Cherry nutrition: the balancing act of feeding fruit for high-quality cherries

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Abstract

Cherry tree nutrition and fruit quality is extremely complex, involving regional soil and climatic factors overlaid by cultural factors of cultivar, irrigation and fertiliser application. Over the last decade our team has investigated within-tree to regional variation, fertigation (particularly N) rate and timing (with irrigation overlays), tree uptake and storage and foliar application of the relatively immobile micronutrients, all within the context of fruit quality. Observational studies of within-tree variability revealed that fruit on vertical structures were associated with lower concentrations of micronutrients than fruit on horizontal wood in Kym green bush systems. Observational study of regional variation found negative correlations between colour development with fruit of higher N, Zn and Mn concentration. Follow-up manipulative trials found that foliar applications (but not fertigation-applied) increased fruit concentration of Mn and Zn, but not Ca, but this did not translate to fruit quality improvements postharvest. Manipulative N rates and timing work on multiple sites over consecutive seasons indicated that increased preharvest application (equivalent to 150 or 240 kg ha^{-1}) led to increased fruit N concentration and loss of firmness in N-deficient but not N-sufficient orchard scenarios. Future funded work will use ^{15}N labelled fertilisers to further investigate tree allocation, storage and re-mobilisation of N, and losses of N below the rootzone with a view to developing a full N, and potentially P and K, budget. This, along with critical climate and soil data will allow the development of a grower decision support tool.

Keywords: fertigation, foliar application, Kym green bush, nitrogen, manganese, zinc

INTRODUCTION

Sweet cherry is an unusual temperate tree crop in that fruit sets, matures and ripens within a 60-80 day window (Kappel, 1991) and in less than 50 days in the warmest production regions of Australia. Sweet cherry relies solely on stored nitrogen, predominantly from the main trunk and roots, for at least 30 days post bud break (Millard et al., 2006) and for up to 60 days (Grassi et al., 2002). Given that 30-60 kg ha^{-1} N (depending on crop load), can be removed annually from sweet cherry orchards, replacement via judicious use of fertilisers is critical to ensure adequate reserve accumulation for the subsequent seasons crop. Studies of N^{15} uptake have revealed utilisation efficiency of 65.7% in spring (applied at full bloom) compared to 37.4% in summer (applied 15 days after harvest), though of this 52% of spring applied N was subsequently removed in fruit and summer prunings. This emphasises the need for postharvest fertilisation: Ayala et al. (2014) reported that N applied immediately postharvest had greatest utilisation efficiency relative to later in the season. Achieving balanced nutrition is complicated further as adequate preharvest N uptake is required to support photosynthesis in order to carry the crop. Yet excessive preharvest N fertiliser can lead to poor fruit quality, in terms of colour and sugar development and firmness and potentially postharvest shelf-life. This has led to the general practice of ceasing N application 3-4 weeks prior to harvest, despite studies such as Koumanov et al. (2016) reporting that N can be applied continuously without negative effects on fruit quality for 'Burlat'/'Mazzard' and 'Lapins'/'Gisela5'.

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Xylem uptake of plant immobile nutrients, such as Zn, Mn and Ca, can be limiting to photosynthesis and deficit can negatively impact yield potential and fruit quality. For this reason foliar applications are applied preharvest (Fallahi and Eichert, 2013). Thus orchard management practice, such as fertiliser regimes as well as pruning and tree structures, and regional influences, such as soils and climate, could contribute to variability in fruit quality at the within-tree, within orchard and between region scales. Given tree nutrition has strong effects on fruit quality (Nielsen et al., 2007) we hypothesised that within-tree to between region variation would be associated with fruit quality differences and that fruit quality can be optimised with precise use of fertilisers at the orchard scale. The objectives of this study were to investigate: within-tree- to regional-variation in fruit nutrition and quality and; within orchard study of impact on fruit nutrition and quality by: 1) foliar application of plant immobile nutrients, and 2) N fertigation rate and timing.

