New Zealand and Australia Avocado Grower's Conference '05. 20-22 September 2005. Tauranga, New Zealand. Session 6. Postharvest quality, outturn. 15 pages.

IMPROVING AVOCADO FRUIT QUALITY THROUGH TREE NUTRITION -PRESENT KNOWLEDGE

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SUMMARY

Avocado tree nutrition can have a significant effect on fruit quality. In many studies avocado fruit with more calcium (Ca) often have less rots and internal disorders, with opposite effects for nitrogen (N) and potassium (K). Considering the lack of specific work under Australian conditions, we conducted several studies aimed at improving quality through Ca, K and N soil applications. We also investigated the ability of different avocado varieties commonly used as rootstocks to absorb minerals from the soil.

Microfine gypsum (MicroGyp) applied at flowering increased fruit Ca concentrations slightly in one season, but not sufficient to have large effects on ripe fruit quality (severity of rots or internal disorders). Treatments had only a small effect on soil Ca after 70 days, possibly because the low cation exchange capacity resulting on rapid leaching of soil Ca. Smaller, more regular applications could be more effective in increasing Ca uptake. This approach is being tested. The application of K (as potassium sulphate) to the soil in the same trial (with or without MicroGyp) slightly reduced flesh Ca, and increased internal disorders (diffuse discolouration). In addition, added K to the same soil under glasshouse conditions significantly reduced leaf and sap Ca concentrations in several avocado cultivars. These results suggest that lower annual K application rates or reduced applications during the critical stages for Ca uptake into fruit (early fruit development) should be investigated. Only small fruit quality effects were noted from applying higher rates of N at different fruit growth stages. (The total N application over the season was the same for each treatment.) Under subtropical conditions, higher applications in December should be avoided, while higher applications in late January or mid April could be beneficial.

The results confirm the challenges associated with improving fruit Ca. However, further work is justified given the confirmed benefits of improved fruit minerals concentrations on quality. The varying ability of different avocado cultivars to absorb minerals from the soil was again confirmed. Thus, longer term benefits could be realised by selecting rootstocks with improved ability to optimise fruit minerals concentrations. Using differing annual N application rates to improve fruit quality may require a balance between yield

and quality, which is unlikely to be the case with Ca. However, the effect of annual N rates on yield and quality under Australian conditions is required.

Key words: avocado, fruit, quality, calcium, nitrogen, potassium, rootstock

INTRODUCTION

Mineral nutrition of tree crops, including avocado, can have a significant affect on the postharvest quality of the fruit, in particular its size, shape, shelf life and susceptibility to rots and internal disorders (Hofman et al., 2002a).

Calcium (Ca) is the nutrient most frequently implicated in flesh disorders and diseases in many fruit crops. In avocado, strong correlations have been shown between more fruit Ca and less rots (Penter and Stassen, 2000; Hofman et al., 2002b) and internal disorders such as diffuse discolouration, vascular browning and pulp spot (Hofman et al., 2002a). Also, fruit from higher yielding trees often have less rots and more Ca because of their smaller size (Hofman et al., 2002b). Lower fruit potassium (K) and higher magnesium (Mg) concentrations have also been related to reduced fruit rots and internal disorders, possibly because of their interaction with Ca uptake into the fruit (Hofman et al., 2002a). Therefore, it is likely that the Ca is the dominant factor driving the relationship.

In contrast, higher rates of nitrogen (N) application to avocado trees, especially as ammonium, have been associated with more rots and internal disorders (Arpaia et al., 1996; Penter and Stassen, 2000). More recently, higher fruit flesh and skin N have been correlated with more rots and internal disorders in avocado (Marques et al., 2003; Willingham, 2003; Kruger et al., 2004). However, large strategically timed applications of N can also increase yield and fruit size (Lahav and Whiley, 2002). This highlights the importance of a balanced N nutrition aimed at optimising fruit yield, size and quality.

In addition, recent studies have indicated that rootstocks can significantly affect avocado fruit quality, particularly fruit resistance to rots and internal disorders (Willingham et al., 2001; Marques et al., 2003). These and other studies both with Hass trees on unknown seedling rootstocks (Hofman et al., 2002b) and Hass trees on known rootstocks (Willingham, 2003) have suggested that fruit minerals are likely to be involved in this rootstock/fruit quality interaction, and that there is benefit in understanding how rootstocks can improve fruit minerals concentrations. One of the possible mechanisms may be crop load, since in the latter two reports, trees that produced fruit with better quality generally also had higher yield.

