Horticulture Innovation Australia

Final Report

Precision fertigation for improved apple orchard productivity

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Summary

Apple production requires high nutrient inputs. Much of the industry applies fertiliser based on standard recommendations irrespective of irrigation requirement, crop load, tree size, quality specifications, and the soils capacity to retain and supply nutrients and minimize off-site impact. Therefore there is potential to optimize nutrient inputs to improve fruit quality and shelf-life outcomes for growers. This PIPS1 project aimed to determine the influence of nutrient and water use efficiency on apple trees through fertigation to facilitate the development of fertigation guidelines for growers to optimize whole tree nutrition and fertilizer management in order to increase orchard productivity and sustainability.

To tackle this challenging issue we brought together a research team from within Tasmanian Institute of Agriculture (TIA)'s Perennial Horticulture Centre (PHC), the Department of Economic Development, Jobs, Transport and Resources (DEDJTR) Victoria (formally Department Environment and Primary Industries) and Plant and Food Research (PFR) NZ.

The objectives of the project were to 1) investigate the effect of water stress and water surplus on nitrogen (N) uptake, 2) investigate the effect of N and Potassium (K) fertigation treatments on tree and fruit nutrition, 3) investigate the influence of fertigation on tree N storage and remobilisation, 4) investigate the influence of application type, soil type and rainfall on N leaching, and 5) undertake preliminary investigations of remote sensing of N deficiencies using Canopy Chlorophyll Content Index (CCCI) capability from remote sensing. To ensure maximum industry benefit from this research, we aimed to have a local, regional and national reach. At a local level, growers and advisors participated in the design and implementation of the trials, discussions of trial findings both at the trial orchard and in more formal round table meetings. At a regional scale, we presented trial results and outcomes at annual state conferences, Future Orchards extension campaigns and dedicated extension days. At a national level, results of both Tasmanian and Victorian trials were presented at Speed Updating sessions associated with APAL national conferences.

Project activities included a three year N fertigation and irrigation trial on 'Galaxy' apple trees in southern Tasmania. At the same site, a potassium foliar vs fertigation trial was conducted and a soil infiltration trial to determine the movement of water and nitrogen through the root zone. A labelled nitrogen fertiliser (N^{15}) trial to trace the seasonal movement on N through potted 'Jonagold' apple trees was completed at the University of Tasmania. In Victoria, two deficit irrigation experiments previously established in adjoining commercial orchard blocks of 'Royal Gala' and 'Cripps Pink' in Shepparton East in the Goulburn Valley of Victoria, Australia were utilized to investigate the effect of deficit irrigation on tree N status. The Tasmanian 'Galaxy' block and a block of 'Rosy Glow' in the Goulburn Valley were intensively monitored for nitrogen inputs and outputs, rainfall and water use. This data was used by PFR to parameterize and validate the Soil Plant Atmosphere System Model (SPASMO) so that simulations of the impact of soil type and rainfall on N leaching could be investigated. Equipment and sensors were installed to measure nitrogen leaching, drainage, irrigation inputs, rainfall and climate. In addition, tree N content in the leaves and fruit was measured as well as tree productivity and fruit quality. Preliminary studies on remote sensing of N status were undertaken in commercial apple and pear orchards in the Goulburn Valley, and at experimental sites in VIC and TAS. The research applied methods developed to assess canopy N in wheat to apple production. Canopy reflectance measurements were used to compute the Canopy Chlorophyll Concentration Index (CCCI) and other vegetation indices.

The project found that irrigation management had negligible influence on tree (branch, leaf, bud and fruit) N status, yet did increase tree girth and fruit size under high volume irrigation. Benefits to nitrogen use efficiency (NUE) but risks to fruit quality outcomes were associated with pre-harvest N supply. In contrast, NUE was reduced with post-harvest N supply yet risks to fruit quality outcomes were mitigated. The N15 trial found improved NUE under pre-harvest N supply, but partitioning into storage reserves was substantially improved under post-harvest N supply. Preliminary results from the CCCI research showed a positive, linear relationship between CCCI and leaf N for datasets in VIC and TAS. The research validated the use of a UAV as a platform for acquiring high spatial resolution imagery.

The findings of the project were delivered to industry through 14 presentations at national and international conferences, extension days, state conferences and Future Orchards walks. Three magazine articles were published in Australian Fruit Grower. Two posters were presented at the International Horticultural Congress. One TIA fact sheet was published. Four journal articles in international peer reviewed journals are currently in press and two honours programs were completed which added substantial value to the research program.

From our research, we suggest that total seasonal N supply be tailored to the soil type and desired tree N status of the particular growing region. To maximise fruit quality outcomes, no more than 25% of the recommended total seasonal N be applied pre-harvest N supply and no earlier than four weeks after bud burst. Pre- and post-harvest harvest N applications should be split into multiple applications to minimise nutrient leaching. When growers have invested in an adequate soil nutrient 'bank', additional nutrient supply is not required and N and K fertigation trials in our trial location did not result in non- target nutrient deficiencies. In the longer term deficit irrigation trials in Victoria, water stressed apple orchards in the Goulburn Valley do not require additional fertiliser compared with fully irrigated orchards. It is recommended here also that frequent smaller applications of N fertiliser may prevent leaching of N following winter and spring rainfall events. From the CCCI research it was recommended that investigation of canopy reflectance to measure tree nitrogen status (e.g. Canopy Chlorophyll Concentration Index, CCCI) should continue. Furthermore, research suggested that unmanned aerial vehicles (UAVs) are appropriate platforms for acquiring high spatial resolution imagery for estimating CCCI.

