AVOCADO PLANT NUTRITION REVIEW

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Department of Agriculture and Fisheries, Nambour, Queensland

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1. SURVEY OF AVOCADO PLANT NUTRITION PRACTICES IN AUSTRALIA

The earliest fertiliser guidelines used for avocados were based on the programme developed for citrus in California. The current nutrition guidelines in Australia were first prepared for the 2001 Agrilink Avocado Information Guide and many of these guidelines were based on the needs of the variety 'Fuerte'. This variety was the most popular variety before 'Hass' dominated the industry and it is a very vegetative tree which responds unproductively to moderate levels of nitrogen whereas we have discovered that 'Hass' needs to be treated quite differently to maximise production.

Research and grower experience has produced new insights into fertilising 'Hass' trees and our Australian avocado nutrition guidelines need to be updated.

To gain a snapshot of current grower nutrition practices a questionnaire was developed and growers were individually contacted to invite their participation in the survey. A total of 42 growers were contacted across the eight production regions and 34 survey forms were completed. There was no attempt to invite the whole industry to respond to the survey, rather a sample of growers were chosen from each production region who were most likely to be able to provide the information required. Growers were asked to choose an above average block on their orchard and answer the questions for this block. Growers were also asked if possible to submit a recent soil and leaf analysis for the chosen block.

The results were entered into a large spreadsheet and the results are discussed below. This information was supplied to participants in the meeting of nutrition experts.

Regional distribution of participants was as follows:

- North Queensland 5
- Central Queensland 5
- SEQ 2
- South Queensland 4
- NNSW/Tamborine 4
- Central NSW 2
- Tristate 7
- Western Australia 5

Not all growers were able to complete the questionnaires comprehensively or provide leaf and soil analysis results.

Use of agronomists

Interestingly 26 out of 34 respondents (76%) use an agronomist to assist with developing their nutrition programme; this is a higher result than expected and acknowledges the complexity of the topic and therefore the willingness of growers to seek expert advice. However, in some cases the advice given by agronomists was not always appropriate for avocados.

Leaf and soil tests

The number of growers conducting an annual leaf tissue nutrient analysis of the autumn flush (the traditional time for sampling) was 76% whilst 59% have also adopted an annual leaf test of the spring flush which is a relatively recent development. This is an encouraging result. 47% of growers also conduct an annual soil test, 41% do one every 2-3 years and 6% 'occasionally'. One grower conducts a leaf and soil analysis every two months but it is not known against what standard the out-of-season samples are compared against. 12% of respondents conduct sap tests.

For the leaf analysis results provided the vast majority of leaf nutrient levels were within the currently recommended optimum ranges. The exceptions included excessive chloride where irrigation water quality was poor, two instances where boron was excessive and one where zinc was deficient.

Soil cation exchange capacities ranged from 2 to 22 meq/100g highlighting the fact that because of this and many other reasons including climate differences that nutrition programmes need to be tailored to every farm. Soil pH ranged from 4.6 to 8.4.

Irrigation and nutrition

There was wide acknowledgement of the need for good irrigation to achieve an effective nutrition programme.

Mini-sprinklers are the most common type of irrigation with only three using drippers (all of whom farm in hot, dry environments with sandy soils). All growers had some system for monitoring soil moisture. Nearly all either have capacitance probes, tensiometers, G-bugs or G-dots. Six growers dig holes (most as a backup to one of the above instruments) and one relies solely on evaporation rate data.

Table 1. How often growers check their soil moisture during peak demand

	Continuously	Twice daily	Daily	Every 2 days	Twice a week	Weekly	Fortnightly
No. of growers	2	2	8	5	3	4	1

Mulch and compost

59% of respondents apply mulch materials under the tree and 21% apply compost.

PGRs

59% of respondents use Plant Growth Regulants annually or in some years.

Fertiliser application method

88% use fertigation, half of these also broadcast fertiliser whilst the remaining 12% use broadcasting only.

59% apply foliar boron sprays at flowering time.

Aside from foliar boron applications, 15% of the growers surveyed apply seaweed products and trace elements as foliar sprays. One of these growers also applies potassium nitrate and urea as foliar sprays during times of leaf flush.

Fertiliser products used

A very wide range of nutrition products are used by growers. Some growers use basic fertilisers such as lime, gypsum, urea, sulphate of potash, potassium sulphate, superphosphate, iron sulphate, zinc sulphate and Solubor. Others use more complex fertiliser products. Quite often those using very basic fertilisers are achieving higher yields. If the programmes used by each grower were costed out, there would be a vast range in the fertiliser cost per hectare.

A number of growers are trying to improve soil health through application of products aimed at improving soil biology.

Fertiliser application intervals

Overall, growers are using much shorter intervals between fertiliser applications than they used to and there is general adoption of a “little and often” approach. Not only is this better for plant growth but it is better for the environment too since it will result in less chance of applied nutrient reaching streams and subsurface water.

Nitrogen

One of the particular aims of the survey was to gather information on nitrogen fertiliser rates, timing and application intervals. Recent trends are to use higher rates than in the past and to increase the rates further if the fruitset and crop load is heavy. Whilst the average N rate was 212 kg N/ha/year, some growers apply as little as 69 and others as high as 528.

The higher rates sometimes correlate with above average yields but the lower rates are also associated with reasonably good yields. 35% of respondents increase their nitrogen rates in the presence of a heavy crop load in the belief that this extra nitrogen not only feeds the current crop but also sets the tree up for the next season – generating a healthy canopy and enough wood for the next flowering. However, given that the balance between nitrogen and calcium affects fruit quality and that too much nitrogen depresses calcium so are we risking poor fruit quality by increasing rates of nitrogen?

Table 2. Kg nitrogen applied /ha/year

Range of N	<101	101-150	151-200	201-250	251-300	301-350	351-400	401-450	451-500	501-550
No. of growers	5	7	10	3	1	4	2		1	1
Ave yield t/ha	17	12	16	15	16.5	12	23		16	29

Table 3. Frequency of nitrogen fertiliser application

Frequency	Every irrigation	Weekly	Fortnightly	Monthly	Less often than monthly
No. of growers	2	3	4	9	4

Most growers apply nitrogen all year but reduce rates or avoid applications for 2 or 3 months between late winter and a month or so after fruitset.

Table 4. Leaf nitrogen levels

Leaf N % range	<2%	2 to 2.25%	2.26 to 2.5%	2.51 to 2.75%	2.76 to 3%	>3%
No. of results in each category	1	2	6	5	1	1

Phosphorus

Phosphorus use ranged from 0 to 100 kg P/ha/year and averaged 31 kg P.

Potassium

Potassium use ranged from 0 to 320 kg/ha/year and averaged 146 kg K.

Calcium

Most growers are aware of the link between high fruit calcium and fruit quality and that there is a limited window of opportunity when calcium is deposited in the fruit (the first 6 to 8 weeks after fruitset). However, is a soil calcium content of 65 to 70% of the base saturation sufficient to supply this or is it necessary to apply extra calcium at this time? Many growers now apply the very soluble (and expensive) calcium thiosulphate during this window but is it necessary or making a difference to fruit quality? Many others apply an ultra-fine form of gypsum or lime. Are growers risking an imbalance of cations due to excessive applications of calcium and thus for example a shortage of magnesium or potassium in the plant? Perhaps the extra calcium applications are complementing the increased rates of nitrogen and keeping the balance of N:Ca where it should be for fruit quality?

Adjusting the nutrition programme during the year

Almost all growers modify their nutrition programmes through the year based on appearance of trees, crop load and rainfall.

Particular issues or difficulties

24% of respondents reported difficulty getting boron levels right. Difficulty keeping zinc levels adequate was also mentioned a few times. The other issues that came up included knowing how much nitrogen to apply, getting a balance between nitrogen and calcium, and adjusting fertiliser rates after heavy rain. One grower also reported difficulty getting adequate iron and phosphorous levels.

Yields and yield variation

Bearing in mind that growers were asked to select an above average block for the survey, average yields on mature trees varied from 5 (two young orchards reported this yield) to 29 t/ha and the average across all respondents was 16.2 t/ha. 26% of respondents reported that their yields varied by less than 30% each year, 32% that they varied between 30 and 50%, and 15% that they varied by more than 50% (the remaining 27% of growers did not answer the question).

What growers consider are key factors for a successful nutrition programme

- Keeping water up.
- Monitor and adjust (mainly N) according to crop load, flowering & flush. Add 10% more N if PGRs used.
- A little bit often
- Do what a good agronomist tells you to do
- Visit and rate tree health every block every fortnight. Adjust fertiliser according to observations of health & crop load. Get irrigation right. Apply fertiliser at frequent intervals. Use granular where possible because cheaper.
- Irrigation. There is a point in Mar/Apr when the tree appears to switch from extracting moisture from shallow to deeper soil & you must be ready for it in terms of optimum soil moisture, or tree

will go into stress, which will affect fruitset later. Growcal & Ca thiosulphate appeared to have increased fruit size.

- Have a good feel for your trees. Experience. Closely follow soil moisture. Check how efficiently you are applying your fertiliser.
- Getting soil biology up & active with fungi & healthy microbes while trickling on the nutrition w/o damage.
- Timing, little & often, compost for soil health.
- Follow recommendations. If heavy fruitset increase nitrogen.
- Frequency, visual observation, leaf tests.
- Work with consultant/agronomist. Timing of applications. Monitoring trees. Combination of water & feed. Feeding of the tree/crop ratio. Timing of elements with respect to growth cycle - buds, flowers, flush & fruitset.
- Having timely relevant data from leaf analysis, observation of tree health/condition & accurate assessment of crop load to be both proactive & reactive to adjust application & quantity of elements required for growth & removed from orchard by crop.
- Emphasize using less N at flowering & immediately after to limit fruit drop since I want to limit tall growth of trees on sloping land. I note that NZ uses much more N.
- Twice yearly leaf analysis & interpretation from agronomist.
- Leaf & soil analysis by consultant.
- Frequent applications of small amounts (fertigation). Good organic matter levels maintained under tree. Historical yields improved significantly when fertigation introduced 6 years ago. Average yield 20 t/ha for 6 years.
- Successful irrigation - a good irrigator makes a good fertiliser applicator.
- Treat each patch on its merits. Nitrogen management clearly the biggest challenge nutritionally. Setting a good crop makes it easier to manage and push trees as opposed to managing growth.
- Spread fertiliser over whole year. Get out & look at trees every day if possible. Cost of fertiliser = $1600/ha
- Adjust (through the year).
- No roots = no tree Managing water & nitrogen
- Good irrigation infrastructure and management.
- Get better advice, I am still learning, listen to what others may be doing then make an informed decision.
- Have regular nutrient input, e.g. fertigation done every fortnight.
- Monitor tree health, flowering & fruit load and apply what I think will be extracted by the fruit, difficult as some of this data is to find.
- a) Knowledge of avocado growth physiology is most critical. b) Implement nutrition program based on regular soil & leaf test. c) Implement primary & secondary nutrients based on crop growth stage. E.g. Spring flush - avoid too much N, fruit set - lots of Ca and trace elements, fruit fill - K to fill the expanded fruit cells and so on.
- Weekly applications. Have professional advice.

Conclusions

Nutrition is a complex subject and every orchard has different needs. Although this was a limited survey it has provided a snap shot of Australian avocado growers' practices, included those of very successful producers, and in doing so has provided a starting point for commencing the discussion to update the nutrition guidelines. The standard of practices of growers surveyed was generally high and nutrient analyses and yield results bear this out. Those surveyed generally show a high level of adoption of recommended practices and have taken on board recent developments.

Some of the questions to arise from this survey are:

- What are the most appropriate rates of nitrogen and calcium to optimise yield and fruit quality?
- What level of nitrogen is safe to apply through the flowering and fruitset period?
- Does extra nitrogen applied when fruitset/crop load is high help combat irregular bearing?
- Is it necessary to purchase special forms of fertiliser or will basic fertilisers achieve the same result in most situations if used correctly?

These and other questions were discussed at the webinar of experts held on 31 October and minuted below.

2. MINUTES OF WEBINAR HELD WITH AGRONOMISTS ON 31 OCTOBER 2017

Participants (9): Tim Heath (GT Ag Services, Mareeba), Lisa Martin (Ripe Horticulture, Bundaberg), Geoff Dickinson, Simon Newett & Peter Rigden (DAF), Chris Searle (Stahmann Farms), Denis Roe (SFFCS), Ben Thomas (BTC), Graeme Thomas (GLT)

Apologies (2): Alan Blight (AVOWEST), Dudley Mitchell (HCMS)

General comments on survey results

Graeme Thomas prefaced the meeting by pointing out that before a nutrition programme is considered *Phytophthora cinnamomi* root rot has to be under control in order to have a healthy root system and soil moisture management needs to be good.

Ben Thomas remarked that there was good adoption of leaf testing amongst the survey respondents. Simon qualified this by pointing out that the survey had an element of bias since growers were picked for the survey that were most likely to be able to answer the questions.

Nitrogen

Graeme Thomas pointed out that nitrogen needs vary tremendously between localities.