The above discussion confirms the significance of nutrition in avocado fruit quality, and highlights the advantages of developing systems to improve fruit nutrition, especially Ca and N. However, most of these results were obtained by comparing fruit from different production locations and relating fruit quality to minerals concentration, or by obtaining fruit from trees growing on different rootstocks. Hence, the “manipulation” of fruit minerals has been by indirect means, such as variations in soil type and rootstock genetics.

Attempts to manipulate fruit quality directly by fertiliser application have been less successful, especially with Ca. This can be partly the reason why the South African

avocado industry has moved away from Ca to improve fruit quality and is now concentrating on N, which is easier to manipulate and control (Wolstenholme, 2004). This may be the best approach in situations of excess residual soil N where both yield and quality could be suppressed because of excessive vegetative vigour. However, in Australia most avocado orchards are unlikely to have high residual soil N, and in most cases reducing N further could also reduce yield. Therefore, it is important to continue to focus on Ca in order to maintain and improve quality.

However, increasing Ca concentration in fruit by increasing soil applications has often been inconsistent. This is thought to be primarily due to the relatively immobility of Ca in the soil and plant and its dependence on water for distribution in plant tissue (Lahav and Whiley, 2002). Because Ca moves passively, it tends to concentrate in those tissues that lose more water. Therefore, leaves tend to accumulate more Ca at the expense of developing fruit. Thus, Ca absorption and regulation into fruit requires a holistic approach which should consider rootstock, soil type, water availability to the roots, and the potential for excess vegetative vigour (which can be promoted by N fertilisation) to compete with Ca accumulation in the fruit.

This paper summarises some of the results from several research projects aimed at improving fruit quality through fruit nutrition. Most of the focus is on Ca, but we will also report on some work with N. The Ca trials were designed to identify soil application treatments to improve fruit Ca concentration and quality. Potassium was also applied because of the known Ca/K interactions. We also investigated in more detail the interaction between Ca and K in several rootstocks grown in the glasshouse. Finally, we looked at whether the timing of nitrogen application can affect fruit quality.

MATERIALS AND METHODS

Calcium

Soil applications

Visually uniform 10-year old ‘Hass’ trees on seedling rootstocks of unknown origin were selected in a commercial avocado orchard at Bundaberg (south east Queensland). The trees were at 10mx5m intervals (200 trees/ha). The soil type is classified as a Kurosol, consisting of a light sandy loam over a heavier soil. Treatments were randomly applied to 5 tree plots, with the middle 3 trees being the experimental trees. The two outer trees were guard trees between each treatment. The trial used 6 rows of trees, with a total of 144 treatment trees. The experiment was conducted on the same site over three seasons (starting in 2002/3), but only the results of the 2003/4 season are presented.

Calcium as microfine gypsum (MicroGyp) and K as potassium sulphate (K_2SO_4) were evenly applied under the drip zone of each tree within one week of full flowering (26th September 2003) at the rates given in Table 1.

Six soil samples per plot at each of 0-10, 10-20 and 20-30 cm depths, were taken 70 days after fertilizer application and combined for each depth (total of 6 samples per treatment per depth). Fruit were harvested in early May 2004 (commercial maturity, 23.4% dry matter) and total yield per tree determined. The height, breath and width of the trees were measured to determine canopy volume. Thirteen average sized fruit per

tree were selected, transported to the laboratory, ripened and individually assessed for quality (see section 'Postharvest operations'). A further 7 fruit per tree were sampled to determine percentage dry matter (% DM) and minerals concentration (see section 'Dry matter and minerals analyses').

Table 1. Calcium soil applications trial. Form and rates of Ca and K applied to avocado trees in 2003 just before flowering.

Treat.	**Form**	**Rate of form** (kg/35 m^2)	**Rate of element** (g/m^2)	**Rate of element** (kg/ha)
1	No Ca	Nil	Nil	Nil
2	MicroGyp	Ca: 1.0	29	66
3	MicroGyp	Ca: 3.0	86	199
4	MicroGyp	Ca: 6.0	171	398
5	MicroGyp	Ca: 12.0	342	797
6	K_2SO_4	K: 4:00	0; 114	516
7	MicroGyp, K_2SO_4	Ca: 1.0, K: 2.0	29; 58	66; 258
8	MicroGyp, K_2SO_4	Ca: 1.0, K: 4.0	29; 114	133, 516

Calcium/potassium soil interactions

To test the ability of different Ca/K ratios in the soil, and of avocado rootstocks to take up Ca from the soil, seedlings of four avocado cultivars were grown in the glasshouse in soil from the Bundaberg field trials, with the addition of Ca and K to the growing medium (a high K rate was used to significantly change the ratio of K to Ca in the soil).