Keywords

fertiliser, deficit irrigation, nitrogen, N^{15}, remote sensing, soil N, leaf nitrogen and potassium, drainage, leaching, SPASMO

Introduction

The original version of the Soils, Water & Nutrients (SWN) project (AP09034) included a 3rd subproject 'Precision Fertigation' to begin in year 3 of the Productivity, Irrigation, Pests & Soils (PIPS) Program. This logically built on the combined outputs of both soil nutrition and irrigation sub-projects, in that the soil component will identify plant nutrient-availability as a function of the active root-zone and the seasonal variation in temperature and water availability and the irrigation component will identify site-specific crop water requirements. Therefore, the project will ensure ultimate value-gain from the synthesis of outputs from these earlier sub-projects whilst gaining new knowledge from large scale multistate orchard trials.

Precision farming through fertigation can facilitate efficient utilization of resources and improve returns per unit area and time to growers. Fertigation delivers both water and essential nutrients such as N, directly to the active root zone of growing crops through micro irrigation systems, thereby minimising water and nutrient loss and improving productivity (Klein et al., 1989). Whilst fertigation is commonly practiced by apple growers in Australia, research and management guidelines for optimal supply of tree nutrient requirements are limited. In addition, problems induced by fertigation have included rapid soil acidification leading to nutrient imbalances such as K deficiency (Neilsen et al., 1995a). Inadequate leaf nutrient concentrations have also been observed for high density orchards receiving N fertigation, implying that strategies for maintenance of balanced tree nutrition are also important (Neilsen et al., 1995b).

Deciduous fruit trees accumulate and store carbohydrates and nutrients at the end of the growing season for remobilisation in the following spring (Loescher et al., 1990). This resource remobilisation is critical for growth of flowers, fruit, leaves and shoots, yet little is known about seasonal nutrient budgets and the storage and remobilisation of nutrients (Frak et al., 2006). It is well recognised that increasing the rate of N application can increase vegetative growth, bud development and yield but adversely affect fruit quality by decreasing fruit colour and firmness (Oberly and Boynton, 1966, Neilsen et al., 2003, Fallahi et al., 1993, Stefanelli et al., 2010). In addition, studies have shown that the efficacy of N application in orchards is related to irrigation practice as excess water can leach N below the root zone (Neilsen and Neilsen, 2002) while soil water stress may reduce the tree's capacity for nutrient uptake. Therefore, the regulation of N and water is a crucial management consideration for commercial orchard production. The effectiveness of matching nutrient supply with tree demand requires a sophisticated understanding of seasonal apple tree N recycling to maximize the advantages inherent in being able to apply N and water simultaneously.

This project aimed to determine the influence of nutrient and water use efficiency on apple trees through fertigation to facilitate the consistent production of high quality fruit. Furthermore, it aimed to develop fertigation guidelines for growers to optimise whole tree nutrition and fertiliser management in order to increase orchard productivity and sustainability.

The project objectives were:

1. Investigate the effect of water stress and water surplus on N uptake.

The efficacy of N application in apple orchards is related to irrigation practice. To achieve a balance between tree water stress (deficit and excess irrigation) and nutrient leaching below the root zone, we ask the question: What is the effect of deficit/excess irrigation on N uptake for bud development and fertility, shoot growth, fruit set and fruit quality?

2. Investigate the effect of N, Ca and K fertigation treatments on tree and fruit nutrition.

Fertigation provides the capacity to deliver nutrients directly to the active root zone. However, due to increased nutrient use by vegetative growth and yield of trees and soil changes due to fertiliser application, nutrient deficiencies have been observed in trees in fertigated apple orchards. To understand the role of fertigation in supplying adequate tree nutrition, the following questions are asked: What is the influence of application rate and timing of application on tree N uptake and how does this influence yield and fruit quality? Are there other nutrient (such as Ca and K) deficiencies in apple orchards as a consequence of N fertigation and can these be overcome with fertigation of deficient nutrients?

3. Investigate the influence of fertigation on N storage and remobilisation.

Given that the amount of N stored influences availability for remobilisation for new growth the following season, a better understanding of seasonal N cycling is required to optimise timing and application rate of N fertigants. To improve our understanding of N recycling, the following questions are asked: What is the importance of N remobilisation versus N uptake by roots for new shoot growth and when does this occur? Can the quantity of N stored be influenced by timing and application rate of N fertigation?

4. Investigate the influence of soil type and rainfall on N leaching.

Seasonal rainfall is unpredictable and may impact the availability of N to plant roots through waterlogging and N leaching below the root zone. To mitigate against N loss and over irrigation we need to estimate N leaching through the soil profile after rainfall events. Using fluxmeters to determine N leaching through the soil profile, can we make use of rainfall prediction to adjust N applications to minimise leaching and maximise N uptake? Use this information to fill parameters of the SPASMO model.

5. Undertake preliminary investigations of remote sensing of N deficiencies using Canopy Chlorophyll Content Index (CCCI) capability from remote sensing.

Research in macadamia nuts and grain crops has shown that spectral properties of leaves can be used to estimate nitrogen deficiency. This trial utilised an unmanned aerial vehicle with multispectral and thermal cameras to remotely measure water and nitrogen stress. Can the CCCI be used to detect N deficiency in apple trees?

The aims and objectives of this project were aligned with Primary Objective 1 of Apple Pear Australia Ltd. (APAL)'s RD&E 2010-2015 Investment Plan: stimulate domestic demand by 5 per cent through product quality and innovation. This project was integrated with APAL's Future Orchards project by implementing trials in the Future Orchard's Gala and Cripps Pink sites used for the Tree Structure Program in the Huon Valley, Tasmania. This has facilitated industry development and extension through incorporation of findings into Future Orchards walks and growers presentations. The project objectives and design were strengthened through input and endorsement by PIPS, Technical Industry and Communications Committee (TICC) and National Apple, Pear Advisory Committee (NAPAC). Whilst the research for this project was dedicated to apples, the findings will apply across the Pome Fruit Industry, particularly once intensive growing systems for pears have been further developed.