Graeme Thomas said that if the leaf N was 1.9% for 'Hass' he would be comfortable to keep applying N through flowering but if the level was 2.6% he wouldn't. Bear in mind that, although fruit will continue to grow for its entire life by means of cell division, fruit size is mainly determined in the first 12 weeks after fruitset, so it is important to ensure that there is sufficient nutrient available to feed these growing fruitlets so that they don't end up as small fruit.

With the variety 'Shepard' it is a different story.

Comparing Hass trees growing in NQ vs WA, where there are two crops hanging on the trees in WA he would apply about double the rate of N than he would to trees in NQ. However Graeme would still back off the rates for the two months around flowering time especially if leaf N levels at the last analysis were in the 2.6 to 2.7% N range. It is a case of 'horses for courses' and to keep monitoring leaf nutrient levels.

On the question of whether we should be aiming for higher leaf nitrogen levels Chris Searle pointed out that in the late 1990s leaf nitrogen levels reached 2.6 to 3% in orchards at Palmwoods, Mt Tamborine (Gold Coast hinterland) and an orchard at Childers was really ramping up the nitrogen, this orchard grew enormous trees but it took a fair while to get the nitrogen levels back down. The trees became too vegetative with enormous water shoots and there was also enormous variability between the yields of individual trees within the same blocks from equivalent to 6 up to 30 t/ha. Back then all the nitrogen was applied in a small number of big doses. These high nitrogen applications raised concern about fruit quality and triggered some research into calcium. Chris said you will get a very different result by applying the same amount of nitrogen in one or two applications vs. say a dozen small applications. If the heavy doses were applied around warm wet weather and fruitset then you would lose crop.

More frequent applications – 4 or 5 times per year.

Geoff Dickinson described how a Shepard orchard in NQ known to pump up their nitrogen rates had a problem with fruit breakdown. Work done by Kaila Ridgway in NQ recently showed post-harvest breakdown of fruit that were high in fruit flesh nitrogen and low in calcium. There was a very good inverse relationship between the amount of calcium in the flesh and the amount of breakdown. Leaf N levels were not measured but were expected to be very high in N since the sap tests were. Tim Heath mentioned that there would have been a variation in flowering time with Shepard which might have had some effect on the results.

Chris Searle pointed out that in the calcium research there was actually more variability between individual trees than between treatments suggesting that the rootstock had a very large effect on calcium levels.

Work by Peter Hofman showed that by overdosing with calcium the potassium levels fall, thus an imbalance in cations was induced.

How do you get the benefits of high nitrogen without dropping fruit calcium and putting fruit quality at risk? Perhaps have different N:Ca ratios at different stages of the growth cycle?

There is concern that by going for higher nitrogen applications (e.g. to try and overcome irregular bearing) and associated higher leaf N that we might be putting fruit quality at risk (given that higher flesh N means lower flesh Ca). However if we use calcium nitrate does that help keep the two elements in balance?

Chris Searle – Peter Hofman's work showed that as well as the N:Ca balance it was also the Ca:Mg:K balance that was important.

Graeme Thomas – should we look at the cation balance and look at changing it marginally for the first 12 weeks after flowering? Don't know – the headache may be in getting it back to a balance after this 12 week period. Difficult to do on a research level but maybe encourage growers to measure levels in flesh and leaves at this time and build up a database of this information.

Chris Searle said that some years ago it was decided to put off further nutrition research work until there were a sufficient number of blocks of clonal trees on which to conduct the research since there is too much variability in blocks of seedling trees.

Lisa Martin reported that in her work over the past 13 years (irrespective of the region in Australia) it showed that the worst 'offender' in displacing other cations was potassium. Potassium is always too high and even if you haven't recently put any out, the plant is still taking it up in high levels and this is inhibiting the uptake of calcium, even if you are putting out calcium and nitrogen in a 1:1 ratio.

Graeme mentioned that some work in the Bundaberg area a few years ago that indicated that potassium stays in the soil better than calcium does.

Chris Searle reported on some work he had been involved in which showed that high doses of one cation will displace the other cations, e.g. high doses of potassium will displace calcium on the exchange sites in the soil but it does depend on the soil type.

The practice of increasing nitrogen doses if the fruit set looks heavy

There was general agreement that the nitrogen rates need to be increased if there is a large crop set. Tim Heath felt that in NQ this doesn't work as well on trees older than about 15 years. Graeme Thomas said that it does depend on the locality.

Graeme – it depends on the stage when you increase the nitrogen but yes by using this practice in WA he has been able to get 59 t/ha one year and over 30 t/ha the next.

Tim Heath agreed with the approach but feels that once the trees get older, say from about 15 years old, you don't get a response anyway.

Graeme said that on individual trees with a heavy crop in Pemberton WA he was putting on an extra 5 kg of calcium nitrate per tree per month from January till October. Leaf analysis showed that the N level in these trees were actually lower than in those trees with the lower crop that were not getting the extra nitrogen. And the heavy cropping trees are now flowering quite reasonably again. The high yielding trees were picked the other day and the yield from them was equivalent to about 80 t/ha. Graeme feels that if he hadn't put the extra N on these trees the N leaf level would be about 1.8% and they wouldn't have much crop next year.

Calcium

Question: Is it necessary to apply large amounts of calcium in that 6 weeks following fruitset (to try and improve fruit Ca levels) through application of finely ground lime and gypsum, calcium thiosulphate etc? Or if the cation balance is good in the soil and there is good soil moisture available will there be sufficient uptake anyway without these extra applications?

Lisa just doesn't think it is that easy. You have to use all tools in your tool box to get the uptake that you require and this depends on tree size (the bigger the tree the harder it is). Lisa has found that in high pH soils calcium thiosulphate is the only thing that works. Even calcium nitrate wasn't that effective because you can't get levels too high in the soil without upsetting the balance of other nutrients. Soil biology needs to be watched too. Lisa prefers liquid gypsum because of its solubility.

Graeme pointed out that the leaf Ca level increases with leaf age. Chris Searle said that it depends on the level of root rot too, without healthy roots you are not going to get much calcium in the tree whatever you apply. Chris argues that Ca uptake is largely a function of root health which in turn is a function of your ability to manage Phytophthora root rot. No root tips = no calcium uptake.

Ben Thomas – in the Tristate he is largely dealing with high pH soils and what he has been seeing (in avocados and in other crops) is that we can't get enough Ca up at particular times so there is a transient deficiency issue. So leaf testing may not give you the information that is relevant to what is available say in that first 6 weeks after fruitset.

Chris added that this is why we need to look at fruit sampling at a range of times instead of relying solely on leaf levels.

What has sap testing shown? Lisa – has been testing a range of tissues and at different ages. For example she has found the highest Ca levels are in the roots. The whole apple industry collaborated in a study doing weekly sap tests on the flesh of little fruit in the first 8 weeks then they were able to fine tune the calcium levels and found out that with a calcium level below 50ppm the fruit would develop bitter rot but above 50ppm they wouldn't. A lot of samples are required for this sort of study.

Lisa has tried a range of different calcium products and application methods but the sap test sampling results have been too varied to make any sense out of what has worked better.

A fruit skin test to measure the Ca:N ratio it might be a good option because Liz Dann's work has shown that this can be correlated well with disease susceptibility.

Simon – is most of the calcium held as cations in the soil at a deeper level than the feeder roots? Is this why growers are advised to fertigate it through the critical period? Lisa – soil tests in the Tristate show that there is heaps of calcium in the soil but none of it is available.

Magnesium

Important in relation to the cation balance. More danger of upsetting the cation balance in sandier soils.

Potassium

Do we really need to apply as much K as we do?

Lisa thinks that perhaps there is too much potassium going on. Lisa recommends its application at several growth stages.

Geoff – one thing we tend to overlook is that mulch has a very high proportion of potassium in it, about 4% and with typical levels of mulch we might be applying about 500 kg k/ha/yr with annual mulch applications of setaria and even with the poorer mulches around 100 kg K/ha/yr. Potassium is generally the most abundant nutrients in hay.

Graeme – in terms of best practice – rely on leaf analysis results. There are times when he wouldn't recommend any K.

Simon – K is viewed as one of those elements that leaches easily and therefore growers feel it is one of those elements that needs to be applied regularly as a maintenance dressing.

Graeme – many growers use compound fertiliser blends where NPK is in the product whether you need it or not and thus it can be overdone especially if mulch is used as well.

Ben – there is usually plenty of K in the soil but in some soils the movement of K into the soil solution may be too slow at particular times, and it may occur below where the feeder roots are (especially in sandy soils).

Chris – feels that it is imbedded in the psyche that you can't grow a crop of anything without putting heaps of potassium on. In macadamia in a 4 t/ha crop you are removing only 8 kg K/ha, but some growers are applying up to 300 kg K/ha in fertiliser – so what is happening to the remaining 292 kg of K?

Denis finds it very difficult to make a potassium recommendation based on leaf levels so relies on the soil K level. Denis believes that if there is enough K in the soil it will get into the tree. Graeme has records of about 4,000 leaf nutrient tests and reckons that there wouldn't be many with a deficient level (i.e. below about 0.8% K).

Phosphorus

Avner Silber in his recent lecture tour suggested that perhaps we need to apply higher levels of P (based on the fat that avocados are a high energy product and P is involved in energy transfer within the plant).

Graeme – many growers apply P as part of a compound fertiliser blend but he has one grower in WA with a soil Colwell test of 854 ppm P and this is causing a major tie up of Zn in the soil and deficient leaf levels but a leaf P test of not much over 0.2%. So even though soil P levels are massive it doesn't push the leaf P level very high. A really low soil Colwell P level of 11ppm at Hampton (near Toowoomba) still gave a leaf P level of 0.18% P (within the optimum range) in the leaf. So Graeme feels that phosphorus is significantly overdone in Australia.

Ben – in the Tristate soils we don't have much P, so it depends where you are. The Mallee soils are notoriously low in P largely a result of the calcareous soils and applications of P don't seem to make much difference in making P available. One of the challenges is to try and find the P that has been applied. For this reason Ben works out rates based on nutrient budgets for what the crop has removed. The leaf P levels don't move much in the leaf in the Tristate, they are not deficient. Growers tend to apply P regularly in the Tristate but doesn't believe it is overdone in that region.

Chris – like Graeme, tends to see more cases where P is overdone and the resulting induced deficiency of Zn.

Chris – does anyone use P buffer index to adjust levels? Ben said he did.

Silicon

Simon - quite a lot of interest in Si at present.

Lisa – it's hard to measure. Now including it in sap tests. Feels its uptake is similar to calcium. Has seen it work well in annual crops for holding of fruit and post-harvest quality but couldn't currently say whether it is necessary for avocado.

Ben has never worried about Si for avocado.

Denis – considered as a micro-nutrient so is only needed in very small quantities.

Graeme – current attitude is that if Liz Dann's work shows that we can improve fruit quality then we will apply it but in the meantime won't be recommending it.

Molybdenum

Graeme – its role in melons is absolutely critical. Tony Whiley commented that Mo plays no role in the physiology of the avocado but Nigel Wolstenholme (University of Natal in South Africa) thinks that it does.

Ben – Mo has been a problem in grapevines where deficiency affected fruitset, this mainly occurs in the acid soils rather than the calcareous soils.

Lisa – has noticed that the Mo level in sap analyses is quite seasonal and weather dependent. E.g. a dry summer correlates with low Mo in the plant.

Simon – so we should treat Si and Mo as both 'watching briefs'?

Lisa – if there is a problem with levels of nitrate or ammonia then look at Mo levels.

Application methods

Foliar applications

Simon - foliar applications of nutrients not generally considered effective in avocados

Lisa – agrees with Simon that foliar nutrient applications are a "band-aid" measure but reports some success with foliar zinc applications in correcting deficiency symptoms, particularly with Zn EDTA. It works to a lesser degree for iron using iron chelate.

Ben says that Zn nutrition is an issue in the Tristate with tie ups. It needs to be applied when the leaf is the most receptive – before it has hardened off (no point in applying it after this). Ben has tried foliar iron sprays over the years but wouldn't bother.

Chris – zinc banding works to a certain extent – making "feeding stations". Apply it in a concentrated band close to where there is a high density of roots and where organic matter is highest.

Iron and zinc deficiency can occur in spring time because soils are too cold for uptake.

Fertigation

Can be issues of acidification in the wetted zone. Especially with drippers which create more of a point source where the fertilisers are placed. They never thought they'd see a problem of acidification in the Tristate but is happening in the wetted zone.

Lisa – a build-up of salts in your soil as a result of fertigation is becoming a bit of an issue, this can also be related to the quality of fertilisers being used.

Ben – recommends regular lime banded along the wetted zone – easier on sandy soils. Work out the rate required to maintain the soil pH where you want it and put it on every year as a matter of course.

Chris Searle – on krasnozem soils because of the high tie-up of phosphorus – banding is more effective than broadcasting.

Timing

We have some idea of the timing of calcium, nitrogen and boron but what do we know about the timing needs of the other nutrients?

