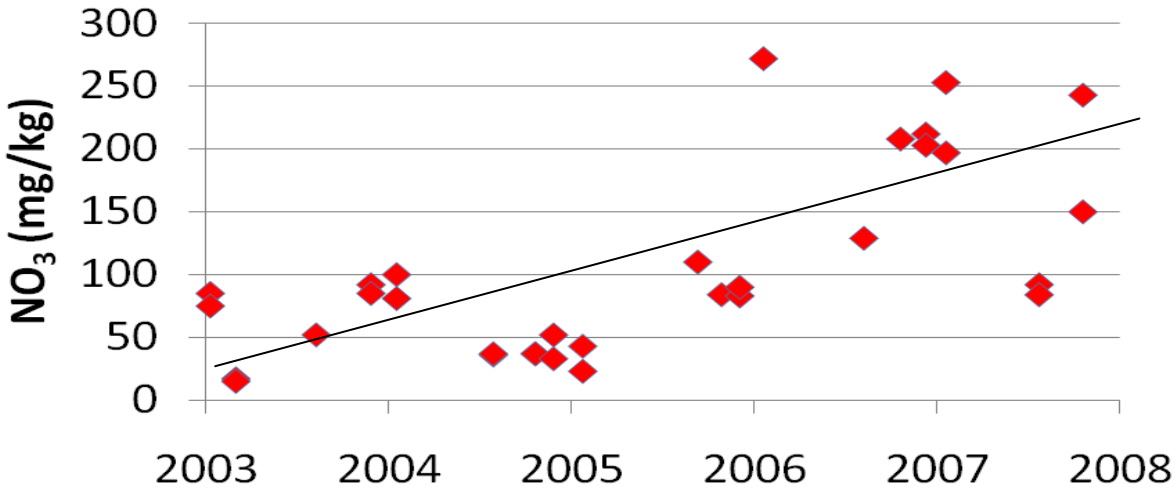

Figure 4. Treatment 1, 100-151cm.

Soil Potassium

Fourthly, the data indicates a significant increase in available potassium below 50cm (Figure 5) – this is also of importance to growers who may wish to adapt or adopt the strategies trialled at CT Farms. Movement of potassium through the soil profile and below the rootzone is not a common feature in irrigated orchards as potassium is positively charged and is more likely to bind with the negatively charged soil particles rather than be leached away. An analysis of the inputs (i.e. fertiliser quantities) in comparison to the outputs (i.e. crop removal of potassium) suggests a neutral to positive balance of available potassium in the Trial. Consequently, the movement of potassium could be attributed to an out of balance supply, leading to an increase in soil solution concentrations of potassium (i.e. available potassium) and the movement through the soil profile brought about by slight over application of irrigation water at some times in the season.

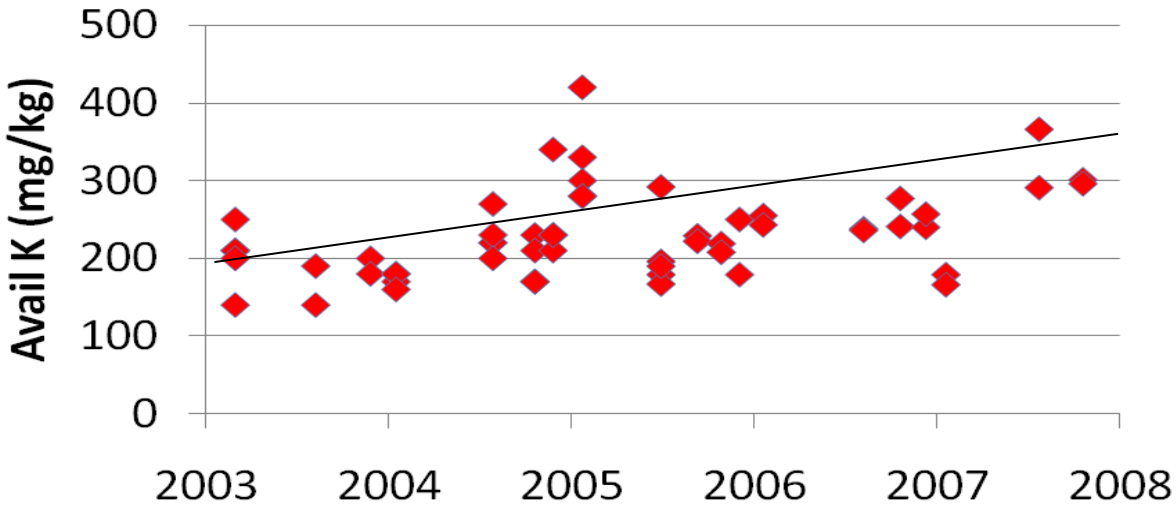

Figure 5. Treatment 1, 51-100cm.

Future Directions

The questions raised by the detailed examination of the soil chemical data have pointed out that management of the movement of water and nutrients such as nitrogen and potassium under an intensive, pulse irrigation regime are not fully understood. Both on the trial site and on any sites where the experience at the Trial is being adapted for commercial use, constant analysis of water movement through the soil profile and measurement of changes in soil chemical values will be needed if the system is to be sustainable. It is to address these issues that new features have recently been introduced to the CT Trial. These include:

a) The installation of soil solution extractors to monitor soil pH, nutrient movement, nutrient concentrations and nutrient uptake. It is hoped that this work will identify when losses to leaching occur and define the extent of such losses. It will also show how serious the build up in salinity below the rootzone might be and whether there will be risks to future tree health and crop production.

b) A closer investigation of the crop factors and associated irrigation quantities for the 100% irrigation treatments. It is hoped that this work will make it possible for orchard managers to control (not prevent) the losses of water below the rootzone.

c) A more detailed investigation of a nutrient balance between inputs (i.e. fertiliser applications) and outputs (i.e. crop removal of nutrients). This will mean better nutrient use efficiency and lowered production costs.

Monitoring is important

For further information on appropriate sampling procedures where components of the CT Trial are being tested on commercial orchards contact Ben Brown, Industry Liaison Manager. It is obvious that pH changes in the soil occur slowly and nutrient losses through the rootzone are not at this stage too serious. However, an annual monitoring program could help define risks and point to management changes in time to forestall development of more serious problems.