MATERIALS AND METHODS

Within-tree variation in fruit nutrition and quality

Four trees of seven-year-old 'Simone' on 'Colt' at Hansen's Orchard in the Huon Valley (38 km south of Hobart, Tasmania, Australia; 43.0295°S; 147.0580°E) had branches on the north and south aspect of the canopy tagged to include 100 flowers working back from the start of two-year-old wood. Individual flowers were tagged and labelled with the date at the time of opening. At commercial harvest date tagged fruit was sampled and measured for fruit quality (as reported in Bound et al., 2013) and nutrient concentration. Spur caliper, distance from proximal branch-end, spur fruit and leaf number and branch orientation were measured.

Regional variation in fruit nutrition and quality

'Lapins' fruit from 7 orchard locations (Table 1), all produced on a 'Kym green bush' (KGB) training system on 'Colt' or 'F12-1' rootstocks, were harvested from upright limbs on the northern aspect of the canopy. Fruit were sampled from four randomly selected trees. At commercial harvest, fruit were transported to the laboratory, allocated to measurement of fruit quality (per Bound et al., 2013) at 0, 10, 20, 30, and 40 days postharvest per orchard then stored in a cool room at 0°C at close to 100% relative humidity with no atmospheric control. In addition a sub-sample of 20 fruit per orchard was allocated to mineral nutrient analysis at harvest.

Table 1. Location and soil type of each orchard used to investigate fruit nutrition and quality variability.

Orchard	Region	Soil type[1]	Location
1	Derwent Valley	Sodosol	-42.578242°; 146.751843°
2	Derwent Valley	Sodosol	-42.765073°; 147.034912°
3	Derwent Valley	Sodosol	-42.756834°; 147.288536°
4	Derwent Valley	Sodosol	-42.719175°; 146.904150°
5	Huon Valley	Ferrosol	-43.069203°; 147.044202°
6	Huon Valley	Kurosol	-43.015336°; 147.066701°
7	Channel	Ferrosol	-43.172653°; 147.237562°

[1]Isbell (2002): Sodosols are texture contrast soils consisting of sand to sandy loam topsoil overlying a sodic (exchangeable sodium percent equal or greater than 6%) clay subsoil which is not strongly acid. Sodosols are often formed on mudstone, sandstone or alluvial deposits. Ferrosols are well-structured soils in which the subsoil is high in free iron oxide (>5%) and lack a strong texture contrast. Ferrosols are usually formed in high rainfall areas from basalt or dolerite. Kurosols are texture contrast soils consisting of sand to sandy loam topsoil overlying a strongly acid clay subsoil. Kurosols are often formed on mudstone, sandstone or alluvial deposits.

Fertigation and foliar application of N, Mn, Zn and Ca and fruit quality

Trials were established at Grove Research Station (considered a nutrient deficient orchard) and Ridgy Didge Orchard (considered nutrient sufficient) in the Huon Valley of southern Tasmania. At Grove Research Station 10-year-old 'Lapins' on 'Colt' were trained to KGB with tree spacing of 2 m and row spacing of 4.5 m. Fertiliser application was ceased by the orchard managers in the experimental rows during the trial period and all other commercial orchard management continued.

To assess the influence of preharvest N fertigation on cherry fruit quality and postharvest storage, 5 replicates each of 12 trees of N treatments of 0 N control, low (25 g N tree^{-1}), medium (50 g N tree^{-1}) and high (75 g N tree^{-1}) were split into four weekly applications commencing approximately one month after bud burst.

At Ridgy Didge Orchard the trial was conducted on 12-year-old 'Simone' trees on 'Colt' rootstock, trained to a KGB system with tree spacing of 2 m and row spacing of 4.5 m. Each replicate of 12 trees was further split into four blocks of three trees to which N treatments were randomly allocated. Pre- and postharvest N treatments of 0 N control, low (40 kg N ha^{-1}; grower's standard rate), medium (80 kg N ha^{-1}) and high (120 kg N ha^{-1}) split into four weekly applications.