Lisa – timing of potassium, puts a little on throughout the season with a higher application in about May to coincide with the root flush depending on the soil levels and if it is needed. Phosphorus applied then too. To capitalize on uptake whilst the roots are flushing.

Probably need to do some more definitive work on appropriate timing of N, P & K.

Nutrient monitoring

Frequency of soil testing. May need to be done more often in light soils if you are trying to drive a change in order to monitor progress.

Important to monitor soil boron. Many growers and resellers unaware that there are different optimum soil boron ranges for different soil textures.

Leaf testing

Spring leaf testing is commonly used now in addition to autumn leaf testing. Graeme has been conducting spring leaf tests since the mid-1990s and is comfortable that we can use the same optimum levels that were worked out for the autumn leaf test, just make sure you always take leaves from a non-bearing branch. Tony Whiley is comfortable with this. Just need to bear in mind that in the regions where you have two crops hanging on the tree at the same time that the levels can drop quite quickly.

Use the same norms.

Lisa – given that some growers are getting higher yields now do we need to re-visit the optimum ranges? Graeme says that you might have to put more fertiliser on but the optimum levels to aim for are still the same.

May need some more discussion on where in the block and the tree you take the sample from. It is a good monitoring tool but one of several.

Chris Searle – hyperspectral analysis (a remote sensing technology) will allow many more samples to be tested because it is much cheaper than traditional laboratory based leaf analysis, it will help us pick the right leaf. An analogy of the cost would be comparing digital photos vs. rolls of film that need developing.

Sap testing

Lisa – really good for all nutrients except for nitrogen when you are testing new leaves. Also using it for testing chlorophyll levels in the leaf. It's not something that everyone could use. Sap testing leaves, leaf petioles, and fruit.

K, P and micro nutrients are good – e.g. if you are putting nutrients out and want to see if they are being taken up then sap testing is useful for showing this.

Fruit testing

Have to work out what part of the fruit and when to test it.

Apple testing was conducted by AgVita lab in Tasmania over a 4 year period to work out the best time to sample, what to sample etc.

Seemed to be interest by the group for investigating the potential for following nutrient levels in fruit.

Different costs of fertiliser programmes

There are certain times you may need to specific products.

Ben strong on straights.

Denis – depends on what the client wants. Straights are better to use because you have more control over what goes on.

Geoff – Kaila found that some growers were reluctant to tell her what products they were using.

Graeme – with the current high price of avocados the cost of fertiliser is a small proportion.

Tim – soluble solids in layers in the 1 tonne bulk bags – tipped into fertigation tank. Some concerns about this practice.

Final comments

Chris Searle - *Phytophthora cinnamomi* root rot management and soil management are paramount. Need to maintain very viable root system. And very important to build the organic matter level in the soil which is a very important part of the nutrition programme.

Ben – ditto for having a good irrigation programme.

Graeme – many growers don't have good *Phytophthora cinnamomi* root rot or soil moisture management.

Most of the nutrient uptake is from the top 15cm of soil and this can dry out in a single day – therefore nutrient availability can be very restricted.

Need more emphasis on *Phytophthora cinnamomi* root rot and water management in the nutrition review notes in BPR.

Tim – get growers to work towards a fruit testing system. These levels won't lie.

3. LITERATURE REVIEW OF RECENT AVOCADO PLANT NUTRITION RESEARCH AND PRACTICES

Management of Phytophthora root rot and irrigation for effective nutrition

In avocado since the feeder roots must take up the vast majority of nutrients, an essential pre-requisite for an effective nutrition programme is a healthy root system (good control of *Phytophthora cinnamomi* root rot) and good soil moisture. These two pre-requisites are intrinsically linked since trees infected with phytophthora root rot cannot take up sufficient moisture or nutrients. Remember too that most of the tree's feeder roots are in the top 15cm of soil, this has implications for watering and fertilising and helps explain why small doses of fertiliser applied often works well for avocado.

In a trial to test different root rot control treatments Whiley *et al* (1986) reported that avocado trees protected from phytophthora root rot had greater fruit yields and less ring neck (a symptom of moisture stress). Trees with the least disease had a combined two-year yield that was 82% higher than untreated diseased trees.

Kiggundu *et al* (2012) conducted a trial to determine the effect of fertiliser rate and irrigation scheduling on water use, nutrient leaching and fruit yield of young avocado trees in Florida. Seven nutrient and irrigation management practices were evaluated that compared a combination of treatments that included irrigation scheduling based on evapotranspiration, by a set schedule or by irrigating when soil moisture potential reached – 15 kPa, and the application of 50%, 100% or 200% of standard fertiliser rates. Yield was measured for four years when the trees were between three and six years old. The treatment with the best yield, highest water use efficiency and least phosphorus leaching was from the trees that were irrigated when soil moisture potential reached – 15 kPa and 100% of the standard fertiliser rate was applied. The trigger for irrigating closely matches the recommendation of Thomas, G. (personal communication, 2017) which is to irrigate when soil moisture potential reaches -14 kPa.

Typical fertiliser rates

The following examples give an idea of the range of fertiliser rates applied to avocado at different locations around the world, naturally rates will vary according to climate and other environment and orchard factors.

Australia

The current standard nitrogen recommendation in the Best Practice Resource for mature trees with an optimum leaf nitrogen level (2.2 to 2.6% for Hass) is about 110 kg N/ha/year (14 g N/m^2 of canopy area). This is assuming a spacing of about 9x4m (278 trees/ha) and with the canopy covering about 78% the total orchard floor (continuous hedgerow and 2m wide interow space for machinery access). For the same orchard and assuming that the leaf potassium is optimum (0.75 to 2% for Hass) the typical annual recommended rate is about 80 kg K/ha/year.

Newett (2017), in a survey of Australian avocado growers' nutrition practices, found that there was a vast range in the rates of nitrogen used. This ranged from 69 to 528 kg N/ha/year with an average of 212 kg N. Phosphorus use ranged from 0 to 100 kg P/ha/year and averaged 31 kg P, and potassium use ranged from 0 to 320 kg/ha/year and averaged 146 kg K.

Hall (2015) reported that nitrogen use by the 10 most profitable growers (out of the 55 measured) ranged from 85 to 140 kg N/ha/year.

Brazil

Cantuarias-Aviles, T. (personal communication, 2018) provided the guidelines developed by the Instituto Agronômico de Campinas (IAC) many years ago for bearing avocado orchards in Brazil. http://www.iac.sp.gov.br/areasdepesquisa/frutas/frutiferas_cont.php?nome=Abacate. Note that 90% of avocado orchards in Brazil are rain fed only and the rainy season occurs in summer from October until March. For an expected yield of 10 to 25 tonnes/ha, the recommendations are to apply 60 to 120 kg/ha of N when leaf N is below 2%, and according to soil analysis, apply between 9 to 53 kg phosphorus/ha and 28 to 140 kg potassium/ha. It is recommended that the annual fertiliser rate, especially the nitrogen and potassium, be split into three applications through the rainy season. Recent research has established that April is the best month for taking leaf samples, optimum leaf levels have been defined for three varieties including 'Hass' and the mineral content of fruit has also recently been established.

California

The annual rate of nitrogen used in two separate nutrition studies has been 140 kg N/ha/year (Lovatt, 2001 and Salvo and Lovatt, 2016). Lovatt and Witney (2001) report that 101 kg N/ha/year are required to produce a yield of 12.35 t/ha.

Faber, B. (personal communication 2018) believes that while good nutrition is important it is relatively simple and irrigation is much more important.

Nutrition guidelines are available for Californian growers at:
https://apps1.cdfa.ca.gov/FertilizerResearch/docs/Avocado.html

The nitrogen and potassium rate guidelines are based on crop removal. For example for a yield of 10 t/ha, the guidelines recommend 72 kg N and 65 kg K/ha, whilst for a yield of 20 t/ha, 100 kg N and 130 kg K/ha are recommended.

Chile

Atucha *et al* (2013) listed the typical macro nutrient application to a mature field of avocados growing on hillsides in central Chile to be:

- 120 – 250 kg N/ha/yr
- 50 – 80 kg P/ha/yr
- 50 kg K/ha/yr

Newett (2015a) reported that the range of nitrogen being used on the ultra-high density 'Hass' orchards at Llay Llay in Chile (Mediterranean climate, soil types mainly clay or clay loam with pH $_{water}$ about 7.4) was between 115 and 150 kg N/ha/year and yields of 30 t/ha were being achieved with these rates. Mena, F. (personal communication, 2015) said that on these orchards potassium was only applied when the leaf levels dropped below 0.55%; the optimum potassium range used in Australia is 0.75 to 2.0% so the target level in Chile is significantly lower. Zinc rates depend on leaf levels but are very high compared to Australia, possibly because of the relatively high clay content of the soils (clay is known to tie up zinc in the soil). If leaf zinc levels are below 40 ppm, 66 kg Zn/ha/year (300 kg of zinc sulphate heptahydrate) is applied; if leaf levels are between 40 to 70 ppm, 51 kg Zn/ha/year (230 kg of zinc sulphate heptahydrate); and if leaf levels are above 70 ppm none is applied (the optimum leaf zinc level used in Australia is 40 to 80 ppm).

At this orchard great importance is placed on the correct sampling of leaves; here they sample the spring leaf flush, and care is taken to only sample mature, hardened, spring leaf flush from stems that do not have fruit. Great importance is also placed on looking at the trees and observing the colour, shine and size of the leaves.

A Chilean fertiliser company funded a trial to test different forms of nutrients including N, P, K, S, Mg, Zn, B and Mn at this site and this was compared against the standard programme used by the orchard. After four years they found no differences in crop performance but the cost of the fertiliser company's program was USD2,000/ha whilst the orchard's standard program cost just USD300/ha.

Florida

Kiggundu *et al* (2012) applied the following amounts to 3 year old 'Simmonds' avocados growing in a very gravelly soil overlying limestone in Florida.

- 156 kg N/ha/yr
- 25 kg P/ha/yr
- 146 kg K/ha/yr
- 58 kg Mg/ha/yr

Israel

Noy, M. (personal communication, 2018) explained that in Israel (Mediterranean climate) where irrigation is mainly only applied in the warmer (dry) months (from spring to autumn), nutrients are generally applied with every irrigation (as fertigation) and this includes nitrogen at 40 to 50 ppm in the water. Approximately 300 kg N, 50 kg P and 300 kg K are applied per hectare per year to high yielding orchards. Iron must also be regularly applied because of the high soil pH and calcareous soils. Since much of the irrigation water in Israel is recycled, the nutrient content of this water must be considered.

New Zealand

Partridge, C. (personal communication, 2018) provided an example of an annual nutrient application program he recommended this current season. It was for an orchard consisting of large trees in a high yielding orchard on wide spacing, growing in a well-drained soil derived from volcanic ash in the Bay of Plenty. Leaf nutrient levels were in the optimum range. The fertiliser rates he recommended were 280 N, 36 P and 165 K (kg nutrient/ha/year). The rate is split into seven applications through the year - June 5%, August 7%, late October 16%, December 12%, January 21%, March 23% and April 16%. Partridge noted that programmes would be different for orchards established in sandy or higher clay soils and adjusted during the season depending on factors such as crop loading or planned canopy management actions.

Peru

Newett (2015b) gathered information on the nutrition programmes of orchards visited in Peru in 2015. The first four orchards listed in the table below were for young orchards established on desert sands where organic matter is incorporated before planting.

Table 5. Typical ranges of fertiliser used in the orchards visited in Peru in 2015 (Newett, 2015b)

Orchard	Soil	N	P	K	Comment
		kg element/ha/yr			
'Casablanca' near Chiclayo	Sand	200	?	160	For a yield of 32 t/ha.
'Agricola Cerro Prieto' near Chiclayo	Sand	380	76	373	Nitrogen daily with lower dose in winter and higher dose during flowering. 6 year old trees yield between 20 – 26 t/ha.

‘Arato Montegrande’, near Trujillo	Sand	260	100	300	Trees 4 yrs and older. Yields on ‘Lula’ rootstock are about 17 t/ha.
‘En Sueno’, near Trujillo	Sand	240	60	300	Nitrogen rates are increased during pre-flowering, flowering and fruitset, reduced during the first fruitlet shedding, increased again during fruit growth then gradually reduced during the latter stages of fruit growth. Potassium rates are lowest pre-flowering, start to increase during flowering and reach their peak just before harvest. Yields average about 16t/ha.
‘La Calera’ Chincha Valley south of Lima	Alluvial loam	200	48	332	Mostly applied as chicken manure. Yields are in the region of 20 t/ha.
‘Hoja Redondo’ Chincha Valley south of Lima	Alluvial loam	180	44	208	Typical yields are 18 t/ha.

South Africa

Lutge, A. (personal communication, 2018) reports that in South Africa Snijder and Stassen (2000) established kilograms of element (nitrogen, phosphorus, potassium, calcium and magnesium) that must be replenished each year per tonne of crop removed for each of three different soil types. As an alternative, they also provided rates of these nutrients to apply per centimetre of trunk circumference for unpruned trees. These base levels are adjusted according to leaf and soil analyses and crop vigour and are adapted for each farm over a number of years of observations. The nitrogen rate is increased by up to 20% where thunderstorms do not occur.