Plants and growing conditions

Thirty plants each of Velvick (Mexican), Reed (Guatemalan), Smerdon (Guatemalan-Mexican) and Toro Canyon (Mexican) were potted in 5 L plastic pots with sandy loam soil from the Bundaberg field site. The soil was taken from about 5-30 cm depth (top organic layer removed), sieved to about 10 mm, then steam sterilised at about 70°C for 45 min. To further reduce the risk of water logging, 20% perlite by volume was mixed with the soil, and each plant given 200 mL of water only when the top of the soil was very dry (every 3-4 days). Nitrogen was applied as a 1% urea spray weekly as required, and as 200 mL per pot of ammonium nitrate at 26.5 g/100 L fortnightly. Any leachate was collected in trays under each pot and returned to the soil. The plants were grown in a glasshouse at 30°C day/20°C night.

Treatments

The following soil treatments were applied to 10 seedlings from each cultivar:

- Control No additional soil treatment
- 2-Ca Double the current exchangeable Ca content of the soil. Gypsum was added at 3.27 g/kg dry soil, equivalent to 0.75 g Ca/kg, or roughly 3 tonnes gypsum /ha.
- 4-K Quadruple the current exchangeable K content of the soil. Potassium sulphate was added at 0.73 g /kg dry soil, equivalent to 0.31 g K/kg or roughly 300 kg K/ha.

Xylem sap and leaf samples

All plants were watered to field capacity the afternoon before sample collection. About 0.1-0.5 mL of xylem sap was collected by cutting the stem of each plant at ground level and placing the bottom 10 mm of the stem (after removal of bark) under (95 mm) vacuum. Ten mature leaves per plant were also sampled for minerals analysis.

Time of nitrogen applications

Two sections of the orchard with 48 uniform trees each were selected on the same farm as The "Soil Ca applications" experiment. One section received 2 L/tree of a 1% solution of 'Sunny' at the recommended time, at about 80% flowering and 10% flushing (initial application on 8th August 2000, and every year at the same phenological stage). The other section received no Sunny. Trees from both areas were divided into 8 blocks of 6 trees each. Each block received randomly one of six treatments (one treatment per tree per block), in which urea was applied from September 2000 to April 2004. All treatments received approximately 1.08 kg of urea per tree per year (Table 2). The control consisted of six even applications, which is the current commercial recommendation. The remaining treatments received more urea at specific times than at others. Treatment Mid-Sep is the current recommended practice when Sunny is used.

Table 2. Time of nitrogen trial. Times and rates of N (as urea) applied to avocado trees from 2000 to 2004.

Treatment	Time and rate (g/tree) of urea application				
	Mid Sep	End Oct	Mid Dec	End Jan	Mid Apr
Control	217	217	217	217	217
Mid-Sep	**360**	180	180	180	180
End-Oct	180	**360**	180	180	180
Mid-Dec	180	180	**360**	180	180
End-Jan	180	180	180	**360**	180
Mid-Apr	180	180	180	180	**360**

Fruit were harvested at commercial maturity. From 2001-4, fruit from each tree were placed through the packing line, and the total fruit number and size per tree recorded. In 2004, the height, breath and width of the trees were measured to determine canopy volume. In 2005, yield and fruit number per tree were recorded. In 2004 and 2005, 20 fruit per tree were sampled from the northern side of the canopy, transported to the laboratory, ripened and assessed for quality. Leaf and fruit samples were also taken for % DM and minerals analysis.

Postharvest operations

On arrival at the laboratory, the fruit from the 2003-4 season were dipped in 0.55 ml L^{-1} Sportak® (a.i. 450g L^{-1} Prochloraz) for 30 sec for disease control, dried and placed in single layer trays. Fruit from both seasons were held at 10°C for 5-7 days, then 5°C for

3-4 days, then ripened at 18°C with 10 ppm ethylene for 3-5 days until the fruit well sprung (fruit deformed by 2-3 mm under extreme thumb pressure), then held at 2°C for 3-5 days before ripening at 20°C. This program simulated average commercial conditions from the packhouse to the retail store (Hofman and Ledger, 2001). Fruit softening and ripe fruit quality were assessed as described in the Avocare Assessment Manual (White et al., 2001). Severity ratings for internal disorders (mainly diffuse discolouration and vascular browning) and diseases were based on the percentage of the flesh volume affected by lesions. Diseases were classified as either body or stem-end rots based on the location of the lesion on the fruit, rather than detailed identification of the fungi causing each lesion.