Published by Almond Board of Australia, ***PO Box 2246, Berri, South Australia 5343***
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ACKNOWLEDGEMENTS
The input and suggestions made by Ray Correll, Dr Ben Robinson and Brett Rosenzweig.

All About Almonds

Fact Sheet 08 – Crop Nutrient Removal

Welcome to the eighth edition of "All About Almonds", Crop Nutrient Removal. Fact sheets are distributed to almond growers via email and fax, in addition to being made available for download from the almond growers' section of the ABA website: www.australianalmonds.com.au (follow links to the login section of the "industry" page).

The information provided in these fact sheets should be kept confidential.

Background

Historically, fertiliser programs for most horticultural crops have been monitored using leaf analysis at a particular period of the growing season. Whilst this technique has been useful in assessing nutrient status and nutrient levels, it does not either directly indicate the quantity of nutrients required to produce a crop or provide an accurate assessment of the nutrient ratios which the season's fertiliser program should be based around. The more recent introduction of "new" intensive water and fertiliser management systems such as the CT Optimisation Trial and Hydroponic systems has made it possible to adjust fertiliser inputs quite precisely, so understanding how much nutrient is removed when the crop is harvested could be very helpful in setting input quantities and ratios.

Measuring crop removal at harvest could be used three ways:

1. Evaluation of the current season's fertiliser program against a set of standards or past results, the same way leaf analysis is used.
2. Calculating the **minimum** quantity of nutrients required in a fertiliser program to at least replace the nutrients removed at harvest. This could involve the replacement of both macro elements (i.e. N, P, K, Ca, Mg) and micro elements (i.e. Cu, Zn, Mn, Fe and B).
3. Understanding the approximate ratio of nutrients that should be included in the fertigation program

Although an understanding of the composition of the harvested nuts and calculation of nutrient removal provides the manager an important basis for the preliminary design of a fertiliser program, it does have limitations. It does not help us understand; a) when best to apply the nutrients to

match the trees' requirements at the different phenological (development) stages of the growing season, b) how much, or which nutrients are being supplied to the tree from other sources, such as soil mineralisation, c) how much, or which additional nutrients are required to grow new foliage and roots, d) what the inefficiencies and limitations of on-farm fertiliser and water application may be, e) which nutrients are lost through volatilisation, leaching below the active root zone or soil fixation, or f) which nutrients are left behind at harvest and stored within the tree. In the future, information on crop nutrient removal will be extremely helpful as the basis of modern, best practice fertiliser programs and after a number of years will allow mangers to benchmark against previous seasons and, estimate the majority of nutrients required to produce a crop and in what ratio.

Until better research information is available, a rough rule of thumb can be used to estimate the additional nutrient required to meet the other growth demands (e.g. foliage and root growth) and losses. Present information would suggest applying further 20-30% to the crop nutrient removal figures.

Methodology

Growers who would like to begin to measure crop removal could use the nut sampling method used on the CT Trial. Samples are collected just prior to **harvest.** The same trees used for leaf analysis are visited and the same sampling criteria are used, that is:

Sampling

- **Small to medium sized trees** - if good light interception is present around the whole tree, the sample should include four fruit (one from each of the north, east, south and west sides of the tree) from twenty to twenty five trees at shoulder height.
- **Large trees or hedgerow plantings** - the sample should include four fruit (two from each side of the tree) from twenty to twenty five trees at shoulder height.
- **A representative area** - Regardless of the situation, the sample should take into account variety (commonly Nonpareil is the only variety sampled), rootstock, age, soil type, topography, etc and avoid diseased, damaged, irregular sized, water stressed fruit, end trees and end rows. Commonly a diagonal transect is taken from one corner of the patch to the opposite corner. In hedgerow plantings an up and back loop through the orchard may be used. The sampling track should be recorded so that the same trees can be sampled each year.

The fruit should be hand cracked by the grower into the three fruit components, husk, shell and kernel (no blanks or part thereof are to be included in the sample) and each sample placed in three separate, well labelled paper bags. The fruit could be analysed as whole fruit but more information such as hull boron levels, nutrient partitioning, etc can be obtained from the separate analysis.

Analysis

The bags should be delivered to the same laboratory used in previous year's fruit or leaf analysis. However, to satisfy quality control or curiosity, additional sub-samples may be sent to another laboratory for cross checking.

Commonly used laboratory:

Geoff Proudfoot
CSBP Soil & Plant Laboratory
2 Altona Street
Bibra Lake, WA, 6163
Phone: (08) 9434 4600

Growers will need to specify to the laboratory that the following tests are required for each sample:

- Wet weight (gm).
- Dry weight (gm).
- Moisture content (%) (Calculated from the above measurements and enabling a comparison against your processor's crack out results. Of course, this comparison needs to be made in reference to stockpiling duration, moisture loss, etc).
- Dry matter production (%) is consequently calculated.
- Full analysis of the sample to include Nitrogen (N%), Phosphorus (P%), Potassium (K%), Sulphur (S%), Calcium (Ca%), Magnesium (Mg%), Sodium (Na%), Chloride (Cl%), Zinc (Zn mg/kg), Manganese (Mn mg/kg), Iron (Fe mg/kg), Copper (Cu mg/kg), Boron (B mg/kg).

Once the data has been received from the laboratory, it is possible to calculate nutrient removal using the sample patch yield result (kg/ha of kernel). It can be entered into the crop nutrient removal section of the "Almond Water Use, Irrigation, Fertiliser and Foliar Spreadsheet" located in the login section of the Almond industry website: www. australianalmonds.com.au. The result will provide an indication of the partitioning of the nutrients within the fruit and the amount of nutrients removed at harvest.