Methodology

To address the project objectives, field trials were established in the Huon Valley, southern Tasmania and Shepparton East in the Goulburn Valley, Victoria (Table 1). For specific details of the methods applied in each trial please refer to the appendices noted.

Table 1. Details of fertigation and irrigation trials established at Lucaston and Shepparton East.

Trial, duration, objectives and reference	Location	Variety and rootstock	Treatments
N fertigation and irrigation trial (2012-2015). Objectives 1, 2, 3 and 4. Appendix 1 and 3	Lucaston Park Orchards, southern Tasmania	'Galaxy' on M26 rootstock	Irrigation: High (3.9L/hr), Medium (2.3L/hr and Low (1.6L/hr). Fertigation: a) Zero N control; b) split 25%N Pre harvest and 25%N Post harvest; c) split 50% N Pre harvest and 50% N Post Harvest; d) 50% N Post harvest and e) 100%N Post harvest equivalent to an rate of annual 60kg/N/ha of $Ca(NO_3)_2$. Monitoring included irrigation loggers, drainage fluxmeters, tree water use, tree N status, light interception, tree productivity and fruit quality.
Potassium trial (2014-2015). Objective 2, Appendix 2	Lucaston Park Orchards, southern Tasmania	'Galaxy' on M26 rootstock	Potassium nitrate (KNO_3) and Potassium sulphate (K_2SO_4) applied as either foliar or fertigated pre-harvest equivalent to an annual rate of 50kg K/ha
N^{15} trial (2014 – 2015). Objective 3, Appendix 3 and 5	TIA Horticulture Centre, UTAS Sandy Bay Campus	'Jonogold' on M26 rootstock	3 treatments of 5% enriched $Ca(NO_3)_2$. a) Pre-harvest application (24g N/tree); post-harvest application (24g N/tree; and a control (zero N^{15})
Nitrogen and Irrigation Infiltration trial, (2013), Objective 1 and 4, Appendix 4	Lucaston Park Orchards, southern Tasmania	'Galaxy' on M26 rootstock	Irrigation: High (3.9L/hr) and Low (1.6L/hr). Fertigation: equivalent to an rate of annual 60kg/N/ha of $Ca(NO_3)_2$. Monitoring included dye tracer, resistivity, NO_3^- soil monitoring, field excavation.
Deficit Irrigation trial. (2012-2014). Objective 1, 2 and	Shepparton East in the Goulburn Valley of	'Royal Gala' and 'Cripps Pink' on M106	Irrigation treatments of 38, 50, 74, 100 and 162 % of grower irrigation practice. Treatments received the equivalent amount of N fertilizer as

Trial, duration, objectives and reference	Location	Variety and rootstock	Treatments
4, Appendix 2 and 3	Victoria, Australia	rootstock	the 162 % treatment
N flux trial to parameterize SPASMO. (2012-2014). Objective 1 and 4, Appendix 2 and 3	Shepparton East in the Goulburn Valley of Victoria, Australia	'Ruby Pink' on M26 rootstock	Irrigation and fertilizer managed by grower. Monitoring included irrigation loggers, drainage fluxmeters, tree water use, tree N status, light interception, tree productivity and fruit quality.
Remote sensing of N deficiencies. (2012-2015). Objective 5, Appendix 2	Shepparton east, Lucaston Park and Tatura (pears)	'Cripps Pink', 'Royal Gala' and pears: v. ANP-0131 on BP1 rootstock	At Shepparton - Three levels of N were applied: grower practice (nil), 180 kg N /ha equivalent, and 360 kg N /ha equivalent applied three times during the season as calcium nitrate with 17% total N. At Lucaston – see above At Tatura - Three levels of N were applied to provide a range of leaf N values: grower practice (nil), 105 kg N /ha equivalent, and 209 kg N /ha equivalent applied three times during the season as calcium nitrate with 15.5% total N 4 levels of imagery: satellite, ground based multispectral, airborne based multispectral, SPAD

The outcomes of the project activities, although specific to the individual region where they were undertaken, were intended to have a local, regional and national reach. At a local level, growers and advisors participated in the design and implementation of the trials. Growers and advisors (consultants) were included in the decision making of suitable fertiliser and irrigation rates as well as the most ideal location to implement the trial. Throughout the duration of the trial, growers and advisors participated in discussions of trial findings both at the trial orchard and in more formal round table meetings. At a regional scale, we presented trial results and outcomes at annual state conferences, Future Orchards talk sessions and dedicated extension days. Growers and advisors were invited on numerous occasions to field trial sites as part of state conference field days, Future Orchards walks etc. At a national level, results of both Tasmanian and Victorian trials were presented at Speed Updating sessions associated with APAL national conferences. By incorporating a modelling tool to pull together and interpret the data collected from Tasmanian and Victorian field trials, we are able to make broader scale recommendations to industry rather than site specific interpretations. For further information on specific technology transfer, please refer to the list of outputs below.

Outputs

Magazine Articles

Goodwin, I., Perry, E. and Cornwall, D. (2013). Irrigation deficits and nitrogen status. Australian Fruitgrower 7(8):35-37.

Swarts, N, "Apple orchard fertigation trial: second season results", *Australian Fruitgrower*, Apple and Pear Australia Ltd, Melbourne, Australia, **8**, 7, pp. 22-24. (2014) [Magazine Article]

Swarts, ND and Close, DC and Goodwin, I* and Green, S* and Clothier, B*, "Precision fertigation for improved orchard productivity", *pips Apple & Pear*, Australian Fruit Grower, www.apal.org.au, March, p. 26. (2013)

Posters

Perry, E.M., Goodwin, I. and Cornwall, D. (2013). Prediction of canopy nitrogen in apple orchards using a nitrogen index from remote sensing. Poster. Combined Fruit Industry Conference 'Innovate or Real-Estate', Gold Coast. 17 – 19 July

Perry, E., Bluml, M., Goodwin, I., Swarts, N. and Cornwall, D. (2014). Remote sensing of N deficiencies in apple and pear orchards. Poster. XXIX International Horticultural Congress: IHC2014, Brisbane, Australia. 17 – 22 August.