Dry matter and minerals analyses

Root, leaf, fruit skin and fruit flesh samples (about 20 g) were dried at 60^{o}C in a dehydrating oven until constant weight to determine % DM. Tissue Ca, K and Mg were analysed by inductively coupled plasma atomic emission spectrophotometer (ICPAES) and N by combustion (Marques et al., 2003). All results are presented on a dry weight basis.

The sap samples were placed in a freezer overnight just before analysis, then thawed to remove any particulate matter. They were then diluted 2:1 with concentrated nitric acid and analysed by ICPAES. The results are expressed as mg/mL of sap.

All soil samples were re-wetted to near field capacity where necessary and stored at 3 °C before extraction. About 250 g of wet soil was vacuum filtered through Whatman No 1 filter paper. The filtrate was then acidified with concentrated HCl and stored at 4°C prior to analysis by ICPAES. A sub-sample of the wet soil was then air dried, ground to pass a 2mm screen, and a 5 g sample weighed into a 50 mL centrifuge tube and extracted with 1M ammonium acetate on an end-over-end shaker for 30 minutes. The tubes were then centrifuged at 3000 rpm for 10 minutes and a 5 mL sample of the supernatant transferred to a plastic vial for analysis by ICPAES (Australian Standard Method 15D3). The results represent the cations on the exchange complex plus those in the soil solution, and are referred to as exchangeable cations (cmol/kg soil).

Statistical analysis

Data were analysed with Genstat 5® (Release 6.1) for Windows. The protected least significant difference (LSD) procedure at F=0.05 was used to test for differences between treatment means.

RESULTS AND DISCUSSION

Calcium

Soil applications

<u>Soil minerals</u>

The highest Ca treatment (treatment 5) resulted in more exchangeable soil Ca than the lowest ones (2 and 3) and the K alone treatment (6), but was not significantly different from the control (1) (Table 3). Adding Ca to the K treatments (7 and 8) increased

exchangeable Ca compared with the K alone treatment (6). The higher Ca rates (treatments 4 and 5) reduced exchangeable Mg compared with the control. As expected, exchangeable K increased with added K (treatments 6, 7 and 8), but was not affected by the addition of Ca alone (treatments 2, 3, 4 and 5). These results suggest that the soil treatments had only a small effect on soil Ca 70 days after treatment.

There was more exchangeable Ca, Mg and K in the top profile (0-10 cm), decreasing with greater depth (Table 3). Calculations indicated that the majority of the added Ca was not detected in the top 30 cm after 70 days, although large variations between samples made firm conclusions difficult. This suggests that most of the added Ca was leached from the top 30 cm within 70 days of application, contrary to the popular belief that Ca moves slowly through the soil profile. The higher Ca retained in the top 10 cm was likely due to higher organic matter in this layer, as evidenced from the darker colour of this layer compared to deeper layers. The poor overall retention of Ca in the surface 30 cm is most likely due to the low cation exchange capacity (CEC), with the top 10 cm having a CEC of 4.5 $cmol_c/kg$, compared with 2-2.6 $cmol_c/kg$ for the 10-30 cm layers. This CEC is fairly representative of many of the coastal Australian avocado soils and suggests that a single application of Ca at the start of flowering may have little effect on available Ca to the roots during early fruit growth (Moody, personal communication). More frequent, smaller applications are more likely to improve Ca availability.

Table 3. Concentrations of exchangeable Ca, Mg and K concentrations (cmol(+)/kg) in the soil 70 days after application, as affected by Ca (as microfine gypsum; Microgyp) and K (as potassium sulphate) soil applications just before flowering to 'Hass' avocado trees in 2003.

Treatment	Soil application (g/m^2)		Exchangeable (cmol(+)/kg soil)		
	MicroGyp	K_2SO_4	**Ca**	**Mg**	**K**
1	0	0	2.26 ^{abc}	0.55 ^{c}	0.076 ^{a}
2	29	0	1.95 ^{ab}	0.47 ^{abc}	0.048 ^{a}
3	86	0	2.24 ^{ab}	0.54 ^{bc}	0.051 ^{a}
4	171	0	2.26 ^{abc}	0.43 ^{ab}	0.051 ^{a}
5	342	0	2.64 ^{c}	0.40 ^{a}	0.061 ^{a}
6	0	114	1.92 ^{a}	0.47 ^{abc}	0.145 ^{b}
7	29	58	2.33 ^{bc}	0.53 ^{bc}	0.225 ^{c}
8	29	114	2.35 ^{bc}	0.55 ^{c}	0.191 ^{bc}
LSD			0.40	0.11	0.05
Depth					
0-10 cm			3.26 ^{c}	0.82 ^{c}	0.15 ^{b}
10-20 cm			1.98 ^{b}	0.40 ^{b}	0.10 ^{a}
20-30 cm			1.49 ^{a}	0.26 ^{a}	0.07 ^{a}
LSD			0.25	0.07	0.03

Means of 18 samples per soil treatment, and 48 samples per depth.