For those who prefer to do their own calculations, the formula for each fruit compartment (i.e. husk, shell and kernel) which are then summed together to provide whole fruit, is simply:

- (Wet weight yield (kg/ha) x % element (wet weight basis)) = kg/ha element removed

Or

- (Wet weight yield (kg/ha) x mg/kg element (wet weight basis))/1,000,000 = kg/ha element removed

Results and Interpretation

There are no conclusive standards for the nutrient analysis of almonds in the literature, however the nutrient analysis data collected over the last few years from the ABA's commercial demonstration sites and from the CT Trial is provided in Table 1~~Table 1~~ as a guide.

Table 1. 2007/08 and 2008/09 Nonpareil nutrient analysis.

		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Cl (%)	Zn (mg/kg)	Mn (mg/kg)	Fe^ (mg/kg)	Cu (mg/kg)	B (mg/kg)	S (%)
Keane	**Husk**	0.62	0.11	2.40	0.15	0.08	0.10	0.22	25.50	14.00	161.00	5.95	54.00	0.02
	Shell	0.54	0.03	0.82	0.16	0.03	0.07	0.09	4.00	5.40	55.50	4.70	23.00	0.02
	Kernel	3.85	0.50	0.82	0.25	0.30	0.01	0.05	41.50	27.50	71.00	13.50	20.00	0.15
Jubilee	**Husk**	0.81	0.09	2.75	0.14	0.08	0.01	0.07	20.00	14.50	62.00	4.75	54.00	0.04
	Shell	0.43	0.03	1.40	0.11	0.03	0.01	0.06	5.20	6.35	15.00	4.10	21.00	0.02
	Kernel	3.95	0.54	0.89	0.19	0.28	0.01	0.05	38.00	27.00	50.00	11.50	15.50	0.15
Pearce	**Husk**	1.30	0.14	3.15	0.15	0.07	0.02	0.20	27.00	51.00	232.00	5.10	45.50	0.04
	Shell	0.60	0.03	1.25	0.14	0.03	0.02	0.08	4.10	15.50	83.00	4.40	25.50	0.02
	Kernel	4.10	0.54	0.83	0.23	0.31	0.01	0.05	42.00	42.00	72.50	12.00	19.00	0.17
CT Trial#	**Husk**	0.3-0.5	0.02-0.05	1.4-2.6	0.06-0.08	0.02-0.03	0.01	0.03-0.07	30-82	3.2-7.5	29-42	0.8-2.2	28-56	0.01
	Shell	0.3-0.5	0.01-0.02	0.5-1.8	0.05-0.1	0.01-0.03	0.01	0.05-0.07	7.3-15	2.4-8.7	5.1-27	0.9-2.7	11-28	0.01-0.02
	Kernel	1.7-3.4	0.19-0.39	0.34-0.756	0.09-0.2	0.11-0.24	0.01	0.07	19-51	11-37	20-50	3.1-7.9	11-31	0.01-0.13

#Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.

^Husk Fe levels are normally unusually high due to contamination from the orchard floor (soil) at harvest.

Using the data in Table 1~~Table 1~~ and the kernel yield results, crop nutrient removal, crop nutrient removal plus 20% and an approximate nutrient balance is provided in Table 2~~Table 2~~, Table 3~~Table 3~~ and, Table 4~~Table 4~~ respectively.

Table 2. 2007/08 and 2008/09 Nonpareil whole fruit nutrient removal (kg/ha).

	Kernel Yield (kg/ha)	Water (ML/ha)	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	Fe^	Cu	B	S
Keane	2,625	9.37	145.82	20.10	179.93	17.64	12.69	7.01	15.83	0.27	0.17	1.25	0.08	0.41	5.42
Jubilee	4,510	16.09	266.32	33.74	340.00	23.81	20.64	1.64	10.16	0.38	0.28	0.87	0.11	0.65	10.52
Pearce	3,977	10.87	247.64	29.28	231.46	20.56	16.36	1.63	14.16	0.32	0.47	1.72	0.09	0.39	9.41
CT Trial#	3,785-4,138	11.10-17.70	95-291	10-27	136-357	8-21	7-17	1-3	5-18	0.5-1.0	0.1-0.3	0.3-1.1	0.02-0.07	0.3-1.3	2-7

#Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.

^Husk Fe levels are normally unusually high due to contamination from the orchard floor (soil) at harvest.

Table 3. 2007/08 and 2008/09 Nonpareil whole fruit nutrient removal plus 20%.

	Kernel Yield (kg/ha)	Water (ML/ha)	N	P	K	Ca	Mg	Na	Cl	Zn	Mn	Fe^	Cu	B	S
Keane	NA	9.37	174.98	24.12	215.92	21.17	15.23	8.41	19.00	0.32	0.20	1.50	0.10	0.49	6.50
Jubilee	NA	16.09	319.58	40.49	408.00	28.57	24.77	1.97	12.19	0.46	0.34	1.04	0.13	0.78	12.62
Pearce	NA	10.87	297.17	35.14	277.75	24.67	19.63	1.96	16.99	0.38	0.56	2.06	0.11	0.47	11.29
CT Trial#	NA	11.10-17.70	114-349	12-32	163-428	10-25	8-20	1.2-3.6	6-22	0.6-1.2	0.1-0.4	0.4-1.3	0.02-0.08	0.4-1.6	2-8

#Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.

^Husk Fe levels are normally unusually high due to contamination from the orchard floor (soil) at harvest.

Table 4. Nonpareil 2007/08 and 2008/09 whole fruit nutrient balance.

	N (kg/ha)			P (kg/ha)			K (kg/ha)		
	Actual Applied (IN)	**Calculated Removal + 20% (OUT)**	**Balance (+/-)**	**Actual Applied (IN)**	**Calculated Removal + 20% (OUT)**	**Balance (+/-)**	**Actual Applied (IN)**	**Calculated Removal + 20% (OUT)**	**Balance (+/-)**
Keane	240	175	+65	25	24	+1	400	216	+184
Jubilee	320	320	0	50	41	+9	600	408	+192
Pearce	320	297	+23	38	35	+3	500	278	+222
CT Trial#	240-320	114-349	+206 to -109	54	12-32	+22 to -42	400-600	163-428	+237 to +172

#Due to the increased number of samples and considerable variation in results, a range has been displayed rather than an average.