Table 6. Macro element fertiliser guidelines established for ‘Hass’ in South Africa based on crop removal (Snijder & Stassen, 2000)

Soil texture	kg of element recommended to be applied/tonne of yield				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Sandy (0-12% clay)	7.1	1.2	10.2	3.3	2.3
Medium potential soils (13-24% clay)	5.7	1	8.2	2.6	1.8
High potential soils (more than 24% clay)	4.5	0.8	6.5	2.1	1.5

Lutge reports that for a ‘Hass’ orchard growing on a soil high in clay and yielding about 20 t/ha, Westfalia Fruit Estates apply roughly 90-110 kg N/ha, 20 kg P/ha and 140-160 kg K/ha. This is adjusted up or down according to leaf and soil analysis. Nitrogen is split into eight applications by hand through the year starting in August and ending in April with higher rates applied from February to April. Where fertigation is used small amounts of nitrogen and potassium are also applied through the winter months. Nitrogen and potassium are generally applied together, phosphorus is split into two applications during root flushes and zinc and boron are applied at flowering and again in March/April.

Estimate of nutrients (kg of element) removed from the field by avocados

Some growers and agronomists use estimates of the nutrients removed in the harvested crop as a basis for calculating fertiliser rates to apply and then multiply these estimates by factors to allow for leaching, volatilisation and other losses.

Table 7. Various estimates of nutrients (kg nutrient) removed by one tonne of avocado fruit

Researcher	N	P	K	Ca	Mg
Rosecrance, R. *et al* (2012) 'Hass'	2.2	0.4	3	0.1	0.3
Stassen, P. *et al* (2010) 'Hass'	2.4	0.6	5.3	0.1	0.3
Dirou, J. and Huett, D. (2001) 'Hass'	3.8	0.66	5.7	0.48	0.55
Snijder, B. (2015) 'Maluma'	5.3				

Nitrogen rates and timing

There is strong evidence that timing of nitrogen application is an important factor in influencing Hass yield (Lovatt, 2001 and Lovatt and Salvo, 2016).

Lovatt (2001) proposed supplying sufficiently high amounts of nitrogen to meet the demands of the competing growth processes so that floral shoot development, fruit set, fruit growth and vegetative shoot growth would not compromise yield. In the trial, all trees received 140 kg N/ha (as ammonium nitrate) split into five applications of 28 kg N/ha. These were applied in the southern hemisphere equivalent months of July, August, October (full bloom), December and May, then a double dose was applied to different plots of trees for each of these months (thus receiving a total of 168 kg N/ha/year). The control treatment received no extra nitrogen. The research demonstrated that in Californian conditions applying a double dose of nitrogen at full bloom <u>or</u> in autumn (after cessation of leaf growth) significantly increased cumulative four year yields and fruit size, compared with applying 5 equal applications every second month from spring through till autumn. The higher dose at flowering also reduced the severity of alternate bearing.

The success of the extra application at full bloom was explained by supplying sufficient nitrogen so that the flowering/fruit set process was not competing with the developing leaf flush for nitrogen. The theory of supplying extra nitrogen in autumn was to pre-load the tree with nitrogen to increase flowering, fruit set and fruit retention. In a subsequent trial, the researchers established that it was unnecessary to apply a double dose as it was the correct timing that produced the beneficial result.

In the ultra-high density orchards in Chile, Mena, F. (reported by Newett, 2015a) explained that 30 to 40% of the nitrogen was applied at flowering time for fruit development and spring leaf flush with the amount being adjusted according to the intensity of the flowering – the greater the intensity the higher the rate. 20 to 30% was applied in January for fruit sizing and summer flush (harvest is conducted between September and January at this orchard), and the remaining 40% was applied in April to start building the tree up for a good flowering. Nitrogen was once not recommended at flowering, but this has since changed. Mena reported that there was a problem if nitrogen was applied a month prior to flowering in this environment.

In Australia, Whiley, A. (personal communication, 2018) does not recommend any nitrogen be applied through early to mid-winter unless the autumn leaf analysis indicates it is needed. Nitrogen applications are commenced with a relatively high dose at the cauliflower stage of flower bud development then reduced until mid to late autumn when 30% of the annual rate is applied. The autumn leaf analysis is taken after the last application has had enough time to be taken up by the tree.

Lovatt and Salvo (2016) investigated nitrogen fertilisation strategies to increase yield without decreasing fruit size. The research project was conducted over four consecutive seasons in California (Mediterranean climate) on 17-year-old Hass trees, on Duke 7 clonal rootstocks, growing in a loam soil. The phenological cycle in California is most like that of trees growing in SW Western Australia and Tristate. Trees were harvested 16 months after flowering (equivalent to February in Australia, so quite late).

All treatments (with one exception) received 140 kg nitrogen/ha/year split into 5 doses throughout the year at the times listed below in Table 7. Ammonium nitrate was used as the nitrogen source with the exception of the foliar application where low biuret urea was used. The ‘control’ treatment received equal doses at each of the five stages whilst the other treatments received different proportions at these five stages. The exception received just 45 kg nitrogen/ha/year split into two doses, namely in January and February (southern hemisphere equivalents).

The lower yield associated with treatment number 3 where 40% was applied at flowering and 40% again in autumn may appear to contradict the results achieved by Lovatt (2001) discussed above. However it was likely to be the consequence of applying only 14% of the annual nitrogen dose through the summer growing period, thus highlighting the importance of supplying enough nitrogen at this time.

Leaf N levels in the trial site were high, 2.71% at the start of the experiment, and high residual nitrogen in the soil may have been responsible for sustaining the performance of the trees in all treatments including No. 8 which received much lower rates of N than the others. The result in treatment 8 may also reinforce the importance of nitrogen applications in summer since this was the only time that this treatment received nitrogen fertiliser applications. The leaf levels decreased over the life of the project and average levels over the four year period were in the 2.54 to 2.62% range for all treatments, except the low nitrogen treatment which averaged 2.46%. However by year four the leaf nitrogen levels had dropped to a 2.31 to 2.45% range with the low dose treatment (8) at 2.28%. This indicates that residual nitrogen levels in the soil may have been quite high initially and suggests that an annual dose of 140 kg N/ha/year may not be sufficient in the long term.

Salvo & Lovatt (2016) state that in California summer vegetative shoots contribute to 60-70% of the total inflorescences in the subsequent flowering. This suggests that N fertiliser should be applied to the soil during the summer at an adequate rate to mitigate June drop and support competing growth processes of the fruit and summer vegetative shoots.

The highest leaf N was found in Treatment 6 (averaging 2.62% N over the four-year experiment and finishing at 2.45% N by year 4). This treatment received 60% of its annual N dose at flowering but the yield was only just higher than the average, suggesting that insufficient nitrogen was being applied at other times.

Table 8. Salvo and Lovatt (2016) nitrogen treatments and result

	Timing of N applications (S. hemisphere, WA & Tristate equivalents)						
	Jul	Oct	Jan	Feb	May		
Treatment number	Flower bud swell	Flowering, fruitset & initiation of spring leaf flush	Shedding of small fruitlets, initiation of exponential fruit growth and summer leaf flush	Exponential fruit growth, initiation of next season's flowers	Floral buds are committed to floral development, end of leaf growth	% of 140 kg N/ha/year	
	Percentage of the total annual dose of 140 kg N/ha/year						Result over 4 years
1	20%	20%	20%	20%	20%	100%	Good yield, average fruit size
2	15%	**40%**	15%	15%	15%	100%	Highest yield but smaller fruit & greatest degree of alternate bearing.
3	7%	**40%**	7%	7%	**40%**	100%	Lower yield
4	15%	15%	15%	**40%**	15%	100%	
5	15%	15%	15%	15%	**40%**	100%	Good fruit size
6	10%	**60%**	10%	10%	10%	100%	Highest leaf N.
7	10%	**60%** foliar	10%	10%	10%	100%	Low yield but lowest number of small fruit.
8	-	-	16%	16%	-	32%	Good fruit size. Highest number (but not statistically significant) of commercially valuable sized fruit.

There were no significant differences in fruit quality between the treatments.

This study reinforces the strategy of applying nitrogen 'little and often' throughout the year. In the experiment the annual dose was 140 kg N/ha/year. With a tree density of 271 trees/ha (5.5 x 6.7m tree spacing) the average annual yield was 15.5 t/ha but the average Alternate Bearing Index was

0.48 (meaning that the average yield in an ‘on’ year was about 23 t/ha but dropped to about 8 t/ha in the ‘off’ year).

Silber (2015 & 2017) investigated when the critical periodic demand for water and nutrients occurred in avocado. Lysimeter and field experiments were conducted to better understand and thus overcome the low avocado yields (10 t/ha) in Israel caused predominantly by the summer fruit shedding event and alternate bearing. The results can be summarised as follows.

Table 9. Silber (2015 & 2017) research treatments

	Fertiliser treatment (S. hemisphere equivalents)	**Comment**
1	Continuous fertigation (NPK + trace elements) over the whole year	Best results
2	No fertiliser until mid- September (just before flowering) then same as Trt 1.	Nutrient deficiency induced (a) leaf abscission (b) fruitlet and fruit drop
3	No fertiliser until mid- November (after fruitset) then same as Trt 1.	Flower development was delayed. Leaf drop occurred at flowering.

Different irrigation treatments induced significant differences in fruitlet drop. Silber (2015 & 2017) concluded that the differences in plant response to the irrigation treatments might point towards water and/or nutrient availability. He argues that unavailability of water and/or nutrients may lead to a malfunction of the embryo or seed and that fruitlet drop was the final step in a multifaceted process that started weeks or even months before. He emphasised the importance of fertilising the tree prior to flowering and of continuous application of all the necessary macro and micro nutrients throughout the growth period, recommending that a special effort should be made to match demand for water and nutrients during the flowering and fruitset processes. He showed that whereas fruit nitrogen levels built up at a constant level in the fruit as it developed, the rate of phosphorus and potassium accumulation intensified in the latter stages of fruit development.

Rosecrance et al (2012) found that in California nitrogen fertilisation in spring increased both fruit size, yield, and reduced the severity of alternate bearing compared with trees receiving nitrogen at any other time of the year except flowering. Nitrogen fertilisation at flowering and fruitset appears to be critical for fruit set of the new crop, for growth of the vegetative shoot flushes, and to support fruit growth of the maturing crop. In their study, they followed the accumulation of nutrients in avocado fruit. Calcium only accumulated during early fruit development and for this reason it was recommended that an abundant supply of calcium should be available during early fruit development. This concurs with the current understanding in Australia that calcium can only accumulate in the fruit during the first 6 to 8 weeks of its development i.e. before its stomata close permanently and turn into lenticels, and that soil moisture has to be optimal at this time too to facilitate uptake. The rate of nitrogen and phosphorus accumulation in the fruit continued at moderate levels as the fruit matured whilst the rate of potassium, magnesium and sulphur appeared to increase quite markedly in the final few months of fruit growth. These findings have implications for the timing of nutrient applications.

Thomas, G. (personal communication, 2017) and Mena, F. (personal communication, 2015) recommend that fruitset be closely followed and if it appears to be heavy then as soon as the early shedding of small fruit is over then nitrogen rates need to be increased. This is to feed this heavy crop and ensure there is also sufficient for leaf growth too. Newett (2015a) reported that Mena was investigating more efficient ways of assessing flowering and fruitset intensity (e.g. remote sensing with drones) for determining this nitrogen adjustment as well as for timing of PGR application. Thomas, G. aims to supply enough extra nitrogen (up to another 50% of the annual rate if leaf nitrogen is deficient and fruitset is exceptional) over the next two or three months in order to grow about 45cm of leaf flush beyond the young fruit. As described below under 'Foliar applied nutrients', if flowering is heavy and a big leaf drop is expected, Roe, D. (personal communication, 2018) recommends foliar low biuret urea sprays at flowering to delay leaf drop.

Nitrogen supplied by organic matter content of soil

Wolstenholme (2004) points out that the amount of nitrogen supplied to trees from the mineralisation of soil organic matter can be quite significant and this supply of nitrogen needs to be considered when developing fertiliser application programmes. Theoretically it can range from about 75 kg N/ha/year in soils with an organic matter content of less than 2%, to about 150 kg N/ha/year in soils with an organic matter content of more than 4%, however only a proportion of this potential nitrogen is mineralised each year. The rate of mineralisation is governed by factors including soil type, soil pH, the C:N ratio, temperature, moisture content and aeration. High temperatures, moisture, aeration, the application of lime to raise soil pH and the inclusion of a legume in the sward all favour mineralisation. Guidelines need to be developed that can estimate the amount of nitrogen made available through mineralisation each year in different situations.

In South Africa investigations into fruit quality problems (especially in the Pinkerton variety) led to the identification of orchards planted in old banana lands with a high organic nitrogen content as high risk (Snijder *et al,* 2003). In some of these orchards the supply of nitrogen from mineralisation of organic matter was sufficient on its own to cause quality problems even with no addition of nitrogen fertiliser.