Micronutrient trials were also established at Grove Research Station and Woodstock in the Huon Valley. Fertigation treatments were applied to four replicates of twelve trees. Each replicate was further split into sub-blocks of three trees to which treatments were randomly allocated. Treatments included 30 kg ha^{-1} calcium carboxylate (6% Ca w/v, SLTec), 20 L ha^{-1} ZM^{2} (2.3% Zn w/v, Stoller's) and zero fertiliser water only control. Treatments were applied weekly for three weeks commencing in late November 2011.

At both orchards foliar spray treatments were applied to three replicates, each consisting of five sub-blocks of three and six trees at Grove and Woodstock respectively, to which the treatments were applied with two border trees separating treatment trees. The treatments were randomly ordered within the blocks. Foliar spray treatments of Ca, Mn, Zn and water (control) (Table 2) were applied on both sides of the rows. All treatments were applied using a motorized air blower backpack spray unit. Foliar sprays were applied in a fine mist covering leaves to dripping point. The foliar sprays were applied in December 2012, in the morning, two weeks apart with the final application approximately three weeks before harvest. In both orchards, micronutrient application was ceased for the duration of this trial in the experimental row, however, all other commercial orchard management practices continued.

Table 2. Rates and products of micronutrients used in foliar trial.

Micro-nutrient	Industry name	Analysis	Manufacturer	Recommended application	Applied quantity
Ca	Pitstop	17% w/v Ca	Agrichem	5-10 L ha^{-1}	6 mL tree^{-1}
Mn	Manni-Plex Mn	6% w/v Mn; 2.8% w/v N as nitrate; 5.6% w/v N as urea	Barmac	2-6 L ha^{-1}	6 mL tree^{-1}
Zn	Manni-Plex Zn	8.8% w/v Zn; 2.8% w/v N as urea; 3.6% w/v N as nitrate	Barmac	2-6 L ha^{-1}	6 mL tree^{-1}

Data analysis

Canonical correlation analysis was used to explore relationships between fruit quality and cultivation attributes. The method works by identifying the linear combination of the set of fruit quality variables that is maximally correlated with a linear combination of the set of variable cultivation attributes. These two linear combinations correspond to the first canonical dimension. Then the remaining variation is explained with a second pair of linear combinations, referred to as the second canonical dimension, and so on. The canonical correlation analysis results are interpretable in terms of the correlations of the fruit quality variables and the cultivation attributes with their respective canonical variables. The canonical correlations analysis was calculated using Proc CanCorr in SAS 9. We applied

canonical correlation analysis to explore relationships between fruit nutrient concentration (B, Ca, Cu, Fe, Mg, Mn, N, P, K, S, Zn) with tree attributes of spur caliper, spur distance, spur fruit and leaf number, flowering date and limb orientation (top row) and the same fruit nutrient concentrations with fruit quality attributes of firmness, weight, colour, and soluble solids.

Principal components analysis is an exploratory technique used to describe variation in a set of correlated variables in terms of a new set of uncorrelated variables that are linear combinations of the original set. The first set of linear combinations are chosen to contain as much variation as possible, thus allowing for a simpler low-dimensional interpretation of multivariate data.

Fruit quality assessment data were analysed using a one way ANOVA in SPSS with fertigation and foliar spray treatments considered a fixed factor with, block (replicate) considered as a random factor and with each fruit quality parameter considered as the dependent variable. Post hoc tests were computed using Tukey's honestly significant difference (HSD) or Fishers protected least significant difference (LSD). Significance was calculated at P=0.05 and standard error used for comparison of mean values in the tables and figures. No data transformations were necessary.