Presentations

Armstrong, R., Goodwin, I., O'Leary, G., Tausz, M., Grace, P., Conyers, M. and Mosier, A. (2012). Options and new innovations required to improve nitrogen use efficiency in plants and soil processes in grains and horticulture. Presentation at 2012 PICCC Strategic Science Think Tank. Improving nitrogen use efficiency: a critical next step for food and the environment. 16 August, Melbourne.

Goodwin, I. (2014). Oral presentation on the PIPS SWN project to DEPI Agriculture Research Division Executive Director. 24 July, Tatura.

Goodwin, I. (2014). Oral presentation on the PIPS SWN project to DEPI Agriculture Research Division Executive Director, Research Directors and Research Managers. 12 August, Macleod.

Goodwin, I. (2014). Oral presentation on the PIPS SWN project to visiting South African, Tasmanian and Italian scientists and APAL industry representatives: Angus Crawford & Kevin Sanders. 28 August, Tatura.

Goodwin, I. (2014). Sustainable intensification of horticulture — what does it mean for south east Australia? 2014 PICCC Think Tank. 30 September, Carlton.

Bluml, M., Perry, E., Goodwin, I., Swarts, N. and Cornwall, D. (2014). Remote sensing of N deficiencies in apple and pear orchards. Poster oral presentation. XXIX International Horticultural Congress: IHC2014, Brisbane, Australia. 17 – 22 August.

Swarts, N, "Precision fertigation for improved apple orchard productivity", *National Horticulture Convention 2015*, 25-27 June 2015, Gold Coast, Australia (2015)

Oliver, G and Swarts, N and Hardie, M and Close, D and Rogers, G* and Montague, K*, "Understanding the role of nitrogen management in apple orcharding to mitigate nitrous oxide emissions", *National Agricultural Nitrous Oxide Research Program (NANORP) Meeting*, November 2014, Canberra, Australia (2014) [Plenary Presentation]

Ridges, J and Hardie, M and Swarts, N and Close, D, "Evaluation of electrical resistivity imaging (ERI) for *in situ* mapping of drip irrigation and fertigation wetting patterns", *Australia National Soil Science Conference 2014*, 23-27 November 2014, Melbourne, Australia

Swarts, N and Hardie, M and Close, D and Goodwin, I* and Perry, E* and Green, S* and Clothier, B* and Gentile, R*, "Precision fertigation for improved apple orchard productivity", *Fruit Growers Tasmania Annual May Conference 2014*, 22-25 May 2014, Hobart, Australia (2014) [Plenary Presentation]

Swarts, N and Hardie, M and Green, S* and Close, D, "Precision fertigation for improved apple orchard productivity", *Regional Stone and Pomefruit R&D Forum 2014*, 22 October 2014 (2014) [Plenary Presentation]

Swarts, N and Hardie, M and Oliver, G and Close, D and Rogers, G* and Daynes, C*, "Reducing N_2O emissions in key perennial tree crop industries", *National Agricultural Nitrous Oxide Research Program (NANORP) Meeting*, February 2014, Canberra, Australia (2014) [Plenary Presentation]

Swarts, ND and Hardie, M and Green, S* and Close, DC, "Precision nitrogen fertigation for improved apple quality and reduced leaching", *29th International Horticultural Congress 2014*, 17-22 August 2014, Brisbane, Australia (2014) [Conference Extract]

Morris, M, Swarts, N, Oliver, G, Close, DC, "Influence of application timing on the uptake and internal utilisation of nitrogen in apple trees", Tasmanian Fruits Extension Day, 20 November 2015. Huonville, Australia (2015) [Plenary Presentation]

Fact Sheets

http://www.utas.edu.au/__data/assets/pdf_file/0007/563533/2014-Precision-Fertigation-for-Improved-Appled-Orchard-Productivity.pdf

Literature reviews

Please refer to Appendix 4 and 5.

Fertigation guidelines

Recommendations for fertigation guidelines are presented in the 'Recommendations' section below. We could not complete a tangible 'tool' for fertigation management for Australian apple growers until all the major growing region soils have been adequately characterized and a complete 3D model has been completed for SPASMO. These activities form a key component of the PIPS 2 research (AP14023).

Outcomes

The outcomes of the project are presented against the project objectives and the key research questions we attempted to answer for each objective. Each of these outcomes were presented at *National Conferences, extension field days, magazines (Australian Fruit Grower) and recently on the Future Orchards National Tour*. The outcomes described below will lead to an *increase in the global competitiveness of the Australian Apple industry* as growers and advisors become more aware of not only the economic implications of improved and efficient N management but the physiological influences of N on fruit quality and tree N status. The Future Orchards National Tour presented excellent opportunities for discussion by growers and advisors on the implications of N management and the opportunities for increased $/ha as a result. Although N and irrigation management is by no means the costliest farm management practice, the implications of mismanagement on $/ha return from crop harvest is significant. Whilst during the life of the project, we have no seen a direct increase in production/ha from our research findings across the industry, the key messages of *optimising N use and irrigation efficiency* presented in the findings below will no doubt *lead to improved fruit quality outcomes and a higher value product into the future*.