Timing of nutrient applications other than nitrogen

Lovatt (2001) found that applications of phosphorus and potassium (at 4.2 kg P/ha and 25 kg K/ha) in January and again in February (southern hemisphere equivalents) in combination with 28 kg N/ha at the same time had a positive effect on yield and fruit size compared with trees receiving nitrogen only at this time. Applications of P and K at the other times did not significantly increase yield or fruit size.

Lovatt (2013) reported that in California there was a growing trend to divide the annual amount of fertiliser into six or twelve small equal applications. However she pointed out that this ignores the crop cycle and nutrient demand, so it is possible that transient periods of insufficiency of particular nutrients could occur during key stages in the tree's phenology and these could have a negative effect on yield, fruit size, fruit quality and the next flowering.

Rosecrance *et al* (2012) recommended basing the timing of fertiliser applications on the timing of nutrient accumulation in developing fruit. Following this approach in California (Mediterranean climate where fruit remains on the tree for about 16 months) nitrogen, phosphorus, magnesium, sulphur, iron and zinc need to be applied during the spring growing season after full bloom and repeated again the second year during the same period. This is in order to supply nutrients to the recently pollinated flowers as well as the maturing fruit. Potassium and boron are accumulated more rapidly in fruit in the latter stages of fruit development (in California during the second season of fruit development) so should be applied in order to be available for this stage; a higher application may be needed depending on fruit load. Since most of the calcium is accumulated during early fruit development, an abundant supply must be available at this early stage.

In Australia, Whiley, A. (personal communication, 2018) commences calcium applications from mid-flowering and continues them for 12 weeks. He does not recommend applying potassium until calcium applications are over because potassium replaces calcium at the root absorption sites. Potassium is applied from mid-summer through until the end of autumn, which matches the recommendation of Rosecrance *et al* (2012) to apply it in the latter stages of fruit development. Whiley recommends boron in the months when trees are actively growing and magnesium is applied if necessary during spring. Other elements are applied at any time when required. Martin, L. (personal communication, 2017) believes that potassium is the worst offender in displacing other cations particularly calcium.

Calcium

Lahav *et al* (2013) states that whilst gypsum was the most effective treatment for increasing soil calcium, it also displaced potassium and magnesium from the topsoil and subsoil. Gypsum increased calcium levels to deeper levels than achieved by dolomitic products.

Silicon

The role of silicon as an essential nutrient in avocado has attracted research over the past 10 years or so but has often given inconsistent results (Bekker *et al*, 2007 and Smith *et al*, 2011). The function of silicon as a plant nutrient is thought to be one of making plant cells more resistant to disease attack, partly by enhancing physical barriers to infection and possibly also through a direct fungicidal effect. Recently, Dann and Le (2017) undertook a literature review and conducted trials with two silicon products. One product was soluble potassium silicate and the other was a slow-release milled by-product from the building industry which contains 5% soluble silicon. There were mixed and inconsistent results from using soluble potassium silicate although in some cases improvements were recorded in tree health and in fruit yield and quality. However, results from the slow release product were more promising, improving tree health and raising silicon levels in leaves and fruit peel. The authors concluded that products that deliver silicon consistently for uptake, i.e. slow-release products, are likely to be most successful in perennial crops but that further field trials are warranted.

Molybdenum

Brusca and Haas (1955) showed clear avocado growth responses to the addition of sodium molybdate in pot trials that compared nutrient solutions without molybdenum with those receiving a range of concentrations of this trace element. Growth was stunted in the nil treatment whilst the best growth was achieved with a concentration of 0.5 ppm molybdenum, however at concentrations of 5, 25 and 50 ppm growth declined proportionately suggesting that toxic levels had been reached.

Wolstenholme (2017) undertook a short review of the role and importance of molybdenum in plant nutrition. He pointed out that molybdenum is an essential plant trace element and has a number of roles including being closely involved with nitrogen metabolism (which includes nitrogen fixation in legumes) and as a co-factor (molybdenum co-factor, or 'Mo-co' for short) for several essential enzymes. Deficiency symptoms can appear the same as those for nitrogen deficiency, because of its role in nitrogen metabolism. Molybdenum is required in such trace amounts that in most orchards it is likely to be present in sufficient quantities, but adequate amounts may also be inadvertently supplied as impurities in commonly used fertilisers. It is the only nutrient whose availability increases with pH, i.e. the higher (more alkaline) the soil pH the more available it is, but in acid soils the availability of molybdenum is very low. There is an inverse relationship between molybdenum and manganese so soils high in available manganese (e.g. where there are toxic levels of manganese in acid soils with high water content) can be deficient in molybdenum, especially if organic matter levels are low. In addition, sulphate and molybdate ions compete strongly during root uptake from the soil so sulphate based fertilisers including gypsum will suppress uptake of molybdenum.

Since molybdenum is required in such small amounts and because it is highly phloem-mobile, foliar sprays are likely to be successful in addressing deficiencies.

In summary molybdenum is more likely to be deficient in highly leached, very acid soils especially if they are low in organic matter and have high levels of manganese and sulphates, however it is easy to correct.

Foliar applied nutrients

Newett (2000) conducted a literature review on foliar nutrient applications in avocado and found at that time that there was little evidence to support the use of foliar applied nutrients in avocado. The topic was reviewed for this report.

Lovatt (2013a) claims there is a place for foliar applied nutrients in avocado, e.g. where cold wet soils in spring can restrict nutrient uptake when needed for spring growth, in the presence of soil salinity, where pH is not suitable and where soil chemistry (e.g. nutrient tie-ups) restricts sufficient root absorption. If the plant absorbs a foliar applied nutrient, it also needs to be phloem-mobile in order to be transported to where it is needed. Nutrients listed as phloem-mobile are nitrogen, phosphorus, potassium, chlorine and sulphur. Partially phloem-mobile are zinc, iron, manganese, molybdenum and boron. Calcium is not phloem mobile. It should also be noted that nutrients can have vastly different rates of leaf absorption e.g. in pistachio six months elapsed before an increase in the leaf zinc level was detected following a foliar zinc spray.

Applying foliar nutrients is not widely recommended for avocados because mature avocado leaves have a thick waxy cuticle and only small amounts can be absorbed at best, however some uptake of foliar urea has been achieved through leaves that were only 2/3 expanded (Nevin *et al,* 1990).

Results are not always consistent, for example in California mature leaves did not take up foliar applied urea (Nevin *et al,* 1990) but mature leaves in Israel did (Zilkah *et al,* 1987).

In Spain, Torres *et al* (2002) experimented with foliar applications of boron, copper and zinc on mature Hass trees on Mexican rootstock and on potted trees. In their first experiment boron, copper and zinc sprays were applied to mature trees over a period of three years but none of the sprays affected vegetative growth or yield, and no increase in leaf nutrient levels was achieved. In their second experiment, boron sprays were applied to flowers and this did result in higher boron levels in autumn sampled leaves. In the third experiment, the area to one side of the midrib of the leaf (top and bottom) was sponged with a boron solution but this had no effect on the boron concentration in the other half of the leaf. In a fourth experiment foliar boron sprays were applied to potted trees but even when very young expanding leaves were sprayed no major increase in boron content of the following leaf flush or shoot bark were registered. Addition of wetting agents or acidifiers to the spray did not consistently influence boron levels.

Nevertheless, recent research has indicated that there are instances in some growing environments where well-timed applications of some nutrients applied to immature leaves are able to elicit a response. The chances of success can be improved if nutrients are applied to developing leaves (1/3 to 1/2 expanded) or to plant organs other than leaves (e.g. flowers), and wetting agents and more soluble fertiliser formulations are used.

Jaganath and Lovatt (1998), and Lovatt (1999) in studies with 'Hass' in California reported that a foliar spray of Solubor® (at 6 g B/tree) <u>or</u> of low biuret urea (at 160 g N/tree) targeting the cauliflower stage of flowering (not the leaf) significantly increased cumulative yield over the three year period of the research. This increase was by 12 and 11 t/ha respectively. However, urea sprays were not recommended because of the possible negative effects of urea when the ambient temperature exceeds 32°C. A combination spray of Solubor® and urea resulted in a yield not significantly different from the untreated trees in this experiment. Salazar-Garcia (reported by Lovatt, 2013) and Jaganath (1993) reported that including urea in the spray caused a deformation of flower carpels and Salazar Garcia in Mexico reported a significant reduction in yield from a combined boron plus urea spray.

Roe, D. (personal communication, 2018) recommends three 1% low biuret urea sprays a week apart starting at budburst if a heavy flowering is imminent and a big leaf drop is expected. He reports that this has the effect of keeping the leaves on the tree for longer.

In Mexico, Cossio-Vergas *et al* (2009) reported that in an unirrigated orchard displaying boron deficiency symptoms, a foliar spray of boron at 2 kg B/ha applied at early fruit set improved fruit size. In another treatment a spray at fruit set at 1 kg B/ha followed by a second spray a month later increased both yield and fruit size.

Dixon *et al* (2005) conducted a study on two Hass orchards (one irrigated and the other not) in New Zealand to determine if applying foliar boron (1 g Solubor®/litre), nitrogen (1% solution of low biuret urea) and boron and nitrogen combined (at these same concentrations) would increase fruit set. Sprays were applied when the flower buds had started to expand. The sprays had an inconsistent effect on fruit set that was orchard dependant. The optimum boron concentration in the <u>flower</u> for maximum fruit number was found to be between 50 and 65ppm. This was also reported by Robbertse *et al* (1992) in South Africa. However, there was no advantage in exceeding 65ppm boron level in the flowers e.g. by applying multiple sprays. This may help explain why there are variable results from orchard to orchard. Dixon suggested that fruit set might be negatively affected at levels both above and below the optimum and that multiple sprays were a waste of time. Research by Smith *et al* (1997) confirmed this notion, reporting that foliar boron sprays at flowering only induced a response if the <u>leaf</u> boron level was below 30 ppm (i.e. deficient). Dixon (2006) in a follow up experiment found that multiple sprays of boron are not required for good fruit set and did not overcome the effect of alternate bearing. The experiments found that applying boron as a single or multiple foliar spray at the cauliflower stage of flowering on adequately fertilised 'Hass' trees in New Zealand conditions did not enhance fruit set, this may have been because boron levels were already sufficient.

In California Lovatt (2013b) found that a spray of potassium phosphite at 6.5 L/ha to the cauliflower stage of flower development significantly increased the three year cumulative yield of commercially valuable sized fruit without reducing total yield. Phosphite is more readily absorbed into plant tissues than phosphate. In Mexico Salazar-García (unpublished but reported by Lovatt, 2013) significantly increased fruit size and yield by applying two sprays of potassium phosphite at about 3.5 L/ha each, the first at the beginning of the exponential fruit growth period and the second a month later. However, it is not clear from either of the investigations how much of the benefits were the result of improvements in nutrient status and how much were from possible improvements in tree health because of the fungicidal properties on Phytophthora root rot, although the timing was wrong for root rot treatment.

In Australia, Martin, L. (personal communication, 2017) reports some success in curing zinc deficiency symptoms in leaves with foliar applications of zinc chelate EDTA. Thomas, B (personal communication, 2017) reports that zinc deficiency can be a problem in the South Australia/Victoria region due to tie up in the soil and possibly cold soil temperatures in spring, and claims some success with foliar zinc sprays if applied to new leaf flush before it hardens.

However, Salazar-Garcia *et al* (2008) found over a four year trial in Mexico that zinc sulphate foliar sprays (applied at cauliflower stage of flower buds with new leaf flush already emerging) were ineffective in correcting zinc deficiency and had no positive effect on yield and fruit size. But he did find that two soil applications of 0.75 kg zinc sulphate per tree per year were effective in increasing yield, fruit size and fruit shape. A poor relationship was found between the amount of zinc applied and the zinc leaf level.

Nutrient monitoring

The recommended time in Australia to monitor nutrient levels in leaves is autumn (sampling mature summer flush) and this is widely practiced however it is becoming a common and accepted practice to also sample in early summer (mature spring flush from shoots without fruit) (Newett, 2017). Soil nutrient status is generally examined once every one to three years.

Leaf analysis is the most common method for monitoring nutrient status but it has limitations. Firstly, it is well documented that 'Hass' avocado yield and fruit size in California are not related to leaf nitrogen concentration (Arpaia *et al*, 1996; Embleton and Jones, 1972; Embleton *et al,* 1968; Lovatt, 2001; Lovatt and Witney, 2001; Yates *et al,* 1993; reported by Salvo and Lovatt, 2016). Secondly many elements (e.g. calcium and magnesium) accumulate with leaf age so the result for these elements tends to reflect the age of the leaf sampled rather than the calcium and magnesium status in the tree. Thirdly it is easy to select the wrong leaf for analysis. Fourthly, leaf iron levels are not considered a reliable indicator for plant usable iron, the leaf may have deficiency symptoms but the analysis may indicate ample levels are present. Finally, the timing of sampling is such that no action can be taken to rectify deficiencies or imbalances for the current crop, only for the next one.

