Precision nitrogen fertigation and irrigation management for improved apple quality

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Abstract

Nitrogen (N) management is a balance to meet tree demands for current seasons' crop as well as for internal storage for the subsequent season whilst reducing N loss via runoff and deep drainage. Whilst fertigation is commonly practised by apple growers in Australia, research into tree nutrient requirements and therefore fertigation management strategies are limited. In the Huon valley of southern Tasmania, we applied N ($Ca(NO_3)_2$) treatments pre- and postharvest combined with high (4 L h^{-1}), medium (2.3 L h^{-1}) and low (1.6 L h^{-1}) irrigation treatments to 10 year-old 'Galaxy' trees grafted on M26 rootstocks. We measured yield, fruit quality attributes and fruit N content. Data from the second season revealed fruit in the low irrigation treatments were significantly smaller (152 g) but firmer, with higher total soluble solids (11.8 °Brix). Irrigation treatment had no effect on fruit colour, however fruit background colour decreased significantly with increased current season N application. Fruit N content was not significantly influenced by N application. This study demonstrates the strong linkage between N and irrigation management on the above ground components of orchard production and urges caution for growers implementing preharvest fertigation.

Keywords: fruit size, colour, firmness, total soluble solids, 'Galaxy', Tasmania

INTRODUCTION

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 practised by apple growers in Australia, research and management guidelines for optimal supply of tree nutrient requirements are limited.

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 decrease fruit colour and firmness quality parameters through delayed maturation (Oberly and Boynton, 1966; Neilsen et al., 2004; 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.

The objective of this study was to determine the range of fruit quality outcomes under split pre- and postharvest N application via fertigation overlaid onto three different rates of irrigation in a productive commercial orchard setting. Specifically, we aimed to test if improved fruit quality outcomes and reduced N leaching could be achieved through split pre- and postharvest fertigation in comparison to fertigation postharvest only. Further, we aimed to compare fruit quality outcomes and N leaching under high and low N application and high to low seasonal irrigation volumes.

MATERIALS AND METHODS

Trial design

The fertigation trial was conducted at Lucaston Park Orchards in southern Tasmania on 10-year-old 'Galaxy' trees, grown on M26 rootstock pruned to a central leader training system with 1m tree spacing and 4.5 m row spacing. The variety was chosen to represent a commonly grown variety in the region and trees were subjected to standard orchard management. The experimental layout for the trial consisted of a randomised block design where rows were split into three blocks of approximately 20 trees block^{-1}, one block for each irrigation treatment. Each irrigation block was further split into five sub-blocks, one for each N treatment, consisting of four trees (in some cases this was extended to five or six depending on tree uniformity). Of the four trees, two were guard trees and one of the middle two was chosen for sampling. Four rows were used in the trial, each row constituting a separate replicate. Each row had a high (4 L h^{-1}), Medium (2.3 L h^{-1}) a low (1.6 L h^{-1}) irrigation treatment plumbed into the grower's irrigation system. Trees were treated when the grower irrigated. Each irrigation block received five N treatments consisting of: a) Zero N control; b) split 25% N preharvest and 25% N postharvest; c) split 50% N preharvest and 50% N postharvest; d) 50% N postharvest and e) 100% N postharvest. Ratios were based on a percentage of annual N application at 60 kg N^{-1} ha^{-1}. To deliver the N treatments, five new 13mm polypipe lines were installed down the row, one for each treatment, and 4 L h^{-1} pressure compensated drippers were fixed to the lines at approximately 15cm from the base of the treatment tree on the upward side of the slope. Nitrogen was applied as fertiliser grade $Ca(NO_3)_2$ mixed with water in a 220 L drum header tank and delivered via a fire-fighting pump at constant 70 kPa. Fertiliser application followed standard fertigation practise in which a 10 min water only wetting up period was followed by a 40 min application of the N treatments followed by a 10 min water only rinse. At each application interval, treatments (including the control 0N) were applied once/week for four weeks in approximately 50 L water. Preharvest fertigation treatments commenced in November 2013, coinciding with the first irrigation application for the season and timed to match maximum demand by the tree during leaf canopy development. Postharvest treatments were applied in March/April 2014.

Fruit quality analysis

Fruit was harvested from the middle tree of the treatment sub block during commercial harvest. Total fruit number per tree was counted and 40 individual fruit were randomly collected from the northern face of the tree row. Harvested fruit was returned to the laboratory and 20 blemish-free fruit were measured for weight, firmness, colour and total soluble solids (TSS). 10 fruit from each treatment were cored to remove pips and dried in paper bags at 60°C. Dried fruit were sent to CSBP Soil and Plant Laboratories for chemical analysis. Another 10 fruit were placed in storage at 2°C with no atmospheric control and assessed for firmness and TSS after 12 weeks.

Data analysis

Fruit quality assessment data was analysed using a univariate general linear model approach in SPSS with treatment and time considered as fixed factors. Tukey's HSD was used to identify significance differences between means. No data transformations were necessary.