RESULTS AND DISCUSSION

Following examination of the variance explained by each canonical correlation dimension (54%) we restricted our attention to the first dimension. The 'Simone' on 'Colt' trained to KGB used for within-tree variability in this study comprised 15-20 evenly spaced limbs. However, from examination of the canonical correlations, we found that the more recently re-newed uprights of less caliper tended to bend towards horizontal as the crop developed, particularly where 'grape' bunches occurred (Wilk's lambda $F_{28,268}$=5.47, P<.000). The results of fruit from larger spur caliper, closer spur distance, more horizontal wood and later flowering being associated with poor Ca and to a lesser extent poor Mg, Cu, Mn, P and Zn nutrition (Figure 1) may suggest less xylem and phloem supply of these nutrients (Wilk's lambda $F_{77,415}$=3.22, P<.000). This could arise from less conducting xylem and/or a less favourable light environment providing less transpirational pull, although crop load differences whilst visually similar, were not quantified. That large fruit of poor colour development was associated with poor Ca, Cu and Zn may simply indicate dilution of these micronutrients although the association with colour is not an easily explained observation. Despite the observational nature of these results, the practical implications are that upright wood in a good light environment without excessive crop load leads to the best fruit quality outcomes for 'Lapins' on KGB.

PCA analysis (Figure 2) of fruit nutrition and quality data for the seven orchards in southern Tasmania revealed that fruit from Howards, Magra and Reid's orchards formed site based discrete grouping, whilst data from the other sites generally overlapped. Of note is the greater spread of data points for the Jones orchard which was attributed to the orchard being on a relatively steep ex-pasture site with shallow top soils. PCA groupings were not indicative of regional association of orchards emphasising the impact of orchard management rather than environmental control on fruit quality.