Analysis of the above tables very simply suggests:

- Keane - More nitrogen applied than removed, good balance of phosphorus, more potassium applied than removed
- Jubilee Almonds - Good balance of nitrogen, good balance of phosphorus, more potassium applied than removed
- Pearce - Good balance of nitrogen, good balance of phosphorus, more potassium applied than removed
- CT Trial - Variable.

The variable nutrient removal from the CT Trial compared to the other orchards is difficult to explain and will require further seasons data and investigation. Quite simply, it could be seasonal or sampling variability across the orchard. For example, the three commercial orchards sampling is a result of a bulk sampling procedure and consequently an average of the patch where as the CT Trial results are the range from individual trees with no bulk sampling and averaging.

Each grower's orchard may also have different results due to sampling rigour, a lighter yield, a lower analysis fruit caused by a lighter fertiliser program or different crackout percentages and weights. At this stage we are all feeling our way on how the data should be interpreted, but if all almond orchards included measurements of crop nutrient removal in their yearly monitoring program (for example from one or more representative patches of Nonpareil) it is expect that the usefulness of the data will become evident. The data may slightly vary from one patch to the next but this tool will provide a good basis on which to formulate a strategic fertiliser program from one year to the next. Further analysis of future crops, including traditional leaf analysis, and the use of other tools such as soil sampling and soil solution extractors will not only fine tune the total nutrient requirements of an almond orchard but also the timing of nutrient applications and in what ratios.

For further information contact Ben Brown, Industry Liaison Manager

Published by Almond Board of Australia, ***Po Box 2246, Berri, South Australia 5343***
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ACKNOWLEDGEMENTS
The input and suggestions made by Dr Ben Robinson and Brett Rosenzweig.

ALL ABOUT ALMONDS
October 2010

Fact Sheet 09
Almond Orchards and Soil Acidification

Richard Merry
CSIRO – Land and Water

Ben Brown
Almond Board of Australia

Welcome to the ninth edition of "All About Almonds", Almond Orchards and Soil Acidification. Fact sheets are distributed to almond growers via email, in addition to being made available for download from the ABA website: www.australianalmonds.com.au (follow links to the login section of the growing page).

1. Background

The formation of acid in soil is a side effect of most forms of modern agriculture and can be particularly important in intensive systems. Many of the soils used in Australian agriculture initially had pH values suitable for growth of most plants or have residual calcium carbonate (lime) that counteracts the effects of any acidity formed. This means that low input agriculture can proceed for some time before the undesirable effects of acidification become evident. The changes in the soil are usually slow and may not be noticed until there are severe production decreases.

However, intensification of agriculture (increased fertiliser use, increased production, etc.) can speed up acidification processes and their undesirable effects. Consequently, there is a need to monitor practices, soil condition (usually with a pH measurement) and when necessary, remediate the soil by liming.

It is important to be aware of the processes leading to acidification and what should be done to protect soil and its capacity to support root growth.

Soil types vary in their capacity to cope with acidification. The main difference is in the time taken to reach a critical point where productivity is affected. This is because soils differ in their pH buffering capacity which is the capacity of a soil to resist pH change. Sandy soils have a lower buffering capacity than clayey soils and if lime is present in the soil, the buffer capacity can be very large. If the plant production system produces acid, in the long term it does not matter what the properties of the soil are as the soil is being acidified – poorly buffered soils reach a critical pH sooner than well buffered soils. Although a pH measurement will indicate the condition of the soil that is critical for plant growth, a buffer capacity or lime requirement measurement is needed to estimate the amount of lime needed to raise soil pH to a target level.

Depending on the pH buffering capacity of the soil and its starting pH, it may take decades to reach a situation where plant production is affected and as the process is often slow, it is usually difficult to separate yield decline from normal seasonal variation. For this reason it is important to maintain a satisfactory soil pH condition to avoid potential productivity losses.

Modern almond production systems in Australia produce acidity when yields increase and particular fertilisers are used, especially those ammonium-containing forms of nitrogen (e.g. sulfate of ammonia, urea, UAN, ammonium nitrate, etc). In drip irrigated orchards, the production system concentrates fertiliser placement, water delivery and nutrient uptake into a relatively small proportion of the total soil volume and this zone has a high potential for rapid acidification – significantly more than sprinkler irrigated orchards. This situation has also been observed in many other drip irrigated crops such as citrus orchards and vineyards.

2. Measuring Soil Acidity

Soil acidity (or alkalinity) is measured by a pH test and is a measure of the concentration of hydrogen ions (H^+) in the soil solution. pH is measured on a negative logarithmic scale between 1 and 14 with 7 being neutral (Figure 1).

Soil pH is often measured using two laboratory techniques; 1) 1:5 solution of soil and water (pH_w), or 2) 1:5 solution of soil and a weak solution of calcium chloride (pH_{ca}). The calcium chloride method which is the more commonly used and reliable method, will produce results that are approximately 0.8 of a pH unit lower than water tests and is less subject to seasonal variation.

Due to the logarithmic scale, a change in soil pH of one pH unit represents a tenfold change in hydrogen ion activity. That is, a small decrease in soil pH results in a large increase in acidity. For example, soil with a pH of 4 is ten times more acidic than a soil with a pH of 5 and 100 more times acidic than a soil with a pH of 6.

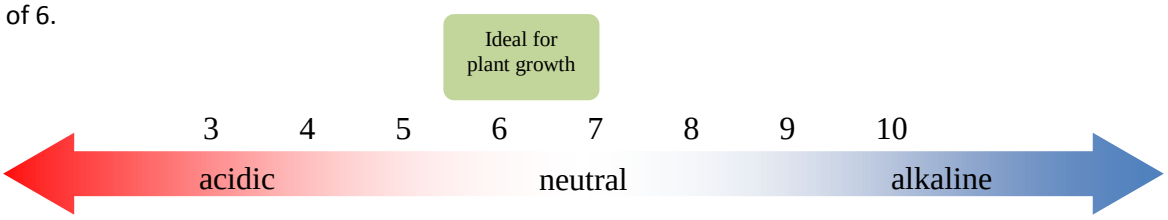

Figure 1 pH Scale

A less common measurement is soil pH buffering capacity. This measurement is more difficult to make and not often carried out. It is the rate of change of soil pH as acid is added. Clays and soils with increased organic matter have a higher pH buffer capacity than sandy soils.