Salazar-Garcia *et al* (2015) conducted a very thorough investigation in order to establish the best time to take leaf samples from orchards in the hot subhumid climate in the state of Nayarit in Mexico for each of the two main leaf flushes per year. Leaves were sampled and analysed monthly until abscission, with nutrient content curves established which allowed the most stable and therefore appropriate timing for sampling to be determined. These curves are a useful reference to demonstrate how the levels of each element change as the leaves gets older and how levels differ between the two different flushes. Leaf flush patterns are different in Nayarit compared with Australia but for their winter flush leaves the best time was when leaves were 6.6 to 7.9 months old and for the summer leaf flush the best time to sample was when leaves were only 3.9 to 4.9 months old. The summer flush leaves grew faster than the winter ones as expected but they had an average lifespan of just 7.8 months while the winter flush leaves lived for an average of 12.5 months.

Dann *et al* (2016) found a link between the N:Ca ratio in fruit skin and fruit quality. The higher the calcium the lower the incidence of fruit rot.

Silber (2017) argues that one needs to replace the quantities of nutrients removed by the crop and therefore we should be analysing nutrient concentrations in the fruit (instead of the leaves) and using this information and the yield to calculate what to apply (with appropriate efficiency factors to account for losses due to leaching, volatilisation etc).

Campisi-Pinto *et al* (2017) in California attempted to identify which 'Hass' avocado tissue had nutrient concentrations that best predicted yields of greater than 40 kg fruit per tree (more than about 11 t/ha). They discovered that nutrient content of flower buds at the cauliflower stage was the best predictor of yield for crop to be borne by those flowers. These cauliflower stage buds were better predictors than inflorescences at full bloom, fruit pedicels at five different stages, or six-month-old spring flush leaves. They found that the concentration of seven nutrients, viz. nitrogen, phosphorus, potassium, magnesium, sulphur and zinc in the flower buds at the cauliflower stage were predictive of trees producing greater than 40 kg fruit annually. Interestingly, the trees producing high yields had nutrient levels for the seven nutrients at the low end of the nutrient ranges measured across all trees in the experiment, whereas those producing low yields were at the high end. Optimum ratios of nutrients were also derived. Calcium, manganese and boron levels in the flower buds were not correlated with high yield, however no deficiency symptoms for any nutrients were visible in the experiment so it is likely that these nutrients were present at sufficient levels. They found that the nutrient status of cauliflower stage flower buds was not related to the nutrient status of leaves sampled at the standard autumn time. The results also indicated that current fertiliser practices (timing or amounts) might be causing nutrient imbalances at this stage of avocado phenology that are limiting productivity. This research is an exciting development that could result in the development of a useful tool and warrants further investigation. One of the potential advantages of this approach could be that you could take immediate action to correct nutrient deficiencies, toxicities or imbalances in time to benefit the crop as it set and developed. Another advantage is that the cauliflower stage of flower bud development is a discrete developmental stage of short duration that is easy to identify and collect compared to the difficulties of sampling the correct leaf for nutrient testing.

Osborne *et al* (2002) showed how remote sensing using hyperspectral analysis has the potential for rapid and non-destructive nutrient analysis of a commercially grown crop. Robson, A. (personal communication, 2016) has been investigating the use of remote sensing to determine nitrogen levels in sugarcane crops in Queensland. This technology may have potential for avocado orchards in the future.

However, recent work by Crowley *et al* (2015 & 2016), and also reported by Span (2016), has 'data mined' hundreds of leaf analysis results and corresponding yields which has shed new light on optimum ratios between leaf nutrients and has established new optimum ranges for leaf nutrient levels in California that correlate with higher yields. This work suggests that leaf nutrient analysis will remain a useful tool into the future. This work is discussed in more detail below.

Correlating leaf nutrient levels with yield and establishing new optimum leaf ranges and ratios

Crowley *et al* (2015 and 2016) and Span (2016) describe how data was collected from hundreds of avocado trees from production areas in Southern California in order to model the relationships between leaf nutrient concentrations and the yields of avocado trees. Using advanced statistical methods and artificial neural network models (a type of machine learning software) they have thrown new light on optimum nutrient levels and relationships between nutrients that correlate with both higher and lower yields.

A significant outcome has been the release of new optimum ranges for leaf nutrients in California. The table below compares Australia's current guidelines with the new ones developed by Crowley *et al* (2015).

Crowley's upper limit (0.15%) for his suggested new optimum range for leaf phosphorus compares closely with Lahav *et al* (2013) who states that when leaf phosphorus is above 0.14% no phosphorus fertiliser should be applied. Similarly for potassium, Lahav *et al* (2013) states that if leaf potassium is above 1.2% no potassium fertiliser should be applied, whilst Crowley goes one step further by suggesting that the upper limit for leaf potassium should be lowered from 2.0% to 0.9%. As mentioned earlier Mena, F. (personal communication, 2015) does not apply potassium fertiliser once the leaf level rises above 0.55% K.

The advanced statistical analysis has also revealed that there are multiple interactions between different nutrients, i.e. as certain nutrient levels go up yields can be further increased by re-optimising other nutrients to obtain the optimum nutrient ratios.

Table 10. New avocado leaf nutrient optimum ranges for 'Hass' grown in California developed by Crowley et al (2015) compared with Australia's current optimum guidelines (hardened summer flush sampled in autumn in both cases)

Nutrient	**Existing optimum range used in Australia (Embleton & Jones, 1964) & (Whiley *et al,* 1996)**	**New optimum range established for California (Crowley, 2015)**	**Comment on the change**
Nitrogen %	2.2 – 2.6	2.25 – 2.9*	Higher range. *N.B. - may be too high for subtropical and tropical production regions.
Phosphorus %	0.08 – 0.25	0.1 – 0.15	Upper limit has been lowered. Narrower range.
Potassium %	0.75 – 2.0	0.7 – 0.9	Upper limit has been lowered. Narrower range.
Calcium %	1.0 – 3.0	1.8 – 2.0	Narrower range.
Magnesium %	0.25 – 0.8	0.6 – 0.9	Narrower range, higher lower limit.
Sulphur %	0.2 – 0.6	0.45 – 0.53	Narrower range.
Zinc ppm	40 – 80	50 – 80	Lower limit has been raised.
Copper ppm	5 - 15	4 - 7	Narrower range, lower upper limit.
Iron ppm	50 – 200	55 – 80	Much narrower range, lower upper limit.
Manganese ppm	30 – 500	110 - 145	Much narrower range, higher lower limit and lower upper limit.
Boron ppm	40 - 60	38 – 60	

A number of other major findings have emerged. Crowley *et al* (2015) state that they can predict yield losses as nutrient levels exceed optimum values, Californian growers may be applying too much nitrogen and potassium which could be causing 'huge losses' in production, large nutrient imbalances between nitrogen and potassium are closely associated with alternate bearing trees, chloride toxicity leads to greatly reduced shelf life whilst increasing calcium can offset this, and the balance between iron and potassium is critical. Another focus of this research was the study of soil salinity and chloride toxicity on avocado yields, and the extent to which this might be controlled by managing tree fertilisation, soil water monitoring, and leaching practices.

Findings from the project will be used to develop a Decision Support Tool that can help growers improve fertilisation and nutrient management while minimising the effects of soil salinity.

Effect of rootstock

Dann *et al* (2016) reported on the effect of rootstock on fruit mineral content and susceptibility to fruit flesh body rots from data collected in the rootstock trials conducted across Australia. Fruit peel samples were collected at harvest and analysed for concentrations of nitrogen, potassium, calcium and magnesium. Fruit were assessed for stem end rot and anthracnose. Rootstock significantly affected marketability of fruit (no stem end rot and less than 5% anthracnose) in 58% of the trials evaluated, with better quality fruit harvested from 'Hass' grafted to Guatemalan and West Indian rootstocks such as 'A10' and 'Velvick'. Fruit quality was frequently poor from trees grafted to Mexican race rootstocks, regardless of growing location. Fruit from rootstocks with superior fruit quality was often associated with lower skin nitrogen and higher calcium concentrations. N:Ca ratios in the skin of unripe avocado fruit may provide one of the best indicators of potential postharvest disease in ripe fruit, and may have implications for fertiliser regimes.

Mycorrhizae

Menge *et al* (1980) found that the introduction of two isolates of the mycorrhiza *Glomus fasciculatus* improved avocado seedling growth by 49 to 254% compared to seedlings grown in sterile soil without mycorrhizae. Both mycorrhizal isolates increased absorption of nitrogen, phosphorus and copper whilst the other also increased absorption of zinc. Fertilisation with phosphorus did not alter phosphorus concentrations in leaves of non-mycorrhizal seedlings but did in inoculated seedlings.

Research conducted by Violi (2005) demonstrated that mycorrhizal fungi colonise avocado roots and increase the uptake of phosphorus, zinc and iron.

Montoya and Osorio (2009) investigated the growth of avocado seedlings in the greenhouse for 150 days in response to the use of arbuscular mycorrhizal fungi *(Glomus fasciculatum)* at three different levels of soil solution phosphorus (0.002, 0.02 and 0.2 mg/L). The mycorrhizal inoculation significantly increased shoot dry weight at 0.002 and 0.02 mg/L soil phosphorus by 48% and 35% respectively but this decreased to 26% at 0.2 mg/L of phosphorus. The results suggested that avocado would benefit considerably from mycorrhizal inoculation when soil phosphorus levels are low.

4. SUMMARY AND SUGGESTIONS

Root rot and soil moisture management

Good phytophthora root rot control and soil moisture management are essential pre-requisites for having an effective plant nutrition programme and achieving high yields of good quality fruit.

- Ensure that *Phytophthora cinnamomi* root rot is under control because no roots = no nutrition or water uptake = no fruit.
- Soil moisture must be very well managed. Adequate water must be available at all times to allow nutrient uptake but not excessive to the point of asphyxiating avocado roots nor facilitating the spread of *Phytophthora cinnamomi* disease through movement of disease zoospores in free water.
- If fertigation is used check the uniformity of the irrigation system at least annually. Uneven watering through the orchard will mean uneven nutrition.
- View the 'Checking irrigation uniformity in avocado orchards' video on the Best Practice Resource.
- Remember that most of the tree's feeder roots are in the top 15cm of soil, so irrigate and fertilise the tree with this in mind.

Customisation of nutrition programmes

Nutrition is a complex subject and there is no 'one size fits all'. For example avocado trees behave differently when grown in a Mediterranean climate (e.g. Tristate and SW Western Australia) compared with a subtropical climate. In the cooler environments it behaves more like a deciduous tree in that it builds up stored carbohydrate levels through summer and autumn which it draws upon for flowering and fruitset, however in a subtropical climate stored carbohydrate levels are never high and the tree is dependent on current photosynthesis to supply the energy for flowering and fruitset, i.e. a more 'hand to mouth' existence. The other obvious difference between these two climates is that average temperatures in a subtropical environment are higher and warmer for longer periods which will produce excessive vegetative growth in response to a high nitrogen regime. This is possibly at the expense of fruit yield and quality. The Mediterranean climate is cooler and high levels of nitrogen fertiliser will not produce the same degree of unwanted vegetative growth. Thus, a programme that works best for a particular environment and/or variety may not be the best approach for another and nutrition practices (especially for nitrogen) need to be customised for each situation.

- Nutrition programmes need to be based on science and tailored to suit each orchard environment.
- Regularly monitor nutrient levels in the leaf and soil, the health of the canopy and feeder roots, and soil moisture.
- Adjust the nutrition programme to take into account management practices such as pruning and late harvest.
- The optimum ratio of cations (calcium, magnesium, potassium and sodium) in the soil is well known and remains relevant.
- Be aware of the different stages of the growth cycle as they occur.
- Be prepared to modify the nutrition programme during the year because each season is different.
- Fertilisers can change soil pH so monitor the soil pH in the wetted zone where the fertigation is applied or where fertiliser is broadcast and correct if necessary.

Nutrient monitoring

As well as following the recommended guidelines to sample leaves for nutrient analysis, namely fully expanded summer flush leaves in autumn from branchlets without fruit, it has become widely accepted that a useful mid-season gauge of tree nutritional status can also be gained from sampling the fully expanded spring flush leaves in summer provided these leaves are taken from shoots without fruit. It is essential that the correct leaves are sampled since sampling mistakes will compromise results.

In some exciting new work in California using advanced statistical methods to analyse leaf analysis and yield data has refined the optimum leaf level ranges and established a clearer picture of desired ratios between some nutrients.

At least four other ways of measuring the nutrient status of the tree have been proposed. The first is to monitor the nutrient content of the fruit as they develop in order to supply particular nutrients at appropriate rates as they are needed. The second is to establish the N:Ca ratio of the skin of unripe fruit as an indicator of fruit quality. Recent research on the nutrient status of flower buds at the cauliflower stage has revealed that it is a very good predictor of yield, furthermore sample selection is straightforward and results are received early enough to correct imbalances that would otherwise impact on yield. Finally, remote sensing using hyperspectral analysis may have a future for determining plant nutrient status as it is quicker, potentially cheaper and non-destructive. More work is needed on all of these approaches to develop them into useful and practical tools.