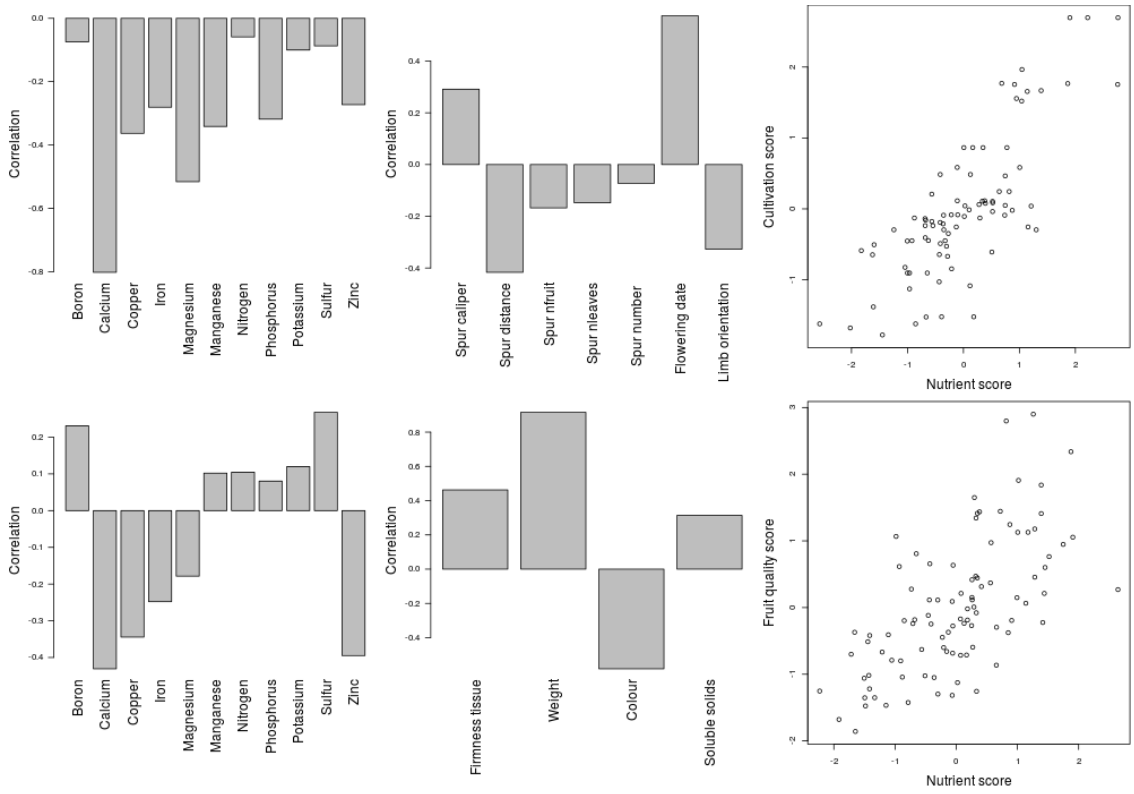

Figure 1. Canonical correlations analysis of fruit nutrient concentration (B, Ca, Cu, Fe, Mg, Mn, N, P, K, S, Zn) with tree attributes of spur caliper, spur distance, spur fruit and leaf number (Spur nfruit and Spur nleaves respectively), flowering date and limb orientation (top row) and with fruit quality attributes of firmness, weight, colour, and soluble solids (bottom row). Shown on the left are correlations of attributes with their respective canonical variables. On the right are shown plots of the first dimension canonical correlation scores.

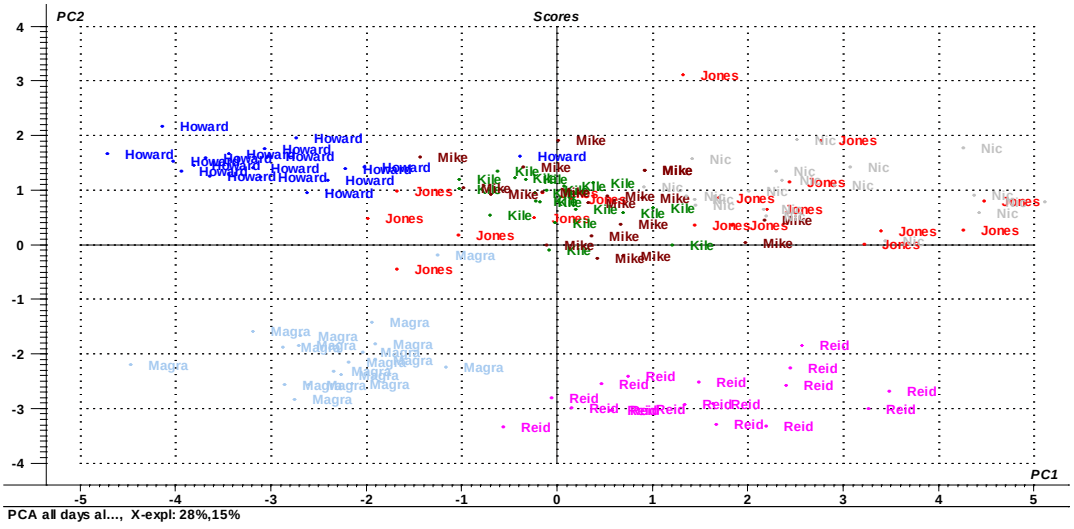

Figure 2. Principal components analysis of fruit nutrient concentration (B, Ca, Cu, Fe, Mg, Mn, N, P, S, Zn), sugar (Brix), total acidity (TA); fruit colour, firmness, size, mass; stem colour and chroma from seven orchards chosen for distinct regions and soil types in southern Tasmania.

Despite the large variability inherent in an observational study of fruit nutrition and quality arising from distinct management practice and regions, significant negative correlations were found between Zn, Mn and N concentration in fruit with fruit colour (Figure 3). The relationship between nitrogen and colour is not unexpected and long-recognised in apple (e.g., Marsh et al., 1996). This could be due to inhibition of anthocyanin synthesis and accumulation and/or delayed chlorophyll degradation (Fallahi et al., 2001; Wang and Cheng, 2011), relatively high crop loads (that were not assessed) and/or greater shading of fruit by vegetative growth (Nielsen et al., 2009). Interestingly we found that patterns of Zn and Mn mirrored the result with N. This may indicate that fruit relatively high in N, Zn and Mn were physiologically immature (Serrano et al., 2009) and not fully expanded, although it should be noted that we found no correlation between fruit nutrition with fruit size when assessed at all sites and fruit from all orchards was sampled at the time of commercial harvest.