Means for either treatment or depth within columns with different letters are significantly different ($P<0.05$).

Fruit minerals

The Ca concentration in the fruit flesh was significantly higher in the highest Ca treatment (5) compared with no Ca application (1), and most of the K treatments (6 and 8) (Table 4). The highest K treatment applied with Ca (8) resulted in significantly less flesh Ca than the same Ca treatment with no added K (2). This suggests an antagonistic effect of K on Ca fruit nutrition. However, the treatment effects on fruit Ca were small when compared to the range of flesh Ca concentrations (180-450 mg/kg) observed across 6-8 farms in SE Queensland, or between adjacent trees on the same site (210-500 mg/kg) (Vuthapanich, 2001; Hofman et al., 2002b).

The highest Ca treatment (5) reduced flesh Mg compared with the lowest Ca rate (2), and the K treatments (6-8) also reduced flesh Mg compared with Ca alone (2). All K treatments (6-8) resulted in higher fruit flesh K concentrations compared with no additional K (1-5). There were no treatment effects on fruit N (data not shown).

Table 4. Concentrations of 'Hass' avocado fruit flesh Ca, Mg and K concentrations (mg/K or g/kg), as affected by Ca (as microfine gypsum) and K (as potassium sulphate) soil applications just before flowering in 2003.

Treatment	Soil application (g/m^2)		Fruit flesh concentration		
	MicroGyp	K_2SO_4	**Ca** (mg/kg)	**Mg** (mg/kg)	**K** (g/kg)
1	0	0	335 ^{ab}	1039 ^{bc}	20.1 ^{ab}
2	29	0	354 ^{bc}	1059 ^{c}	21.4 ^{b}
3	86	0	361 ^{bc}	1039 ^{bc}	19.7 ^{a}
4	171	0	355 ^{bc}	1022 ^{abc}	20.5 ^{ab}
5	342	0	372 ^{c}	1003 ^{ab}	20.1 ^{ab}
6	0	114	336 ^{ab}	1017 ^{ab}	23.4 ^{c}
7	29	58	343 ^{bc}	1013 ^{ab}	23.5 ^{c}
8	29	114	309 ^{a}	995 ^{a}	22.9 ^{c}
LSD			32.7	40.0	1.45

Means of 18 samples (from 13 fruit each) per treatment.
Means within columns with different letters are significantly different ($P<0.05$).

Fruit quality and tree yield

The highest Ca treatment (5) slightly delayed ripening compared with control and most of the other treatments, and the highest K treatments (6 and 8) resulted in faster ripening than all other treatments (Table 5). Treatment 5 had less diffuse discolouration than several of the K treatments, suggesting a positive effect of Ca compared with K. However, there was no significant difference in diffuse discolouration between the Ca treatments and control. In contrast, fruit from the K treatments had less stem end rots and vascular browning than most of the other treatments.

There were no treatment effects on body rots, skin colour, tree yield (mean of 49.6 kg per tree across all treatments), fruit number, average fruit mass (mean of 208 g), or fruit % DM (data not shown).

The effects of Ca and K on ripening time and of K on diffuse discoloration are small, but similar in direction as observed by Hofman et al. (2002a). However, the higher rots

severity with higher Ca treatment (with no added K) is unusual, since fruit with higher Ca often have less rots (Hofman et al., 2002a). It is possible that this unexpected treatment effect is partly due to Ca effect on ripening time. Fruit that ripen more slowly generally have more rots (Vuthapanich, 2001), and fruit from two of the K treatments ripened more quickly and had less rots than all other treatments. The treatment effects of Ca or K on fruit Ca were most likely sufficient to have a small effect on ripening time, but not adequate to override the negative effect of longer ripening time on diseases.

Table 5. Ripening time (days) and severity (as % of the flesh volume affected) of stem end rots, diffuse discolouration and vascular browning in ripe 'Hass' avocado fruit, as affected by Ca (as microfine Gypsum) and K (as potassium sulphate) soil applications to the trees in 2003.