Sap testing is practiced on a limited scale and is useful for monitoring some nutrients but not all, and it requires a specialist to interpret the data.

- It is still essential to base nutrition programmes on the results of recent leaf and soil analysis and to take into account crop load and tree health. Note however that nutrient analysis results will be meaningless and misleading if trees are suffering from anything worse than mild levels of Phytophthora root rot.
- Leaf analysis should be done at least annually in autumn whilst soil analysis is generally necessary every two to four years.
- It is now acceptable to also test the nutrient status of spring flush leaves once hardened in summer provided they are taken from non-bearing branchlets.
- Continue to use the current Australian optimum level guidelines but you may also want to compare your levels against the refined guidelines recently established for California.
- Be aware that there are different optimum soil boron levels for each of five different soil textures.

Nitrogen rates

Nitrogen has been described as the 'dynamite' of plant growth and, assuming other nutrient levels are in balance and available in adequate amounts, the management of nitrogen applications offers the greatest potential for manipulating productivity. However, like dynamite, it must be handled with care as it can have both negative and positive effects on yield and fruit quality. Rates and timing are the critical aspects. Too much nitrogen and/or poor timing of applications can result in large unproductive vegetative trees and poor quality fruit but insufficient nitrogen can result in depressed yields and alternate or irregular bearing. Achieving the right balance with nitrogen is one of the big challenges for avocado growers. Growers also need to be aware of the nitrogen that is supplied to the plant through the mineralisation of soil organic matter which can reach up to 150 kg/ha/year in soils with more than 4% organic matter.

Nitrogen fertiliser rates vary across the world according to the growing environment. The following are some examples for mature orchards; amounts are in kg of N/ha/year:

- 2001 Australian guidelines when leaf N levels are optimum 110 N
- Australia (wide range of growing environments and soils) 70 – 500 N
- Brazil (rain fed) 60 – 120 N
- California (Mediterranean climate) 100 – 140 N
- Chile (Mediterranean climate, generally heavy soils) 115 - 250 N
- Israel (Mediterranean climate) 300 N
- New Zealand (cool climate, for large, high yielding trees) 280 N
- Peru (infertile sands and desert environment) 180 – 380 N
- South Africa (for a 20 t/ha crop on a high clay soil) 90 – 110 N

Estimates of nutrients removed from the field by one tonne of 'Hass' avocados average about 2.8 kg N, 0.5 kg P and 4.7 kg K. However, trying to calculate application rates based on these figures with correction factors to allow for losses due to leaching, volatilisation, uptake efficiency etc can be difficult and factors will vary from season to season. Other methods are arguably just as difficult but whatever approach is used, knowledge of the orchard environment including the soil properties and most importantly, monitoring of the season, weather, tree health, crop load, and plant and soil nutrient levels are essential in order to adjust the nutrition programme accordingly.

Nutrient levels in the leaf reflect the results of your fertiliser rates, products, timing and the impact the season has had and should be used to learn about their impact and how the programme can be fine-tuned for the next season.

Growers should also be aware of the negative effects on the environment that nutrients leaching into groundwater and streams can have. Steps to minimise nutrient leaching include not applying nutrients excess to requirements, splitting applications into several smaller doses (especially on light soils where there is more potential for leaching) and increasing organic matter content of soils.

There has been some useful recent research relating to avocado nitrogen requirements in Mediterranean climates (mainly from California) but very little for subtropical climates.

It is now generally accepted that vegetative and reproductive growth in avocado are in direct competition with each other and growers need to ensure that sufficient nitrogen is available to satisfy the needs of both. To achieve this, rates and timing of nitrogen applications need to be carefully considered. Growers also need to be thinking beyond the immediate needs of the tree and including sufficient and well timed nitrogen applications to produce the summer flush which is going to produce the canopy needed to bear the flowers and generate the carbohydrate needed to fuel the development of the subsequent crop. This must be achieved without upsetting the vegetative/reproductive balance which, if overdone, could result in too much vegetative growth, excessive fruit shedding and poor quality fruit (high fruit nitrogen is accompanied by low fruit calcium). On the other hand, if nitrogen is underdone it will starve the tree and encourage alternate bearing. This is not an easy balance to achieve.

It is now also clear that the annual nitrogen dose should be split into several applications throughout the year, including winter (at low rates) if the autumn leaf analysis indicates that it is needed. Importantly the grower needs to monitor the trees and conditions throughout the year and adjust rates in response to factors including leaf analysis, tree appearance, crop load and weather.

A common emerging practice is to ensure that there is adequate nitrogen available in the tree at flowering so that fruitset, early fruit growth and spring leaf flush are not competing for this nutrient. Some agronomists recommend relatively high applications at or shortly before flowering whilst others are more cautious and, provided nitrogen levels are not deficient, hold off until after the first fruitlet thinning event is over. The higher dose at flowering in California was found to reduce the severity of alternate bearing.

It is also becoming common practice to increase nitrogen rates in response to heavy fruitset and to do this as soon as the first fruit shedding event is over.

- Use a starting rate of between 100 and 200 kg N/ha/year for a mature healthy crop, the lower end for tropical and subtropical regions and the higher end for cool regions where two crops are typically on the tree for some of the year. Adjust it up or down according to leaf nitrogen level, canopy health and crop load. Also take into account other sources of nitrogen that are applied such as mulch and compost, the amount of leaching rain received and the organic matter content of the soil. Refine this rate each year as you get a better understanding of the orchard.
- To manage nitrogen more effectively conduct two leaf analyses per year. Take one sample in autumn of the hardened summer leaf flush (non-bearing branchlets) and the other in summer of hardened spring leaf flush (also from non-bearing branchlets). Ensure that the correct leaf is sampled and continue to use the long established optimum range for leaf nitrogen, namely 2.2 to 2.6%, until new guidelines are established. Fine tune nutrient rates according to leaf test results.
- Observations of the leaf colour, gloss and size are also important indicators of the nitrogen status (and tree health).
- Ensure that there is sufficient nitrogen available by flowering time to supply the needs of both the new crop and the spring leaf flush about to develop.
- Ensure that there is sufficient nitrogen available in summer to not only supply the immediate needs of the tree but also to set it up for the next season. A good application in summer can also reduce the magnitude of alternate bearing.
- If a heavy crop is set then after the first natural shedding of fruitlets start to apply extra nitrogen fertiliser. If leaf levels were deficient in autumn and fruit set is massive then apply up to 50% extra nitrogen above the annual rate, proportionately less if leaf levels were within the optimum range or if fruit set is large but not massive. This extra nitrogen should be applied in several split applications (weekly to monthly) over the ensuing 2 or 3 months. The intention is to promote the growth of about 45cm of spring leaf flush over the developing fruit.
- If plant growth regulants are used at flowering then extra nitrogen needs to be applied, usually about 10%.
- Split the annual nitrogen dose into several applications through the season (see nitrogen timing below).

Nitrogen timing

The timing of nitrogen applications has been the subject of many studies, especially in California and Israel which both have a Mediterranean climate and some common threads are appearing out of the research which provide some useful guidelines for this growing environment.

Suggested guidelines for the timing of nitrogen for a Mediterranean climate (southern hemisphere)
The following guidelines are based on a 'best fit' from the recent research discussed in this report.

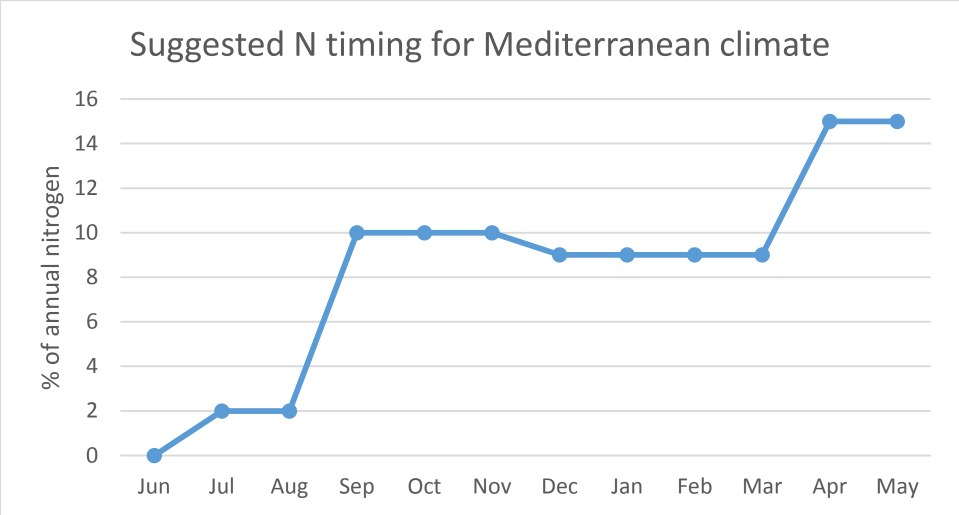

Figure 1. Suggested nitrogen application timing for a Mediterranean climate in Australia

Table 11. Nitrogen timing suggestions for a Mediterranean climate

Growth cycle stage	Flower bud swell		Cauli-flower stage of flower bud	Flowering, fruitset & initiation of spring leaf flush		Shedding of small fruitlets, initiation of exponential fruit growth and summer leaf flush.		Exponential fruit growth, initiation of next season's flowers		Floral buds are committed to floral development, end of leaf growth	
The need	Maintain-ing tree growth, albeit at a low rate.			To ensure sufficient N to meet the needs of flowering, fruitset and the new spring leaf flush. Reduce severity of alternate bearing.		Meeting the needs of developing and maturing fruit, summer leaf flush and mitigating fruitlet shedding.		Meeting the needs of developing fruit and leaf flush.		Setting the tree up for the next flowering and fruitset	
Monitor				Gauge the intensity of fruit set.		Analyse spring leaf flush once fully expanded and adjust N rate if needed.				Analyse summer leaf flush once fully expanded, adjust N rates accordingly.	
Month in Tristate/ SW WA	Jul	Aug	Sep	Oct (flower -ing)	Nov (fruitset)	Dec After 1st fruitlet shedding.	Jan	Feb	Mar	Apr	May
Suggest-ed propor-tion	2%	2%	10%	10%	10%	9% +	9% +	9% +	9%	15%	15%

+ . . . . apply extra nitrogen if big crop set

Suggested guidelines for the timing of nitrogen for a subtropical climate (southern hemisphere)
As already mentioned there is an absence of recent nutrition research for avocados in subtropical environments. The following is based on recent trends and current thinking.

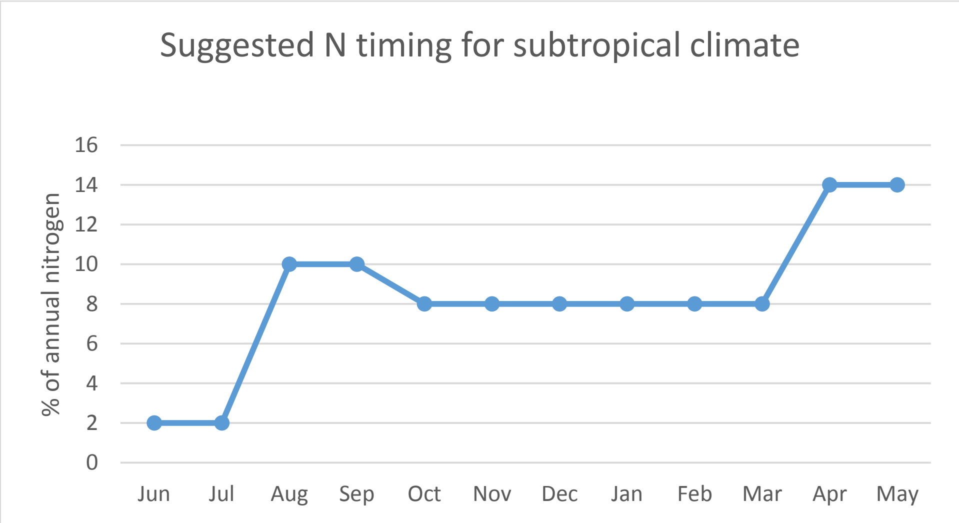

Figure 2. Suggested nitrogen application timing for a subtropical climate in Australia

Table 12. Nitrogen timing suggestions for a subtropical climate

The suggested proportions and timing for a subtropical climate are as follows:

Growth cycle stage	Flower bud swell			Flowering, fruitset & start of spring leaf flush		Spring leaf flush. Initiation of exponential fruit growth. After shedding of small fruitlets.		Fruit growth. Summer leaf flush. Initiation of next season's flowers.			Floral buds are committed to floral development, end of leaf growth	
The need	Maintaining tree growth, albeit at a low rate.			Sufficient N to meet the needs of flowering, fruitset and the new spring leaf flush and reduce alternate bearing.		Meeting the needs of developing fruit and spring leaf flush.		Meeting the needs of developing fruit and summer leaf flush.			Setting the tree up for the next flowering and fruitset.	
Monitor				Gauge the intensity of fruit set.		Analyse spring leaf flush once fully expanded and adjust N rate if needed.					Analyse summer leaf flush once fully expanded and adjust N rates accordingly.	
Month in Central & SE Queensland	Jun	Jul	Aug	Sep flower	Oct fruitset	Nov after first fruitlet shedding	Dec	Jan	Feb	Mar	Apr	May
Suggested proportion	2%	2%	10%	10%	8%	8% +	8% +	8% +	8%	8%	14%	14%

+ . . . . apply extra nitrogen if big crop set

Nitrogen timing for other varieties and regions

Use the most appropriate of the two guidelines outlined above but ensure that nutrient application timings match with events in the growth cycle of your trees (rather than months of the year). Until more specific research is conducted, growers in tropical and subtropical growing regions growers need to be more conservative with nitrogen rates especially around the time of flowering and the first fruit shedding event.