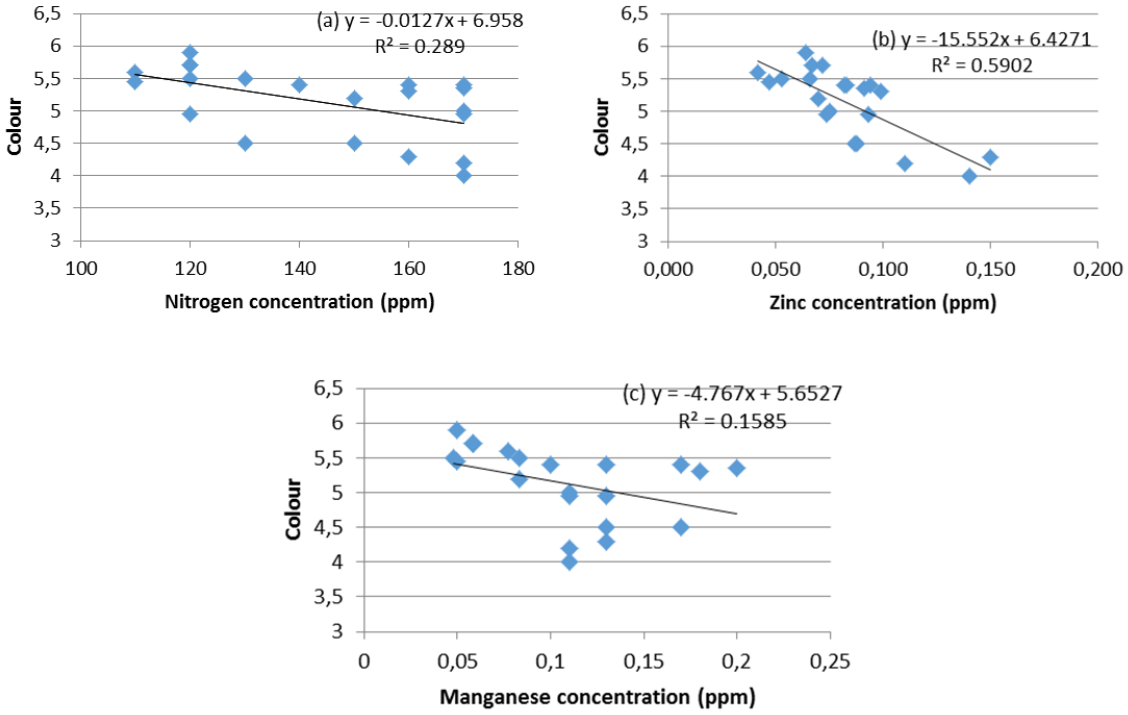

Figure 3. Linear regression of fruit colour, measured using the Australian Cherry Colour Chart (0 = light red to 7 = dark mahogany) which contains six different colour swatches indicating stages from light red with a tinge of orange to a dark mahogany colour, correlated against nitrogen (a), zinc (b) and manganese (c) concentrations of fruit sampled from seven orchards of distinct regions and soil types in southern Tasmania.

Fertigation of Mn, Zn and Ca had no effect on fruit mineral nutrient content (data not shown), similarly reported by Nielsen et al. (2004). Preharvest foliar application of Mn and Zn resulted in significant uptake into leaves (data not shown) and fruit that was more pronounced in a nutrient-deficient than -sufficient orchard scenario (Figure 4). Wojcik and Morgas (2015) applied Zn postharvest to tart cherries and found no effect on leaf Zn status the following season. Zhang and Brown (1999) reported that of the 14-15% foliar Zn absorbed by pistachio only 9.6% was soluble and Zn applied to solutions bathing isolated cells was rapidly absorbed. They concluded that Zn has very limited mobility due to the high binding capacity of leaf tissue. It should be noted however, that Zn is readily absorbed and transported in citrus (Wallihan and Heymann-Herschberg, 1956). Naseri et al. (2002)