Recommendations for fertigation guidelines to improve nitrogen and irrigation management are presented in the 'Recommendations' section and based on the research findings presented below. We could not complete a tangible 'tool' for fertigation management for Australian apple growers until all the major growing region soils have been adequately characterized and a complete 3D model has been completed for SPASMO. These activities form a key component of the PIPS 2 research (AP14023).

1. Investigate the effect of water stress and water surplus on N uptake.

What is the effect of deficit/excess irrigation on N uptake for bud development and fertility, shoot growth, fruit set and fruit quality?

In the Lucaston trial, the analysis of trunk girth after three seasons of treatments suggested that irrigation had a strong influence on tree vigour. Although, in this trial, irrigation in the low treatment (1.6L/hr) was not at deficit levels over the course of the season, it appears that surplus irrigation in the high irrigation (3.9 L/hr) treatment as shown by SPASMO modelling, significantly increases tree girth. The effect of irrigation on branch length didn't replicate its effect on trunk girth in both the 2013 and 2015 season's that were assessed. No interaction was observed between irrigation and fertigation treatments for tree growth. Branch total N content was influenced by N treatments where a trend for increased branch length was observed under current season N application rather than total N applied over a season. This finding was in agreement with findings from the N^{15} trial where the majority of current season N supply was partitioned in the canopy. A similar trend was found for total N (% dry matter) in flower and vegetative buds sampled at harvest. Irrigation supply was found to have no effect on the nitrogen content of woody tissue and buds. Irrigation supply was also shown not to have an effect on the fruit N content when assessed at harvest of each season and leaves when assessed at various times of the growing season. The lack of irrigation treatment response on N status of tree organs may be due to the relatively even spread of rainfall across the months of the growing season and the lack of an irrigation deficit treatment at the Lucaston site. Furthermore, after excavation, apple roots were shown to penetrate deep into the B2 horizon with access to the high water table found at the site.

Fruit set wasn't tested due to the inability to control for thinning practices in the orchard, however, irrigation was shown to significantly increase fruit size under the highest treatment. Fruit firmness and total soluble solids (TSS) was also highest in the smallest fruit under the lowest irrigation treatments.

In the Goulburn Valley, measurements were made of leaf and woody tissue N status in existing irrigation experiments on 'Royal Gala' and 'Cripps Pink', to observe the long-term effects of water deficits and water surplus on tree N status. Similar amounts of nitrogen were applied to each irrigation treatment. Results showed that water stress for three and four consecutive years in 'Cripps Pink' and 'Royal Gala' apple, respectively, did not impact on nitrogen uptake or nitrogen storage in the woody tissue.

2. Investigate the effect of N, Ca and K fertigation treatments on tree and fruit nutrition.

What is the influence of application rate and timing of application on tree N uptake and how does this influence yield and fruit quality?

Application rate of N treatments had a strong effect on tree N uptake and fruit quality outcomes on the 'Galaxy' apple trees at Lucaston. As treatments were split into two application periods and multiple rates, we were able to tease out the relative effect of each. The highest N treatment of the current season supply always had the strongest influence, although the results were not always significant. For example, leaf N in the data presented for 2014 and 2015, under the highest pre-harvest treatment, was consistently higher than other treatments, matched only later in the season by the greatest post-harvest N treatment. This effect was most prevalent in the month following fertiliser application. At harvest, on average, fruit N was greatest with current season N supply, however this result was only significant in the final season of the trial. These results are important as they had an influence on fruit quality outcomes and the ability of the tree to absorb other nutrients as seen in the leaf and fruit nutrient ratios at harvest. Fruit red colour was reduced under high current season N supply as well as a more green background colour indicative of less ripe fruit at commercial harvest. Strong correlations irrespective of treatment between fruit N (%) and fruit colour further highlighted its influence. Although, firmness was more influenced by irrigation than N treatments, strong correlation between fruit N (%) and firmness demonstrated the detrimental effect of high levels of pre-harvest N. These results were not surprising given the sink strength of fruit demonstrated by the N^{15} trial, where over 30% of current season N supply found its way into the fruit.

Are there other nutrient (such as Ca and K) deficiencies in apple orchards as a consequence of N fertigation and can these be overcome with fertigation of deficient nutrients?

When assessed at harvest of the last year of the trial, when we expected treatments to have had their greatest influence, fruit nutrient content reflected in their ratios to N were affected by fertigation treatments. Fruit nutrient ratios of N:K and N:Ca increased in a similar pattern with N supply suggesting that N supply to the fruit may be antagonistic to the supply of other nutrients or simply may reflect increased nutrient availability. Indeed, the highest levels (% dry matter) of K, Ca and Mg were found in the control fruit. This treatment effect was not repeated in the leaf nutrient content. Interestingly, three seasons of N supply as Calcium Nitrate ($Ca(NO_3)_2$), did not lead to an increase in Ca in the fruit or leaves. This may be due to the long legacy of $Ca(NO_3)_2$ application at the site as seen in the very high

Ca level in the leaves (2.5%).

Potassium treatments did little to increase levels of K in the fruit, however leaf K levels one week post application were increased by foliar K treatments. Although not significant, there was a trend for decreased N, Ca and Mg content in harvested fruit under potassium treatments and therefore increasing ratios N:K, K:Ca and K:Mg. No significant differences were found for all fruit quality parameters with exception to Total Soluble Solids after 10 weeks in storage where the foliar treatments performed superior to fertigated treatments.

No nutrient deficiencies were observed in the orchard after three seasons of fertigation and irrigation treatments, however some preference for nutrient uptake was observed following N and K fertilization when more available.

3. Investigate the influence of fertigation on N storage and remobilisation.

What is the importance of N remobilisation versus N uptake by roots for new shoot growth and when does this occur?