Timing of other nutrients

The 'little and often' approach for all nutrients is supported by research and has gained traction in different parts of the avocado growing world but there are times in the growth cycle that are particularly important for particular nutrients. A study of nutrient accumulation in developing fruit suggests that the latter stages of fruit growth require more potassium than the early stages so applications need to take this into account. Potential competition between calcium and potassium at the root absorption sites on the feeder roots also indicate that potassium applications should be withheld until mid-summer when calcium applications are over. According to nutrient accumulation patterns in developing fruit phosphorus, magnesium, sulphur, iron and zinc should be applied at least during the spring growing season after full bloom.

- Ensure there is a readily available supply of soluble calcium in the soil for the first six to eight weeks after fruitset and make especially sure that soil moisture during this time is optimum to enable uptake.
- Do not applying calcium and potassium fertiliser at the same time.
- If potassium is required apply most of it during the second half of fruit growth
- Where needed phosphorus, magnesium, sulphur, iron and zinc should be applied at least during the spring growing season after full bloom.

Calcium

Gypsum is the most effective product to increase soil calcium but it has the potential to displace potassium and magnesium from exchange sites in the soil

- If applying gypsum on a regular basis, monitor soil magnesium and potassium levels and correct with applications if necessary.

Potassium

It is highly likely that some growers are applying too much potassium and this may be having a negative effect on calcium and magnesium nutrition as well as yield and quality.

- If soil and leaf potassium levels are within the optimum range then it may not be necessary to apply any (very sandy soils may be an exception) but continue to monitor levels and if there is a major leaching event conduct a soil test to check whether there is still adequate potassium available in the soil.
- Never use potassium chloride (muriate of potash) or any other chloride based fertiliser.
- Be aware that most compound fertilisers contain potassium so avoid them if soil and leaf levels are adequate.

Phosphorus

In certain soils such as clays and red krasnozems phosphorus is tied up in the soil and it is recommended that phosphorus fertiliser is applied in a concentrated band along the drip line and applied on a relatively regular basis to compensate for the phosphorus that is tied up. However on other soil types it is possible that too much phosphorus is being applied. Crowley *et al* (2015) found in California that as leaf phosphorus increases above 0.2% there are no high yielding trees, illustrating the potential for over-fertilisation or nutrient imbalance that can cause yield loss. Deficient levels of leaf phosphorus are very rare. If soil and leaf levels are adequate it may not be necessary to apply this element since excessive levels can create imbalances and tie up trace elements such as iron and zinc.

- If soil and leaf phosphorus levels are within the optimum range don't apply it (an exception may be soils such as clays where phosphorus can be tied up and be relatively unavailable) but continue to monitor levels regularly.
- Be aware that most compound fertilisers contain phosphorus so avoid them if soil and leaf levels are adequate.
- Where phosphorus fixation in the soil is a problem apply it in a narrow band along the drip line.
- In areas (such as on Mallee soils in the Tristate) where it can be a challenge to get sufficient phosphorus into the tree, experiment with foliar applied potassium phosphite at the cauliflower bud stage of flowering.

Boron

This nutrient needs to be managed very carefully. It is extremely important for avocado and is required in relatively large amounts (for a trace element) and for this reason soil application is the main method of satisfying requirements. However the optimum range between deficiency and toxicity is a narrow one. Applying too much (especially in light soils) will cause toxicity with serious consequences to fruit and foliage whilst deficiency will impact significantly on fruitset, yield and quality. It is very easy to reach toxicity on light soils, clays are more forgiving.

Several studies have been conducted around the world on the use of foliar sprays of boron at flowering. The need, timing and specifications of these sprays are now much clearer. It is important to note that it is not always appropriate to apply a foliar spray of boron.

Research in Mexico showed that in boron deficient orchards a spray at early fruitset followed by another a month later may increase yield and fruit size.

- It is very important to note that there is a different optimum soil boron range for each of five different soil textures. What might be adequate for a light soil is likely to be deficient for a clay soil for example. This is often the cause of error by nutrition laboratories when they judge whether a particular soil level is excessive, adequate or deficient.
- Split the annual boron dose into as many small applications as possible throughout the year whenever growth is occurring (this includes root growth).
- Boron is easily leached from the soil so rates should be adjusted to compensate for losses after major rain events.
- If the autumn boron leaf level was deficient (below 30ppm) apply one application of Solubor® at 1 g/L at the cauliflower stage of flower bud development. Do not add other nutrients to the spray and do not apply more than one application. It has been found that addition of urea to foliar boron sprays can cause deformation of the flower.
- Do not apply a foliar boron spray if the leaf level is adequate as there is evidence that elevating the boron level higher can be counterproductive.
- If a foliar boron spray at the cauliflower stage was recommended but missed there may be some benefit in applying two later ones, one at fruitset and another a month later.

- View the 'Getting boron right' video on the Best Practice Resource, use the associated 'Boron application rate worksheet' and seek expert advice.

Silicon

Research with silicon over the past 10 years or so has delivered inconsistent results but recent experiments are suggesting that what might be important is to have a constant supply of soluble silicon available in the soil. This could be supplied by a slow release product. Potential benefits are improved tree health and better quality fruit.

- Experiment with slow release forms of soluble silicon so that it is available throughout the year and compare fruit quality and tree health with an untreated section of orchard.

Molybdenum

Growth responses have been recorded in avocado from the addition of molybdenum but negative responses have also resulted from levels that were too high. A deficiency is more likely to occur in highly leached, very acid soils that are low in organic matter and/or have high levels of manganese and/or sulphate. This combination of soil properties exists in some of the avocado growing regions on the east coast of Australia (e.g. volcanic krasnozem soils with inherently high manganese levels). This essential trace element is required in particularly small amounts and it would be easy to correct with foliar (it is very phloem-mobile) or soil applications. Care should be taken to apply only a small amount to avoid potential toxicity.

- Where soils are very acid, highly leached, and low in organic matter but have high levels of manganese and sulphates, experiment with a low dose of sodium molybdate as a ground or foliar spray and compare tree health and yield with an untreated section of orchard.
- Only apply a very low dose.

Foliar applied nutrients

Foliar boron and molybdenum sprays are covered above.

Application of nutrients by means of foliar sprays should <u>not</u> be regarded as standard practice in avocado because the waxy leaf does not lend itself to absorption. In addition, if a foliar applied nutrient is absorbed by the plant it also needs to be phloem-mobile in order to be transported to where it is needed, for example in a trial where boron was sponged onto one half of a leaf it did not raise the boron level in the other half.

However there are situations where nutrient is absorbed and reaches parts of the plant in sufficient quantity to make a difference. This can be useful when circumstances such as cold spring soil temperatures, unsuitable soil pH, nutrient tie-ups and saline soils prevent soil applied nutrients being available to the plant at critical times.

Where soil phosphorus levels are very low and it is difficult to raise plant P levels, e.g. on the Mallee soils of the Tristate, foliar sprays of potassium phosphite at the cauliflower stage of flowering or during fruit development may be worth trying as they have resulted in yield and fruit size benefits in California and Mexico.

Mixed success has been reported from zinc foliar sprays (e.g. with zinc chelate) compared with the consistent results achieved by soil applications of zinc sulphate provided adequate rates are used.

- When circumstances such as cold spring soil temperatures, unsuitable soil pH, nutrient tie-ups and saline soils prevent soil applied nutrients being available to the plant at critical times

foliar sprays of phosphorus, zinc and iron sprays can experimented with using products such as potassium phosphite, zinc chelate EDTA and iron chelate.
- Apply when leaf flush is about 2/3 expanded, not older.
- Experiment with potassium phosphite sprays where it is difficult to raise plant phosphorus levels. Always leave an untreated section for comparison.

Rootstock

Research has shown that rootstocks can have a significant effect on yield and fruit quality. 'Hass' grafted onto certain Guatemalan and West Indian race rootstocks (e.g. 'A10' and 'Velvick') produce fruit that is higher in calcium and this is associated with lower levels of flesh rots, this is in contrast to 'Hass' grafted onto Mexican race rootstocks which produces fruit with lower calcium levels and a higher incidence of flesh rots such as anthracnose and stem end rot.

- Make every effort to use well proven rootstocks that are predominantly Guatemalan and/or West Indian race such as 'Velvick', 'Dusa®', 'A10', 'Plowman' and 'Kidd'. If possible avoid Mexican race rootstocks such as 'Zutano', 'Mexicola' and 'Duke 7' which are more susceptible to both *Phytophthora cinnamomi* root rot and body rots, the latter linked to low fruit calcium levels in trees.

Mycorrhizae

There may be merit in introducing appropriate species of mycorrhizae to the potting mix or orchard planting site to improve avocado root uptake of elements including phosphorus, iron, copper and zinc although research has shown that if the phosphorus content of the growing medium is increased the mycorrhizal activity diminishes. It is worthy of further research as mycorrhizae could have other benefits including better moisture uptake.

- Experiment with mycorrhizae species that are known to be beneficial to avocado and compare tree health and yield with an untreated section of orchard.

Raising soil organic matter levels

Good mulching and composting practices can result in huge improvements to tree health and nutritional status however it is important to know what the material contains. For compost and other organic amendments ask for an analysis or have a sample analysed yourself before buying and using. Feedlot and chicken manure can contain high levels of chloride, some municipal waste products can contain heavy metals and chicken manure has high levels of phosphorus which could be counterproductive in your situation. Mulch material can add significant amounts of potassium to the soil based on the large volumes applied.

An increasing number of Australian growers are starting to recognise the benefits of higher organic matter levels in the soil. Not only do they increase the amount of nutrients that the soil can hold but they also reduce nutrient leaching, make nutrients more available to the tree and improve the moisture holding capacity and soil health in general. The simplest and surest way to achieve this is to add mulch and/or compost on a regular basis. The rate at which soil organic matter will rise is slow, taking several years for significant improvements to be achieved but the benefits are evident in the health of the trees and their productivity.

The regular use of good quality compost has a greater positive effect on soil health than mulch and its effect can be transformational for the orchard, relieving soil compaction and raising levels of organic activity in the soil with associated benefits including greater suppression of soil pathogens including *Phytophthora cinnamomi*.

- Wherever possible mulch trees regularly, and/or regularly apply good quality compost under trees.
- Check the analysis of any compost or manure for any problems before using it.
- Include the nutrient content of mulch and compost in the annual nutrition budget but also allow for the fact that these nutrients may only be released slowly.

5. SUGGESTED TOPICS FOR NUTRITION RESEARCH

1. Development of additional or better nutrition monitoring tools:
    - Investigate whether the new optimum leaf nutrient ranges and ratios established in California are applicable to Australia.
    - Back research to develop the analysis and interpretation of nutrient levels using the cauliflower stage of flower buds as a monitoring tool for nutrition.
    - Consider the monitoring of nutrient levels in developing fruit as a possible monitoring tool.
    - Investigate the potential of hyperspectral analysis of the orchard canopy as a practical and effective way to monitor avocado nutrient status.
2. Investigate the specific nutritional needs of 'Shepard' and 'Hass' growing in the tropical and subtropical regions of Australia (including timing and rates of nitrogen in particular) and whether it is necessary to set a different range of optimum leaf nutrient levels for 'Shepard'.
3. Conduct any future nutrition trials on clonal plantings to avoid the variation inherent in seedling rootstocks.
4. Investigate nitrogen, calcium, magnesium and potassium together in order to:
    - Establish upper limits to nitrogen applications before fruit quality is impacted through the suppression of calcium levels in fruit.
    - Establish whether optimum levels of calcium in the soil are adequate to supply the calcium needs of fruit during their early development or whether it is necessary during this period to apply additional and/or different forms of calcium such as more soluble products.
    - Learn more about the role and crop needs of magnesium in avocado.
    - Establish whether we are over applying potassium and the effect of excessive potassium applications on yield and fruit calcium (and magnesium) levels and thus quality.
    - Establish whether we are over applying phosphorus and the effect of excessive phosphorus applications on yield.
5. Further research the benefits and practicalities of using mycorrhizae in avocado production.
6. Develop guidelines for estimating how much nitrogen is made available to trees each year as a result of mineralisation of soil organic matter.

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