Treatment	Soil application (g/m^2)		Ripening time*	Flesh volume affected (%)		
	Gypsum	K_2SO_4	(days)	Stem end Rots	Diffuse Discolour.	Vascular Browning
1	0	0	14.1 ^{bc}	12.2 ^{c}	0.9 ^{abc}	1.8 ^{b}
2	29	0	14.0 ^{bc}	11.7 ^{bc}	0.8 ^{abc}	2.0 ^{b}
3	86	0	14.2 ^{cd}	15.3 ^{e}	0.5 ^{a}	3.1 ^{c}
4	171	0	14.0 ^{bc}	12.9 ^{cd}	0.6 ^{ab}	2.0 ^{b}
5	342	0	14.4 ^{d}	15.0 ^{de}	0.4 ^{a}	1.6 ^{ab}
6	0	114	13.6 ^{a}	9.1 ^{a}	0.5 ^{ab}	1.2 ^{a}
7	29	58	13.9 ^{b}	9.9 ^{ab}	1.1 ^{bc}	1.1 ^{a}
8	29	114	13.6 ^{a}	8.3 ^{a}	1.4 ^{c}	1.2 ^{a}
LSD			0.2	2.2	0.6	0.7

* = following removal from ethylene.
Means of 234 fruit (from 18 trees) per treatment.
Means within columns with different letters are significantly different ($P<0.05$).

These results indicate that the Ca treatments increased fruit Ca concentration, but not enough to have a large impact on fruit quality.

The results suggest that a single application of Ca before flowering had little effect in this trial, and similar responses could be expected in soils with similar CEC and organic matter content because of potentially rapid movement of Ca through the soil. Small, frequent Ca applications are likely to be more effective in providing a continual supply of Ca to the roots. To test this, microfine gypsum (MicroGyp) was applied fortnightly from just before flowering for 12 weeks in 2004. The results indicated a significant increase in the Ca concentration in the soil solution and xylem sap 12 weeks after flowering (data not presented). The results of this trial are still being analysed, but they suggest that small, frequent MicroGyp applications during early fruit growth can be more effective than one large application before flowering Increasing the organic matter and maintaining the pH above 6 will help to retain Ca in the soil.

Rootstock and soil effects

This trial was part of a project looking at minerals uptake in a range of avocado cultivars, with a view to understanding how rootstocks could affect fruit minerals. A previous trial examined the capacity of several rootstock cultivars (including Velvick) to accumulate minerals in the roots and leaves under high and low Ca nutrition regimes.

The results showed that Velvick had higher leaf Ca concentrations, but significantly lower leaf K and higher root K concentrations, compared with Duke 7, Fuerte and Hass (Hofman and Mullen, 2005). Therefore, one of the mechanisms by which Velvick produces high quality Hass fruit could be by increased Ca and reduced K uptake to the leaves and fruit. The following study expanded on this by using soil from the Bundaberg field site, imposing several Ca/K ratios to the soil, and examining the minerals concentrations in the sap and leaves of the plants.

Soil

Added Ca more than doubled the exchangeable Ca in the soil compared with control and added K, and increased Ca in the soil solution by 2.5-4.5 times (Table 6). Added Ca also increased solution Mg, but not K. Added K increased solution K by 12 times, and slightly increased solution Mg and Ca compared with control. Ca and K also increased exchangeable Ca and K, while added K slightly reduced exchangeable Ca. Added Ca also marginally reduced exchangeable Mg.

Table 6. The concentrations of exchangeable Ca, K and Mg in the soil (cmol(+)/kg) and of Ca, K and Mg in the soil solution (mg/L) when approximately 2 times the Ca (as $CaSO_4$) or 4 times the K (as K_2SO_4) concentrations were added compared to no added fertilizer (Control).

Soil treatment	Exchangeable cation in the soil (cmol(+)/kg)			Cation in the soil solution (mg/L)		
	Ca	**K**	**Mg**	**Ca**	**K**	**Mg**
Control	1.90 [a]	0.10 [a]	1.06 [b]	39 [a]	11 [a]	20 [a]
2 x Ca	4.20 [c]	0.12 [a]	0.94 [a]	183 [c]	25 [a]	61 [c]
4 x K	1.80 [b]	0.64 [b]	1.06 [b]	70 [b]	141 [b]	42 [b]
LSD	0.19	0.02	0.09	17.8	19.9	9.7

Means within columns with different letters are significantly different ($P<0.05$).

Sap and leaf

Velvick had the lowest K concentrations in the sap and leaf compared with the other rootstocks (Table 7). Velvick had higher leaf Ca than Toro Canyon, but there were no rootstock differences in sap Ca. This again confirms the significant role that K may play in rootstock effects on fruit Ca and quality.

Adding extra Ca to the soil did not increase sap and leaf Ca or K, and only increased leaf Mg compared with the control (Table 7). In contrast, added soil K reduced sap and leaf Ca by almost half compared with the control and Ca treatments. This is consistent with the lower Ca in the flesh with K soil treatments in the Ca field trial.