We demonstrated that total current season N uptake did not vary significantly between applications made pre- and post-harvest. Despite similar total uptake, the current season N distribution throughout the tree was significantly different. The canopy of the pre-harvest N application accumulated more than half of the total N^{15} absorbed, in comparison with post-harvest application where less than a quarter of absorbed N^{15} was found in the canopy. This is believed to be a result of the sink strength of developing fruit and leaves in the pre-harvest period. Comparison of trunk N^{15} content found little difference between pre- and post-harvest N application, however, N^{15} partitioning towards the trunk was found to increase approaching dormancy indicating its importance as a storage region. More current season N was found in the below ground region of post-harvest treatment compared with trees receiving pre-harvest application. Given that we could only assess current season's uptake, we were unable to determine the influence that remobilized N had on current season growth.

Can the quantity of N stored be influenced by timing and application rate of N fertigation?

Results show a trend of increased current season N allocated to storage after receiving the post-harvest treatment which could possibly increase N availability for the following season's early spring growth. This is not surprising due to the removal of fruits from the pre-harvest treatment where 35% of the applied N^{15} was apportioned. Yet the difference in the quantity of N stored between the treatments wasn't that stark. This is due to the highly efficient withdrawal (100%) of current season N from the leaves back into storage organs.

4. Investigate the influence of soil type and rainfall on N leaching.

Using fluxmeters to determine N leaching through the soil profile, can we make use of rainfall prediction to adjust N applications to minimise leaching and maximise N uptake?

The site at Lucaston received far more winter rainfall compared to the site at Shepparton. As expected the soil moisture levels, and the corresponding drainage losses, were greater at the Lucaston site. For example, the Lucaston soil appeared close to field capacity from between June to November while the Shepparton soil did not fully wet up until late July when drainage also recommenced. These soil moisture data will form the basis of testing the SPASMO modelling water uptake and drainage losses in response to the weather, the tree's leaf area, and to the irrigation level. Current measurements suggest that between 18 - 34 kg/ha of nitrogen per season is leached under the Lucaston orchard. Those measurements are confined to the row (under the trees) so they are expected to be at the upper end of the leaching spectrum on a per hectare basis given that losses will be less from the inter-row. Our data analysis suggests that the applied irrigation at the Lucaston orchard was reasonably accurate for replacing the deficit between orchard ET losses and the effective seasonal rainfall for the seasons measured. Please refer to Appendix 3 for more details on model sensitivity to address this objective.

Measurements of drainage volume and nitrate concentration under a young 'Ruby Pink' apple orchard in the Goulburn Valley showed that drainage volume was strongly influenced by winter rainfall and the occasional large summer rainfall event. Drainage in the drip line occurred when irrigation exceeded our estimates of ET_{apple}. Drainage nitrate concentration was often high (> 200 mg/L). N fertiliser application was dominated by four post-harvest applications of Easy N® in Year 1 and 25.1 kg N/ha of Easy Cal® in Year 2, and Easy N® and Hybrid-Ag in Year 3. These did not cause a spike in drainage nitrate. N removed by the crop combined with N drainage losses exceeded N fertiliser inputs suggesting there was additional reserves of soil N; however, this may not have been readily available to the tree as leaf N status was marginal.

5. Undertake preliminary investigations of remote sensing of N deficiencies using Canopy Chlorophyll Content Index (CCCI) capability from remote sensing.

Can the CCCI be used to detect N deficiency in apple trees?

In a survey of 30 sites across orchards east of Shepparton VIC, leaf N values for apples (v. 'Cripps Pink') were found to be significantly lower than those for pears; the apple leaf N values were near or below the minimum recommended values. Maps of CCCI derived from the satellite imagery indicated patterns of spatial variability within orchard blocks; however, evaluation of the imagery and resulting maps indicated that the tree canopy cover was indistinguishable from the orchard floor vegetation. The remaining research focused on acquiring datasets of canopy reflectance from very high spatial resolution (0.1 m or greater) imagery and corresponding leaf N analysis, using plots with moderate and high levels of N fertilisation to extend the range of leaf values. Preliminary results showed a positive, linear relationship between CCCI and leaf N for datasets in VIC and TAS. The research validated the use of a UAV as a platform for acquiring high spatial resolution imagery, and the approach was demonstrated to a science and industry audience during a field day.

Evaluation and Discussion

This project achieved substantially more outputs than were originally proposed. Specifically, this project achieved two literature reviews (Appendix 4 and 5), three grower articles (Australian Fruit Grower), 14 presentations at national and international conferences, extension days, state conferences and Future Orchards walks, two posters were presented at the International Horticultural Congress, one fact sheet was published, four journal articles in international peer reviewed journals are currently in press and two honours programs were completed. Information including YouTube videos of presentations at APAL's Speed Updating forums are linked to the APAL and TIA websites. Ian Goodwin and Dugald Close presented project findings on Future Orchard field days. Nigel Swarts was the invited guest at the recent Future Orchards National Tour Southern Loop.

Fertigation guidelines are presented as recommendations from research findings in the section below. Fertigation recommendations incorporate knowledge from literature reviews with data accumulated from fertigation trials and modelling completed using the SPASMO framework. Specific guidelines for each growing region cannot be realistically provided until further modelling and soil parametrisation has been completed (PIPS 2, AP14023). General guidelines including the benefits and risks of pre- and post-harvest fertigation are described below. Our literature reviews and discussions with advisors and growers have shown that considerable variation in seasonal N supply exists within and between regions (15 – 200 kg N/ha) delivered in a variety of ways. Advisors generally provide a seasonal fertiliser schedule for growers often in reaction to leaf and fruitlet N status and previous season's crop removal. Furthermore, growers may have additional management considerations, such as reducing vigour through root pruning, which may impact fertiliser management between seasons. As such, there is opportunity for improvements and efficiencies to be made across the sector as well as knowledge transfer from this research.