RESULTS AND DISCUSSION

Across the trial, average yield was 36 kg tree^{-1} equating to harvest total of 81 t ha^{-1}.

Fruit weight at harvest was significantly (P<0.001) reduced in the lowest irrigation treatment with average values ranging from 152 g under low irrigation to 163 g in the highest irrigation treatment (Table 1). Nitrogen treatments had no significant effect on fruit size. The reduction in fruit size under low irrigation treatments was correlated with significantly increased firmness at harvest, a result often reported for smaller fruit (Ebel et al., 1993) due to their higher cellular density. Firmness at harvest decreased with higher irrigation rates and higher current season N treatments highlighting the importance of N and water management preharvest (Figure 1). At picking fruit harvested from the 50% current season N treatment were significantly (P<0.05) less firm in all three irrigation treatments, however following 10 weeks in storage no significant difference in fruit firmness existed between the N and irrigation treatments (Table 1).

Table 1. Fruit quality results for the 2013/2014 season under irrigation and post- (March 2013) and preharvest (November 2013) nitrogen treatments on 10-year-old 'Galaxy' trees at Lucaston Park Orchards.

Fruit quality parameter	Irrigation			Nitrogen				
	High	Medium	Low	0N	50% Post	100% Post	25% Pre and 25% Post	50% Pre and 50% Post
Weight (g)	162.8	161	152.5 (a)	155.9	158.8	158.4	158.5	162.3
Dry matter (%)	15.3	16	16.9 (a)	16.3 (a,b)	16.1 (a,b)	16.5 (b)	16.2 (a,b)	15.2 (a)
Total soluble solids (harvest)	10.9 (a)	11 (b)	11.8 (c)	11.3 (b)	11 (a)	11.5 (c)	11.3 (b,c)	11 (a)
Total soluble solids (storage)	12.1	12.5	13.2 (a)	12.7	12.7	12.9	12.4	12.4
Firmness (harvest)	8.2 (a)	8.4 (b)	8.6 (c)	8.5 (b)	8.4 (b)	8.5 (b)	8.4 (a,b)	8.2 (a)
Firmness (storage)	6 (a,b)	5.7 (a)	5.8 (b)	5.9	5.8	5.9	5.8	5.7
Red colour intensity	6.6 (c)	5.3 (a)	6.2 (b)	6.1	6.1	6.5	6.4	5 (a)
Red colour % cover	3.7 (a)	3.3	3.4	3.4 (b)	3.7 (b,c)	3.8 (c)	3.6 (b,c)	2.9 (a)
Background colour	6	6.1	6	6.2 (b,c)	5.8 (a)	6.3 (c)	6 (a,b)	5.8 (a)
Fruit total N content (%)	0.28	0.25	0.26	0.25	0.27	0.23	0.28	0.29

Letters denote significant differences under irrigation or nitrogen treatments.

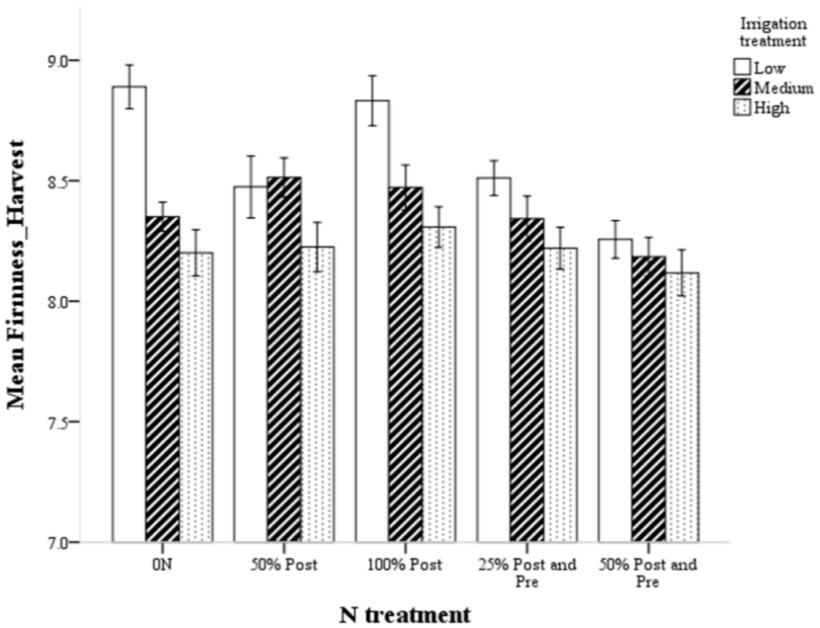

Figure 1. 'Galaxy' fruit firmness at harvest under post (March 2013) and preharvest (November 2013) nitrogen and irrigation treatments at Lucaston Park Orchards.