3. Causes of Soil Acidification in Almond Orchards

There are several important causes of soil acidification and the interactions of the acidification processes can be complex (Figure 2). They have been known and studied for a long period of time – even the early farmers (Etruscans, Romans) knew that lime was needed to offset acidity – and liming practices have long been in place in other parts of the world.

The processes of acidification outlined below are known to be the principle causes of soil acidification in agricultural systems and much more significant than external causes of acidification such as acid rain. The two major causes of soil acidification in almond orchards are the use of some nitrogen fertilisers and product (fruit) removal.

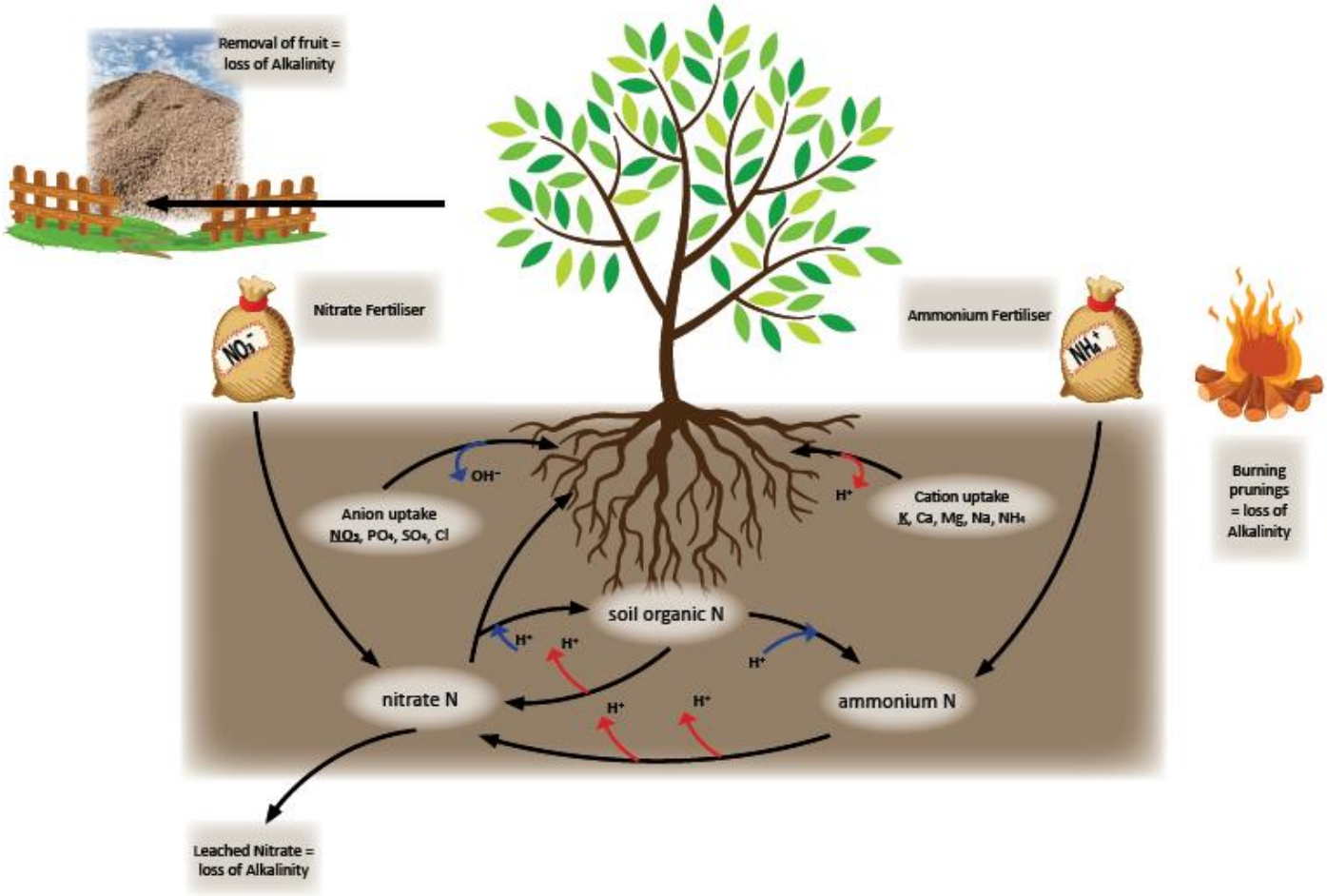

Figure 2 Processes of Soil Acidification in Almond Orchards

3.1 Nitrogen Fertilisers

Nitrogen fertilisers are a major cause of soil acidification when fertilisers containing ammonia are used. Although not exactly the same, urea behaves in a similar way. The processes that are involved are complex and include reactions in the soil, exchanges with the plant root, leaching and volatilisation.

Each ammonium ion (NH_4^+) in the fertiliser is usually transformed to nitrate (NO_3^-) in the soil by bacteria. This process releases two acidifying protons (H^+) for each ammonium ion and one acidifying proton for each amino group (NH_2). The amino group usually comes from the natural decomposition of organic matter.

There is a further process that will determine the severity of the acidification; that is, the fate of the nitrate ion. If the nitrate ion is taken up by the plant, the acidification effect is less than if the nitrate ion were to be leached beyond the root zone. (See the nutrient uptake section below for further explanation of this process).

In practice, scientists mostly use average values for acidification by fertilisers as these values are usually able to account for measured changes in soil acidity (see Table 1).

Fertiliser	Equivalent Lime ($CaCO_3$) Needed to Neutralise Acidity (kg $CaCO_3$ / kg N or S)[b]
Urea	1.8
Ammonium Nitrate	1.8
Ammonium Sulfate	5.4
MAP	5.4
DAP	3.6
Sulfur (elemental)	3.1[c]
N as Nitrate	-3.2[d]

Table 1 The acidity resulting from the use of nitrogen or sulfur in fertilisers. The values presented are the average amount of lime ($CaCO_3$) needed to neutralise the acidity.