Added K also reduced sap and leaf Mg, but increased sap and leaf K concentrations by over 2 times.

These results confirm those of a previous glasshouse trial which also showed that Velvick seedlings accumulated less K in the leaves compared with other rootstocks (data not presented). This, and the fact that added K interfered with Ca uptake and accumulation, suggests that K may be a significant factor in Ca nutrition and quality.

Other reports have indicated that fruit with high K concentrations can develop more severe rots (Vuthapanich, 2001) and internal disorders (Koen et al., 1990). It is generally thought that this is caused primarily by K interfering with Ca uptake by the roots and translocation to the fruit. The K treatment in this trial was relatively high (equivalent of 300 kg/hectare), but the results confirm those obtained in the field trial where added K decreased fruit Ca concentration and was associated with more severe diffuse discoloration compared to the Ca treatments. On this basis, we suggest that more attention be given to K nutrition, with a view to reducing the recommended application rates, or reducing K application during the critical stages for Ca uptake (flowering and early growth fruit growth).

Table 7 calcium, K and Mg concentrations in the xylem sap (mg/L) and leaves (g/kg) of four avocado cultivars grown in soil where approximately 2 times the Ca (as $CaSO_4$) or 4 times the K (as K_2SO_4) concentrations were added compared to no added fertilizer (Control).

Treatment	Sap concentration (mg/L)			Leaf concentration (g/kg)		
	Ca	K	Mg	Ca	K	Mg
Rootstock						
Reed	22	185 ^{b}	25 ^{ab}	10.8 ^{ab}	13.4 ^{c}	5.9 ^{a}
Smerdon	25	177 ^{b}	31 ^{c}	12.6 ^{c}	12.0 ^{bc}	7.5 ^{b}
Toro Canyon	22	193 ^{b}	29 ^{bc}	9.5 ^{a}	11.9 ^{b}	5.9 ^{a}
Velvick	19	144 ^{a}	21 ^{a}	12.1 ^{bc}	10.2 ^{a}	6.1 ^{a}
LSD	ns	33	4.6	1.4	1.4	0.5
Soil						
Control	26 ^{b}	135 ^{a}	27 ^{b}	12.8 ^{b}	8.2 ^{a}	6.6 ^{b}
2 x Ca	26 ^{b}	158 ^{a}	30 ^{b}	13.7 ^{b}	8.0 ^{a}	7.5 ^{c}
4 x K	14 ^{a}	231 ^{b}	22 ^{a}	7.2 ^{a}	19.4 ^{b}	5.0 ^{a}
LSD	4.8	29	4.0	1.3	1.2	0.4

Means for either rootstock or soil within columns with different letters are significantly different ($P<0.05$).

Time of nitrogen application

Fruit quality

In general, there were no large treatment effects of the time of N application on fruit quality, either with or without Sunny treatment (Table 8). In most cases, applying the same amount of N gave similar results as applying slightly more N at one of the application times. The most notable exceptions were significantly lower body rots in the Sunny block with January treatment (End-Jan), and significantly higher body and stem end rots in the no Sunny block with more N applied in December (Mid-Dec). There were slight but inconsistent treatment effects on the other aspects of fruit quality (diffuse discoloration, vascular browning, time to ripen and skin colour). There was little treatment effect on fruit quality in 2004/05 (data not presented).

Table 8. Severity (as % of the flesh volume affected) of body and stem end rots in ripe 'Hass' avocado fruit, as affected by N (as urea) soil applications to the trees in 2003-4.

Treatment	Sunny block		No-Sunny block	
	Flesh volume affected by rots (%)			
	Body	Stem end	Body	Stem end
Control	6.6 [b]	1.7 [a]	4.7 [a]	2.1 [a]
Mid-Sep	6.7 [b]	4.1 [bc]	6.4 [a]	4.0 [bc]
End-Oct	7.0 [b]	4.4 [c]	5.6 [a]	1.8 [a]
Mid-Dec	5.3 [ab]	3.0 [abc]	8.9 [b]	4.7 [c]
End-Jan	4.8 [a]	2.9 [ab]	5.9 [a]	2.7 [ab]
Mid-Apr	6.8 [b]	3.6 [bc]	5.3 [a]	2.9 [ab]
LSD	2.27	1.42	2.22	1.52

Means within columns with different letters are significantly different (P<0.05).
Means of 160 fruit (from 8 trees) per treatment per block.

Fruit minerals

There were no treatment effects on flesh Ca, Mg, K and N concentrations in either block in 2003/04 (data not shown).