Total soluble solids (TSS) in the low irrigation treatment at harvest (11.0 °Brix) and after 10 weeks in storage (13.2 °Brix) were significantly higher than the medium and highest irrigation treatments (Table 1). This result was also reflected in the significantly higher dry matter content (16.8%) observed in fruit harvested from the lowest irrigation treatment. These results reflect data commonly reported for smaller fruit (Naor et al., 1995). Significant differences in TSS at harvest were attributed to N treatment, yet no obvious trend towards a pre- or postharvest advantage was observed. Nitrogen treatments had no effect on TSS after storage, however, when the percentage change in TSS between analysis dates were compared, it was apparent that fruit harvested from current season N treatments were slower to convert starch into fruit sugars indicative of delayed maturation (data not shown).

Further indications of delayed maturation under current season N application were results from a range of fruit colour analyses (Table 1). Intensity of red colour and percentage red colour were significantly reduced under the highest current season N treatment consistent with other research on red skinned apple cultivars (Neilsen et al., 2009). Highest irrigation produced fruit significantly redder both in intensity and percentage cover than the other irrigation treatments. Both current season N treatments produced fruit with background colour indicative of delayed maturity. Interestingly the 100% postharvest N application produced fruit with significantly increased yellow background colour, indicative of faster maturing fruit compared to the other treatments. Irrigation treatments had no significant effect on background colour.

Irrigation and N treatments had no significant effect on fruit N content (0.24-0.28%) at harvest. The calculated N removal from the trial orchard block was approximately 30 kg N^{-1} ha^{-1}. The lack of a significant difference in fruit N content between treatments was attributed to the trees having adequate supply of N under all treatments, even the zero N control due to residual fertiliser application by the grower prior to the commencement of the trial, and high rates of N mineralisation. Additional season's data collection under our treatments will be required before discernable differences between treatments are observed. Trial results indicate that no more than 30 kg N^{-1} ha^{-1} are required to obtain suitable fruit quality outcomes for this orchard block. Future collection of leaf N, soil N, vegetative growth and N drainage below the root zone are not reported here, these together with N15 analysis of tree tissue will facilitate a better understanding of the fate of N following fertigation treatments.

CONCLUSIONS

This study demonstrates the potential negative influence of high current season N application on fruit maturation, and the strong interaction between irrigation and N application. Given that no increase in fruit N was observed under higher N treatments, that zero N treatment produced the firmest fruit, and that sugar conversion was reduced, it is likely that current season (preharvest) N was in oversupply leading to reduced fruit quality parameters and delayed maturation. Given that postharvest N application produced fruit of increased maturity and adequate fruit N content, demonstrates that postharvest N application may be a more reliable N management option for growers not wanting to risk oversupply of N during the current season and poor fruit quality outcomes. Furthermore, postharvest N application maximises opportunity for available N uptake to be used for storage and remobilisation in the following season.

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Literature cited

Ebel, R.C., Proebsting, E.L., and Patterson, M.E. (1993). Regulated deficit irrigation may alter apple maturity, quality, and storage life. HortScience *28* (*2*), 141–143.

Frak, E., Le Roux, X., Millard, P., Guillaumie, S., and Wendler, R. (2006). Nitrogen availability, local light regime and leaf rank effects on the amount and sources of N allocated within the foliage of young walnut (*Juglans nigra* × *regia*) trees. Tree Physiol. *26* (*1*), 43–49. PubMed http://dx.doi.org/10.1093/treephys/26.1.43

Klein, I., Levin, I., Bar-Yosef, B., Assaf, R., and Berkovitz, A. (1989). Drip nitrogen fertigation of 'Starking Delicious' apple trees. Plant Soil *119* (*2*), 305–314 http://dx.doi.org/10.1007/BF02370423.

Loescher, W.H., Mccamant, T., and Keller, J.D. (1990). Carbohydrate reserves, translocation, and storage in woody plant-roots. HortScience *25* (*3*), 274–281.

Naor, A., Klein, I., and Doron, I. (1995). Stem water potential and apple size. J. Am. Soc. Hortic. Sci. *120* (*4*), 577–582.

Neilsen, D., and Neilsen, G.H. (2002). Efficient use of nitrogen and water in high-density apple orchards. Horttechnology *12* (*1*), 19–25.

Neilsen, G.H., Neilsen, D., Hogue, E.J., and Herbert, L.C. (2004). Zinc and boron nutrition management in fertigated high density apple orchards. Can. J. Plant Sci. *84* (*3*), 823–828 http://dx.doi.org/10.4141/P03-153.

Neilsen, G.H., Neilsen, D., and Herbert, L. (2009). Nitrogen fertigation concentration and timing of application affect nitrogen nutrition, yield, firmness, and color of apples grown at high Density. HortScience *44* (*5*), 1425–1431.

Oberly, G., and Boynton, D. (1966). Nutrition of fruit crops. In Apple Nutrition, F. Childers, ed. (New Brunswick: Horticultural Publications, Rutgers), p.22–26.

Stefanelli, D., Goodwin, I., and Jones, R. (2010). Minimal nitrogen and water use in horticulture: effects on quality and content of selected nutrients. Food Res. Int. *43* (*7*), 1833–1843 http://dx.doi.org/10.1016/j.foodres.2010.04.022.