demonstrated significant absorption of Mn within 24 h of foliar spraying on apple. In contrast we found no change in Ca levels in response to foliar application although being a xylem-mobile nutrient it may be that foliar application was too late in the season to affect a response in our trials. Despite the implication of Zn and Mn in fruit quality postharvest from our regional, observational study and despite finding significant Zn and Mn uptake in our factorial within-orchard study, we found no effect of Zn and Mn on fruit quality postharvest.

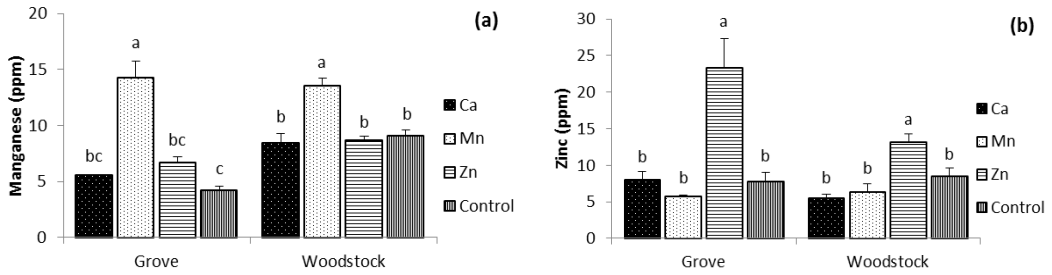

Figure 4. Fruit manganese (a) and zinc (b) concentrations treated with calcium, manganese, zinc and water (control) foliar sprays at the Grove Research Station and Woodstock orchards in southern Tasmania. Analysis of variance using SPSS Statistical Software.

The highest N application treatment at Grove equated to 150 kg N ha^{-1} (3× the preharvest recommended rate), thus the result of elevated fruit N concentration with increased N fertiliser application is as expected in the nutrient-deficient scenario (Table 3). Similarly Nielsen et al. (2007) found that N concentration in 6- to 8-year-old 'Lapins' fruit increased after increased pre-harvest N fertigation. The finding of fruit of >0.7% N correlating to decreased firmness fits with other reports (Nielsen et al., 2004) and with anecdotal observations of when N is deficient in the orchard. Lack of effect at the nutrient-sufficient orchard (Ridgy Didge; Table 3) is consistent with control fruit that received 0% N fertiliser having N concentrations of approximately 0.7% across the treatment range.

Table 3. Sweet cherry flesh firmness and total N concentration at harvest in nitrogen deficient and nitrogen sufficient orchards in southern Tasmania following fertigation treatments.

Treatment	Grove (N deficient)		Ridgy Didge (N sufficient)	
	Flesh firmness (g kg^{-1})	Total N fruit (%)	Flesh firmness (g kg^{-1})	Total N fruit (%)
Control	0.088 ab	0.56 c	0.111	0.825
Low	0.091 a	0.548 c	0.108	0.845
Medium	0.086 b	0.628 b	0.109	0.839
High	0.075 c	0.716 a	0.110	0.857

Letters denote significant differences between treatments when $P<0.05$.

CONCLUSIONS

Our study of within-tree nutrition showed that in KGB fruit from vertical wood has better nutrition and quality than those from horizontal wood. Across regions we found that poor colour development was associated with elevated N, Mn and Zn. However, whilst foliar application of Zn and Mn (but not Ca) was effectively taken up by the trees, there were no effects on fruit quality. Preharvest N fertigation directly affected fruit concentration and firmness in a N deficient orchard, but not in the N-sufficient orchard in which control fruit N concentrations matched fruit from high N treatments. Nitrogen fertiliser rate ha^{-1} should match N removed in the crop and be based on crop load, fruit N status and dry matter content.

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