Crop load and fruit maturity

The N treatments did not significantly affect tree yield, fruit number or average fruit mass in any of the years from 2001 to 2005 in any of the two blocks (data not shown). The Sunny treatments cannot be statistically compared because they were two distinct areas with no replicates. However, considering that both blocks were next to each other and visually very uniform, the means of each block from 2001-2005 suggest that Sunny application increases yield, and particularly fruit size (Table 9), which is an effect commonly observed for Sunny application on avocado trees.

Table 9. Average yield, fruit number and fruit mass of 'Hass' avocado trees from two selected blocks (either with or without Sunny application) from 2001 to 2005. Means of 48 trees per block per year.

Tree performance	Average (2001-2005)	
	No-Sunny block	Sunny block
Yield (kg)	102	108
Fruit number	516	468
Average fruit mass (g)	200	232

Trees with higher yield often produced fruit with lower body rots severity (Figure 1). Also, the quality was more consistent among these higher yielding trees. Similar results were often observed with other disorders, and in the Ca field trial.

In 2003-4 the N treatments also did not affect canopy volume (average across all treatments of 93 and 108 m^3 for No-Sunny and Sunny blocks respectively) or fruit dry matter (average of 25.3% and 24.6% for No-Sunny and Sunny blocks respectively; data not presented).

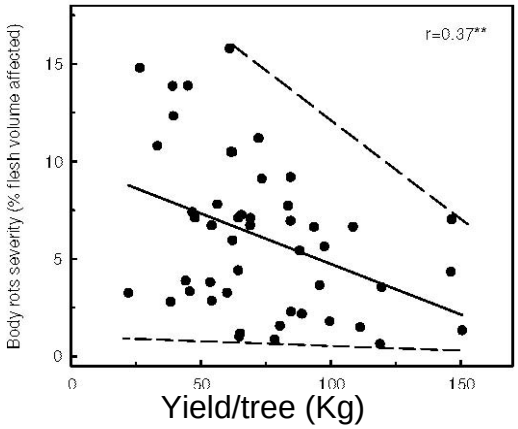

Figure 1. Relationship between Hass avocado yield per tree and body rots severity (average per tree) for the time of nitrogen trial in 2003/4. Each point is the average for individual trees.

Based on the average yield per tree from 2001 to 2004 and the prices per fruit count in 2002, the Mid-Apr treatment would be expected to give better returns per hectare with Sunny application, with mid September and mid December treatments to be avoided (Table 10). Without Sunny, mid September and mid December treatments should be avoided because of lower yields.

In all treatments, Sunny resulted in higher returns than no Sunny, mainly because of the larger fruit size.

Table 10. Estimated return per hectare (A$000/ha) of 'Hass' avocado fruit from two blocks (either with or without application of Sunny), as affected by N (as urea) soil applications. Values are based on the average yield from 2001 to 2004, with 2002 prices for each fruit count, and assuming all fruit were first grade. Means of 8 trees per treatment per block per year. Orchard density: 200 trees/ha.

Treatment	Estimated return ($000/ha)	
	No-Sunny block	Sunny block
Control	59	69
m-Sep	53	60
e-Oct	61	70
m-Dec	49	64
e-Jan	61	66
m-Apr	62	74
Mean	58	67

Based on quality and yield responses, with Sunny, applying more N in mid April gave the best returns, but with a slight loss in quality. Even applications at all times (Control) may be a suitable alternative in high disease pressure seasons. With no Sunny, the end January treatment or even applications gave the best yield and quality. The mid December treatment should be avoided because of lower quality and returns.

Application of these recommendations to other production areas needs to be based on

similar phenological stages, rather than the times used in this trial.

CONCLUSIONS

- The results confirm the difficulty of increasing fruit Ca concentration and quality through soil applications of Ca.
- Because of the low CEC of many of our subtropical avocado soils, smaller more frequent Ca applications are recommended to maintain adequate concentrations in the soil solution from which Ca can be taken up in the roots.
- Given the potentially significant positive effects on fruit quality by optimising fruit Ca, further work is justified to develop a better understanding of Ca uptake and distribution to the fruit.
- Rootstocks may be a suitable long-term alternative to improving fruit quality given the ability of different avocado varieties to take up Ca and K to varying degrees.
- Given the potential negative effects of K on Ca uptake and quality, a reevaluation of K recommendations is justified to either reduce annual applications, or reduce application during the critical stages of Ca uptake into the fruit (early fruit development).
- Timing of N during fruit growth had only a small effect on quality. South African experience indicates that higher fruit N is associated with lower fruit quality. However, reducing N application rates to improve quality are likely to reduce yield under typical Australian conditions. This needs to be investigated further.
- Management practices (other than N) to improve yield are likely to also improve quality.

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