Adapted from Adams (1984)
[b] These are average values for nitrogen and can vary ± 1.8 kg.
[c] This assumes complete conversion to acid; for thiosulfates, the value is about 1.6 per unit of S.
[d] This is negative because nitrate uptake by plants increases the alkalinity of soil. This value assumes 10% of the nitrate is leached.

For reasons outlined below, nitrate fertilisers are not acidifying and can make the soil more alkaline. Ammonium nitrate contains two forms of nitrogen, but the acidification from the ammonium component is greater than the alkalinity that results from the nitrate component.

3.2 Other Fertilisers

Whilst most attention is given to the acidification risk from nitrogen fertilisers, some other fertilisers can also cause acidification. They are mainly fertilisers that contain sulfur – elemental or dusting sulfur, and thiosulfates. In these sulfur-containing materials, some or all of the sulfur is acted on by soil bacteria producing sulfuric acid.

Sulfate fertilisers (such as potassium sulfate, magnesium sulfate, zinc sulfate, etc) do not acidify soils. The only obvious exception is ammonium sulfate which acidifies soil due to its ammonium component, not the sulfate component.

It is a common misconception that superphosphate has caused soil acidification. This is untrue. Using superphosphate has enabled legumes and other plants to grow well and it is the consequences of nitrogen fixation, product removal and associated acidification that is really contributing to acidification.

3.3 Nutrient Uptake and Fruit Removal

When plants grow, they usually take up nutrients such as nitrogen (as nitrate, NO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), phosphorus (as phosphate, $H_2PO_4^{2-}$), sulfur (as sulfate, SO_4^{2-}), and others. You will notice these nutrients have a positive (+) or negative (-) charge. In the process where these charged elements are taken up through plant roots, the plant needs to release an element with equivalent charge. This is achieved in one of two ways:

1. When a positively charged 'cation' (eg K^+) is taken up, the plant exchanges an equivalent positive charge by releasing an acidifying proton (H^+).
2. When a negative charged 'anion' (eg NO_3^-)is taken up, the plant exchanges an equivalent negative charge by releasing an alkaline hydroxyl (OH^-).

Most plants take up more positively charged than negatively charged ions and the net effect is soil acidification. In a closed system where all plant matter is recycled on-site, the uptake of more positive charged ions may not be a problem. However, when plant products (e.g. fruit) are removed, the 'alkalinity' developed in the plant material is lost and the soil is left in a more acidic condition. This is made worse in high yielding agricultural systems (e.g. almond orchards) that produce large quantities of removable plant material, such as almond husks, shells, kernels and prunings.

	Ash Alkalinity of Material (kg $CaCO_3$ / kg, dry)	Indicative Dry Yield (kg/ha)	Equivalent Alkalinity Lost (kg $CaCO_3$ / ha)
Husk	0.043	4,980 6,640	215 285
Shell	0.025	1,250 1,660	31 42
Kernel	0.008	3,000 4,000	24 32
TOTAL		**9,230** **12,300**	**270** **360**

Table 2 Annual plant ash alkalinity, yield of product, percentage dry weight and alkalinity (expressed as calcium carbonate equivalent) of almond husk, shell and kernel.

There are ways of estimating the amount of alkalinity removed and some values expected for almonds can be made using an acidification calculator (Thomas, 2009) and are shown in Table 2. The table is based on limited data but shows estimates of the potential alkalinity lost when almond husks, shells and kernels are removed, per kilogram of these materials, and on a per hectare basis. As all of this plant material is lost, soil acidification equivalent to about 300-400 kg of lime ($CaCO_3$) per hectare is lost by product removal alone each year.

In loamy soils without any natural lime, acidification of 300 kg $CaCO_3$ equivalent each year may result in a soil pH decrease of one unit in:

- Sprinkler Orchards (100% wetted area) – approximately 6 to 8 years, or
- Drip Irrigated Orchards (approx 30% wetted area) – approximately 2 to 2.5 years

In sandy soils, which are traditionally the soils selected for almond orchards, this will occur even faster due to the lower buffering capacity of sand. The use of ammonium-containing fertilisers will also quicken this process.

The almond industry's Optimisation Trial (aka CT Trial) has provided an illustration of how quickly and severely soil acidification can occur on an almond orchard which is planted on sandy textured soil, drip irrigated, receives high amounts of ammonium containing fertilisers, achieves high yield, and doesn't have all of its cations replaced by fertigation (e.g. calcium, magnesium).

A statistical analysis of the CT Trial soil data indicates there has been a statistical effect of the scientific treatments on soil pH, with an approximate decrease in pH_{ca} of 0.25 to 0.65 pH unit/year. The result has seen soil pH_{ca} that began at approximately 8.0 in 2001, decrease to 5.5 at 0 to 20 cm (Figure 3).

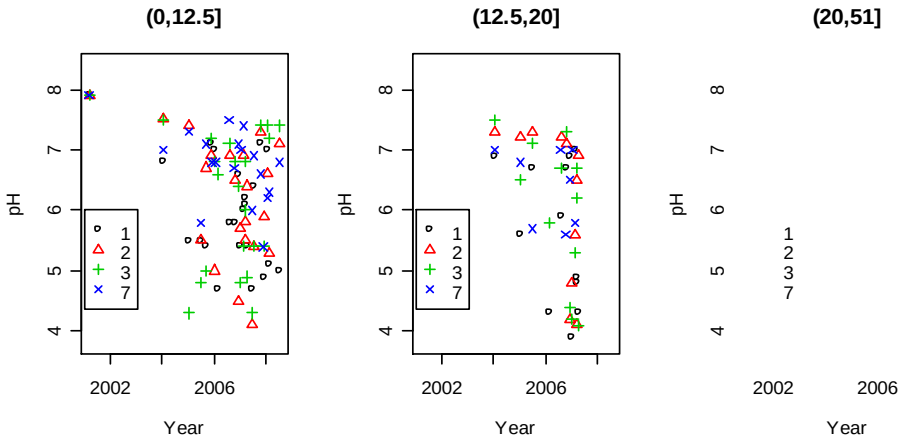

Figure 3 Optimisation Trial, Soil pH at 0-12.5cm and 12.5-20cm

Almonds are deciduous plants, shedding their leaves annually. It is usually assumed that leaves are recycled within the orchard, conserving any of the elements mentioned above. If the leaves, or prunings, are removed or lost from the vicinity of the tree, there will be an additional acidification, but this is thought to be small in comparison to fruit removal at harvest.