Trials were established in a commercial orchard block where both the orchard manager and their advisor were involved in the implementation. Regular contact throughout the trial period with the orchard manager and his staff ensured that the project was aligned with commercial orchard management practises. Feedback on project activities was sought via two grower and advisor focussed workshops where trial methods, fertiliser types and rates and treatment results were presented for discussion. Key growers and advisors from the region were invited to take part in the discussion. In general there was much support for the project by growers and a willingness to discuss the results. Based on feedback, we found that presenting the background of deciduous tree nutrient recycling and the importance of tailoring fertiliser schedules to account for N remobilisation very useful for growers and advisors. Discussion about the benefits and risks of pre-harvest N supply enabled advisors to be more informed when establishing seasonal fertiliser regimes for growers. We anticipate a flow-on effect of this nationally, as results will be presented to each growing region in the February 2016 Future Orchards National Tour by Nigel Swarts.

From presentations at Speed Updating events and Australian Fruit Grower articles, it was difficult to gauge feedback on perception of project relevance and importance. Some follow up questions by growers and advisors were received after speaking events but very few.

Through this project, we have quantified tree irrigation and N requirements, current season N partitioning above and below ground, the outputs of drainage below root zone and fruit removal in a modern commercial orchard. These new data have enabled us to build a simple prototype N budget over a single calendar year. However, a complete and detailed multi-year budget of total N has not been compiled and there is limited understanding of the relative contribution of residual, end-of-growing-season N sources, to both N supply and N uptake and loss. Furthermore, limited data are available to quantify the amount of plant N that is remobilised in the subsequent growing season and how that influences tree demands and fruit quality outcomes. Specifically we require knowledge of the amount of N that is contained in decomposing material of the leaves, prunings and fallen apples, and the rate and proportion of this N that becomes plant-available in the soil during decomposition, or is released to the atmosphere. Through the new PIPS2 project (AP14023), we will quantify the timing and amount of this N source, and develop ways to better manage the soil and irrigation to optimise the natural mineralisation of N in the soil, and retain it there to enable root uptake. Together, these new data will help identify tree N requirements and improve our understanding of when, where and how N is translocated through the plant or lost from the root-zone soil.

We are currently in the process of modifying the tree-growth components of SPASMO to better represent the whole tree dynamics for dry-matter (C) and nutrients (N and P). We are also adding some phenology components to account for events such as budburst, fruit maturity and leaf fall. And we are looking into ways to include ‘fruit quality attributes’ into our model outputs since the goal for industrial horticulture is to obtain the highest quantity of fruit of the best possible quality, with the smallest environmental, economic and environmental ‘foot print’. Meanwhile, the goal of the modelling is to quantify the water and nitrogen budget in order to inform fertiliser and irrigation guidelines developed for the major apple growing regions via a decision support tool built on data accumulated from this project.

Recommendations

Nitrogen fertigation (Lucaston) and N^{15} trial (UTAS)

In our trial site at Lucaston in southern Tasmania, the pre-harvest supply of N at a rate of 30 kg N/ha (50% of the commercial rate) resulted in a trend towards negative fruit quality outcomes and greater canopy growth (branch length) compared to the control and post-harvest treatments. Our research highlighted the slightly improved nitrogen use efficiency of pre-harvest N fertilizer application over post-harvest N application. This was due to the sink strength of leaves and fruit driving current season N supply into the canopy. Although, a high portion of N was lost through crop removal, 100% of current season N was withdrawn from leaves and partitioned to storage. Previous research has demonstrated that early season growth is sustained by remobilized N from storage.

Our data suggests that if additional N is available, trees will utilize it, although there are risks with oversupply of pre-harvest N. By contrast, post-harvest N can meet tree N demand through being partitioned to storage organs for remobilization the next growing season. The risk of post-harvest N supply is that, for late cropping varieties, there is limited capacity for tree uptake of N as rates of transpiration and photosynthesis have slowed down substantially. Both varieties ('Galaxy' and 'Jonagold') studied in this trial are relatively early allowing post-harvest N to be applied by mid-March when tree roots are still active. However, the ability to split the desired amount into multiple smaller rates is lessened. This may increase the risk of nutrient leaching past the root zone and consequently reduced uptake efficiency

We calculated an annual crop removal of approx. 30 kg N/ha based on a yield of 75 t/ha. We found that up to 50% of the pre-harvest applied N leached below the root zone in a sandy loam texture contrast soil type, however this will vary substantially both within an orchard and between regions. For this site, the maximum applied rate of 60kg N/ha adequately met tree demands and optimal fruit quality outcomes could be achieved using up to 75% of the total (60 kg/ha) with the majority supplied post-harvest. The site at Lucaston is vigorous and the 'Galaxy' trees were root-pruned twice over the course of the trial. The rates used in this trial may seem low compared to mainland growing regions, therefore rates must be tailored accordingly.

From the N research completed in this trial, we recommend that:

- Total N supply is matched to the site/soil conditions and to consider tree and fruit responses to historic fertilizer regimes (accurate records greatly assist here!).
- Fertigation is best practice as it results in relatively precise and predictable tree responses to fertilizer application.
- Detailed records of fertilizer management with tree and crop response be kept for discussion and reference with advisor
- Only a portion (up to 25%) of the total season N supply should be provided pre-harvest.
- Pre-harvest N supply should occur no earlier than four weeks after full bloom and uptake

efficiency (avoiding leaching) will be optimized through providing weekly applications

- The balance of total N supply should be provided post-harvest but this may not be ideal for later cropping varieties in some regions
- Further research is required to determine the full range of N sources (eg. Contribution from soil mineralization) to pre-harvest N supply before an ideal rate can be recommended to maximize fruit quality and yield outcomes.