3.4 Leaching

As mentioned above, when plants take up nitrate (NO_3^-) - the usual form that plants take up nitrogen from soils - alkalinity is left behind in the soil at the site of uptake. Nitrate usually comes from the nitrification process mentioned above, which is acidifying, or from nitrate-containing fertilisers. Either way uptake of nitrate ions usually assists in making soil more alkaline.

However, there is an exception in situations where there is a high incidence of flushing events due to rainfall or poorly managed irrigation. In these conditions the nitrate in the soil can be leached to a lower point in the soil profile, or even below the rooting zone, and in the process take with it a companion ion. This results in the upper part of the soil profile becoming more acidic and the subsoil more alkaline when more nitrate is taken up from deeper in the soil.

4. Effects of Soil Acidification

Progressive acidification alters soil properties, usually detrimentally unless the soil is very alkaline. In alkaline soils, where pH_w values are higher than 8.5, some acidification may be beneficial and help increase the availability of some nutrients, such as iron (Fe), manganese (Mn) and zinc (Zn). Lowering the pH_w below 8.5 may also improve the efficiency of the nitrification process. As soil acidifies and reaches pH_w values less than 5 to 5.5, significant detrimental changes begin to occur. These effects are outlined below.

4.1 Acidification Effects on Plant Toxicities and Nutrient Availability

When a soil acidifies and the pH_w decreases to below 5, detrimental changes start to occur in the soil. They may not become visually apparent in the plant or its yield loss until the pH_w is much lower, below 4.5. As the soil acidifies, the acidic protons (H^+), which are very reactive, quickly attack minerals in the soil. Firstly, alkaline materials such as lime are used up as it reacts and neutralises the acid. Once the lime has reacted with the acid, it is removed from the soil permanently. Secondly, when most of the lime has been 'used', the acid starts to attack the clay minerals.

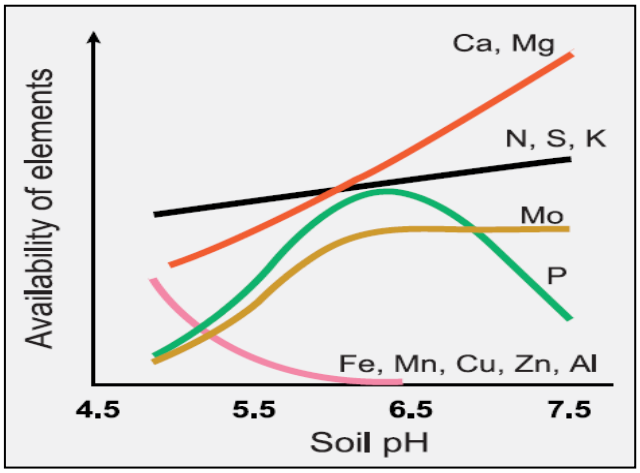

Figure 4 Relationship between soil pH and nutrient availability
(Source: Soil acidity: a guide for WA farmers and consultants)

With increasing acidity (Figure 4), clay mineral decomposition can release elements such as aluminium (Al) and manganese (Mn). Both elements are toxic to plant roots, especially aluminium. Aluminium causes young, growing root tips to become stunted (Figure 5) and roots are often described as 'stubby'. For a plant to be productive its roots must continually grow, so if this is retarded, plant productivity decreases.

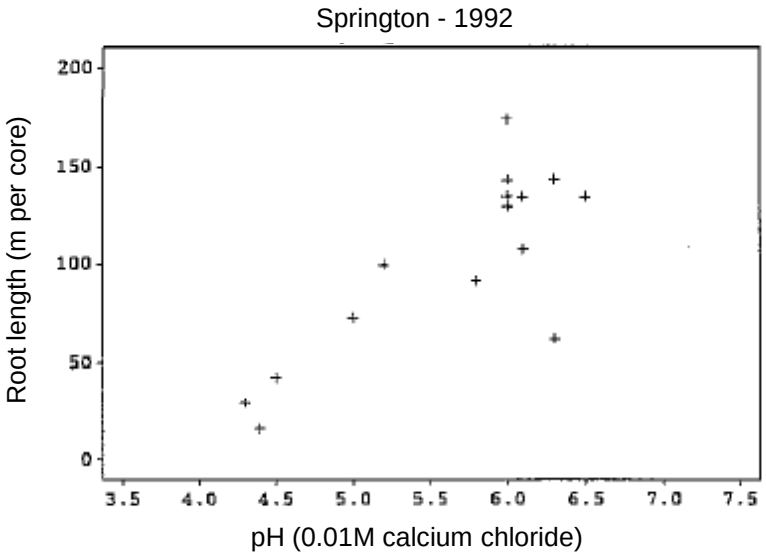

Figure 5 Effect of pH on grapevine root growth (aluminium toxicity), Robinson (2000)

Increased aluminium availability in acidified soils also interferes with the ability of the plant root to take up other elements that are essential for growth, including iron (Fe), calcium (Ca) and magnesium (Mg). Acidification actually increases the solubility and availability of elements like calcium and magnesium, but the low pH and effects of high aluminium prevent uptake. These nutrient elements are then vulnerable to leaching from the soil, so over long periods of time, even mildly acidified soils become impoverished in many nutrients.

Other elements, including many of the trace elements (copper, zinc and manganese) become more readily available to plants. Molybdenum (Mo) does not become more available in acidic soils. It is more available in alkaline soils.

4.2 Urea and Ammonium Conversion to Nitrate

The soil processes that convert urea and ammonium-containing fertilisers to nitrate (nitrification) are enabled by soil microorganisms. The same processes are involved in the conversion of amine nitrogen (from the amino acids in proteins that are part of the soil organic matter) to nitrate. Soil pH_w values below 6 are sufficient to start having a detrimental effect on the efficiency of nitrification and the rates decrease progressively below this pH and become negligible by about pH_w 4.5. Consequently, nitrate availability from ammonium-containing fertilisers and organic matter is reduced in acidic soils.

5. Managing Soil Acidification

Managing almond orchards starts with soil preparation. If a soil is already acidic at the time of orchard establishment, lime should be applied to increase soil pH_w to a value greater than 6.

Orchard fertiliser practices and the rate of product removal can be used as a guide to the likely acidification rate and amount of lime needed to remediate it.

It is very important to manage acidifying fertiliser use to ensure that applications are not excessive. If the soil is likely to acidify, it is important to make an allowance for the purchase of liming materials as part of the orchard fertiliser management plan.

Product removal (husks, shells, kernels) is an important cause of acidification. Since they are removed from the orchard, conservation of their alkalinity is not possible and there is little choice but to:

a) replace all nutrient uptake (that is, more than just nitrogen, phosphorus and potassium) with fertiliser applications, and/or
b) replace the alkalinity lost by using a program of liming.

Soils with naturally occurring lime in surface layers may not show effects of acidification for many years. A soil with 1% $CaCO_3$ has approximately 10,000 kg of lime per hectare 10 centimetres deep. However, soil pH should be monitored annually in high yielding orchards with high fertiliser use, particularly in drip irrigated orchards.

In drip irrigated orchards, most acidification is concentrated in the wetted volume of soil as this is where most nitrification and nutrient uptake occurs, not in the inter-row. This concentration of processes can greatly increase the rate of soil acidification. Work in drip irrigated orchards and vineyards have confirmed this, and this volume of soil should be targeted for pH monitoring and lime application. However, managers should not ignore the inter-row where acidification is usually less or minimal.

12.3 Appendix 3 – Almond Production Spreadsheet: Irrigation and Nutrition Management Programs

6. Remediation of Soil Acidification

Once a soil is acidified, the application of liming materials (lime, dolomite, etc.) is the principal way acidification can be managed. The amount required can be minimised by putting in place management practices outlined above.

Lime application rate is usually based on a pH measurement, identification of a 'target' pH and an estimate of the soil pH buffer capacity. It will also vary depending on the type of lime being used.

Robinson (2000) developed a quick method to estimate buffering capacity by estimating soil texture and using 'rule of thumb' data. The research indicated to raise soil pH by one unit to a depth of approximately 15 cm, the following rates of lime (t/ha) may be required:

- sands, loamy sands 1.0 – 2.0
- sandy loams 2.5 – 3.5
- loams, sandy clay loams 3.5 – 4.0
- loamy clays 4.5 – 5.0

Alternatively, laboratory tests are available.

There can be difficulties in physical application and incorporation of lime in drip irrigated orchards. The soil needs to be moist and the lime 'watered' in. Lime also takes a few months to equilibrate with the soil following application. Consequently, lime application should be followed up with soil pH testing to ascertain is effect.

There can also be difficulties in all orchards if sub-soil layers are allowed to acidify. For these reasons, it is very important to manage acidity before soil deeper than 20 or 30 cm becomes acidified.

Some reversal of acidification can be expected if nitrate fertilisers (for example, calcium or potassium nitrate) are used. There may be cost constraints in using them, but this should be balanced against the cost of applying lime if acidifying fertilisers are used. It should also be noted that fertiliser programs solely based on nitrate-containing fertilisers are not 'healthy' for the plant or fruit.

The chemical properties of irrigation water may also need to be taken into account, depending on its source. Most dam water in high rainfall areas has very low alkalinity. Water from the Murray River has a low and seasonally variable alkalinity. Work assessing dripper irrigated vineyards suggests that it has little beneficial effect in neutralising acidity. However, groundwater from aquifers in limestone which becomes saturated with calcium carbonate can be effective and may significantly raise soil pH. Reclaimed water needs to be analysed on an individual source basis and used with extreme care as some sources have high potassium, sodium and alkalinity, and have potential to cause detrimental changes to the subsoil drainage characteristics.

7. Key Points

- Soil acidification can be a naturally occurring process.
- Horticulture rapidly accelerates the soil acidification process.
- If unmanaged, soil acidification in drip irrigated orchards may occur at approximately three to four times the rate in comparison to sprinkler irrigated orchards due to the rapid exhaustion of such a small, concentrated soil volume.

- Current almond fertiliser programs in drip irrigated orchards are resulting in soil pH values decreasing by approximately of 0.25 to 0.65 pH_{ca} unit/year. The result has seen soil pH_{ca} that began at approximately 8.0 in the year 2001, decrease to 5.5 at 0 to 20 cm by 2008.
- Almond trees take up more positive ions than negative ions, resulting in a potential net soil acidification effect.
- The removal of fruit at harvest exports alkalinity which is not returned to the soil, causing acidification.
- Biggest causes of soil acidification in almonds are fruit removal at harvest and ammonium based fertilisers.
- Other potential causes of soil acidification in almonds are nitrate leaching and removal of prunings.
- Nitrogen fertiliser programs should be more biased towards nitrates (alkaline effect) rather than ammonium (acidifying effect) sources. However, be mindful that nitrate toxicity may be detrimental to fruit quality and nitrate is more readily mobile and susceptible to leaching.
- Fertiliser and acidity management programs should aim to balance nutrients lost, and not just consider nitrogen, phosphorus and potassium. A survey of industry leaf analysis has shown decreasing calcium and magnesium concentrations. Use of dolomitic limestone and calcium nitrate for acidity management will help replace lost calcium and magnesium.
- Monitor soil pH annually.
- Remediate soil acidification with lime applications. Lime applications are to be calculated on current soil pH values, a target soil pH value and an estimate of the soil pH buffering capacity. Re-monitor soil pH.

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ACKNOWLEDGEMENTS
The input and suggestions made by Australian almond processors, marketers and growers.
This project has been facilitated by HAL in partnership with the Almond Board of Australia and has been funded by the Research & Development levy. The Australian Government provides matched funding for all HAL's R&D activities.