Potassium trial (Lucaston)

Our K fertigation and foliar trial suggested more effective uptake of foliar applied K compared to fertigated, but this was most evident a week after application. Fruit quality responses to K treatments were negligible, however it should be noted that chemistry tests revealed already adequate K levels in the soil and leaves.

We recommend that

- The nutrients 'banked' into soil that remains available for tree update, reflects grower investment and when adequate (following discussions with advisor), additional nutrient supply is not required.

Irrigation management trial (Goulburn Valley)

The results from longer term irrigation experiments on' Cripps Pink' and 'Royal Gala' showed that the trees had adequate leaf nitrogen concentrations irrespective of the irrigation regime. Similar amounts of nitrogen were applied to each irrigation treatment suggesting that water stress for three and four consecutive years in 'Cripps Pink' and 'Royal Gala', respectively, did not impact on nitrogen uptake or nitrogen storage in the woody tissue.

We recommend that

- Water stressed apple orchards in the Goulburn Valley do not require additional fertiliser compared with fully irrigated orchards.
- Frequent smaller applications of N fertiliser are preferred as this may prevent leaching of N following winter and spring rainfall events.

CCCI spatial imagery (Shepparton East)

For the CCCI work completed in Victoria, our research highlighted knowledge gaps and the need for commercial deployment. To compute vegetation indices such as CCCI from ground-based systems future research should focus on the use of a single optics camera with spectral bands near 660nm, 720nm, and 810nm. This would allow the determination of CCCI for individual pixels for images taken close to the canopy (e.g., 2 m). Imagery acquired from side views of the canopy often include significant shadow effects, so indices must be evaluated for this effect. To extend the results to commercial deployment, the quality of the commercial imagery currently acquired from UAVs must be improved. Commercial deployment will also require the use of skilled, CASA certified UAV pilots.

Further validation of remote sensed N status is needed by pooling datasets across regions and species (apple and pear), and we will continue to add to the current datasets using both ground-based and UAV platforms to acquire imagery for apple and pear orchards. We will also evaluate any differences between shaded and sunlit canopy in terms of the relationship between the indices (e.g. NDRE/NDVI) and measured leaf N. Given the usefulness of the UAV platform over canopies, a next step is to begin to evaluate the use of thermal infrared imaging to detect differences in canopy temperature, as another input to crop water and nutrient management.

We recommend that

- Unmanned aerial vehicles (UAVs) are appropriate platforms for acquiring high spatial resolution imagery for estimating CCCI.

Future Research

The Precision Fertigation team, together with discussion with an industry panel comprising growers and advisors during the course of the project, have identified key knowledge gaps that should be addressed in the next PIPS2.

- What are the sources, temporal patterns, and relative contributions to N supply of plant-available N in the orchard?
- When is the peak N demand by the tree and how much is provided by internal tree N?
- A decision support tool for advisors and growers to assist with fertigation and irrigation management in all major apple-growing regions.

The ultimate goal is to develop a nationwide decision support tool to guide on-farm irrigation and nutrient management. A number of critical steps are needed to progress the model from a research to a delivery tool. We will begin this process by holding a workshop with TIA staff, advisors, and leading growers to

- demonstrate existing capacity of the SPASMO model,
- identify desired model functions and outputs by growers and advisers
- understand the manner in which growers and advisers wish to interact with the model; i.e. software design, output graphs.

Following this workshop, we then plan to integrate SPASMO into an accessible decision support tool for growers and advisers. This new tool (SPASMO meta-model) would enable growers and advisers in all major growing regions to optimise their irrigation and nutrient inputs and timings, taking into account local soils and climates. Development of the SPASMO meta-model will require further refinement and improvement of the model code, significant investment in soil parameterisation, plus further model validation and incremental model improvement based on current and on-going research. Furthermore, this tool would also serve as a ‘living’ repository for R&D arising from the research, where model performance is incrementally improved as the findings from new research get incorporated into the tools’ calculations.

Scientific Refereed Publications

Perry, E., Bluml, M., Goodwin, I., Swarts, N. and Cornwall, D. (2014). Remote sensing of N deficiencies in apple and pear orchards. Acta Hort. (In press)

Ridgers, J and Hardie, M and Swarts, N and Close, D, “Evaluation of electrical resistivity imaging (ERI) for *in situ* mapping of drip irrigation and fertigation wetting patterns”, *Proceedings of the Soil Science Australia National Soil Science Conference 2014*, 23-27 November 2014, Melbourne, Australia, pp. 1-4. (2014)

Swarts, ND and Hardie, MA and Close, DC, “Precision nitrogen fertigation and irrigation management for improved apple quality”, *Acta Horticulturae* ISSN 0567-7572 (In Press)

Intellectual Property/Commercialisation

No commercial IP generated

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Appendices

Appendix 1: Final fertigation technical report for research trials completed at Lucaston (TIA, Tasmania)

Nigel Swarts, Garth Oliver, Justin Direen, Marcus Hardie, Dugald Close

Appendix 2: Final fertigation and CCCI technical report for research trials completed in Shepparton (DEDJTR – Victoria)

Ian Goodwin, Eileen Perry, David Cornwell

Appendix 3: Final report on SPASMO modelling using data collected from Lucaston and Shepparton research trials (PFR NZ)

Steve Green, Brent Clothier, Roberta Gentile

Appendix 4: Mapping nitrate and soil water movement from drip fertigation in a Tasmanian texture contrast soil (Lucaston, TIA, Honours thesis)

James Ridges, Marcus Hardie, Garth Oliver, Nigel Swarts

Appendix 5: Influence of application timing on the uptake and internal utilization of nitrogen in apple trees (N15 trial, TIA, Honours thesis)

Matthew Morris, Nigel Swarts, Garth Oliver, Justin Direen, Dugald Close