LEAF MINERAL NORMS OF 'HASS' AVOCADO TREES FROM THE WESTERN BAY OF PLENTY OF NEW ZEALAND

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ABSTRACT

The correct fertilisation of avocado trees is a key management activity requiring monitoring of tree nutrient levels. To determine if a fertiliser programme is meeting the needs of the trees a sample of leaves is usually analysed for mineral content. When interpreting leaf test results it is important to identify if the concentrations of individual minerals in the leaves are excessive or deficient so that corrective action can be taken. Presenting this information in an easy to understand format would be helpful to avocado growers to see how their fertiliser programme is working. A survey of orchards comparing yields from the AIC database to leaf test results from Hill Laboratories has been combined to calculate leaf target levels across different yield classes. The range of mineral values was similar across the different yield classes. Regression analysis showed that as yield increased so did the average amount of calcium, magnesium, sulphur and zinc while potassium levels decreased. Boron only tended to increase with yield class. There was little difference in the mineral content of leaves between trees with and without fruit. Compared to leaf target levels in other countries the New Zealand 'Hass' leaf targets calculated here for zinc and boron are low while other minerals are within the normal range of leaf values reported overseas. Leaf boron levels appeared to be very low and were just above deficient levels. The leaf nitrogen levels tended to be high compared to other countries. Presenting leaf test results using a bar chart based on indices of the average and variation around the average was easy to read and interpret. The best use of leaf test results is to determine if the targets are met for the crop in the current year as leaf test results were poorly related to the yield in the following year. The target values for 95% of trees meeting leaf target levels were closely aligned to the leaf target values published in other countries. The 95% leaf target levels could be considered the best target values to ensure good cropping levels.

Keywords: *leaf tests, fertiliser, indices, yield*

INTRODUCTION

In recent years many Hass avocado trees in the main growing region of the Western Bay of Plenty, have exhibited alternate bearing. In the 'off' crop year when the amount of fruit is low and orchard income reduced many New Zealand avocado growers greatly lower their fertiliser inputs to save money and as an attempt to avoid excessive vigour in the trees. In addition to low crops the value of the fruit can be poor in years in the 'on' crop year due to oversupply of fruit. Many avocado growers are reluctant to spend money on fertiliser if the prices for fruit are low. However, achieving consistent high yields is the goal of every avocado grower in New Zealand. The correct fertilisation of avocado trees is a key management activity often requiring monitoring of tree and soil nutrients. To calculate the correct amount of fertiliser to apply to trees necessitates that the current nutrient status of the tree be accurately determined and matched to ideal levels of nutrients needed for a good crop. To determine if a fertiliser programme is meeting the needs of the trees and that fertiliser is not being over or under applied it is useful to take a sample of leaves for analysis of mineral content. The results of a leaf test are then used by specialist nutrition advisers as a guide to the most appropriate fertiliser programme for the trees within an orchard along with a consideration for the crop load on the trees, the condition of the trees with respect to nutrient deficiencies, soil type and climate. The sampling of leaves uses a carefully prescribed methodology (Abercrombie, 2001; Cutting and Barber, 2001; Vock, 2001) for collecting leaves that gives highly reproducible results. A consistent sampling method and standard chemical analytical methods are very important so that leaf test values can be compared from year to year and be used as a guide to establish a fertiliser programme.

The database from which leaf target levels derived for Hass avocados in New Zealand published in the New Zealand Avocado Growers' Manual is not known. It is probable that the values were calculated from a small database of soil and leaf tests in comparison to yields. The exact number of orchards and the number of years over which leaf tests and yield were collected remain undefined. A comparison of the leaf target levels with leaf target levels from Australia, Mexico and Israel indicate that target nitrogen and zinc levels in the Growers' Manual as described are higher than in other countries (Table 1). Conversely, target potassium and sulphur levels are lower than in other countries (Table 1). Confirming that the values published in the Growers' Manual are reasonable would be helpful to ensure that New Zealand avocado growers are given the most suitable mineral leaf target levels under New Zealand conditions. The leaf target levels in Table 1 are average values for orchards or block of trees around which there is a range above or below the average that are acceptable mineral levels in the leaves. When interpreting leaf test results it is important to identify if the concentrations of individual minerals in the leaves are excessive or deficient so that corrective action can be taken. The normal range of minerals can be calculated using the variability around the average. Deficient or excessive levels of minerals can be considered to be outside the normal range when the values are more than two standard deviations above or below the average. These values represent the top and bottom 5% of the mineral values for a particular yield in the data set. Presenting this information in an easy to understand format would be helpful to avocado growers to see how their fertiliser programme is working. In Mexico leaf mineral values are presented as indices in a bar chart using the co-efficient of variation to calculate a normal range for each individual mineral and also where the mineral would be deficient or in excess (Salazar-Garcia, 2002). Graphs of indices for leaf tests and yields will be assessed for their ability to convey useful information to the reader.

On many horticultural crops determining the correct leaf target levels is usually done by extensive field trials where nutrients are withheld to induce deficiency symptoms. The relationship between yield and deficiency is then used to establish the mineral content that no longer limits yield. Worldwide there have been trials on avocados in the USA, Israel, Australia and South

Table 1. Hass leaf target levels from various sources

Mineral	NZ Grower Manual	Agrilink Australia[2]	Avocado Book[3]			Mexico[4]
			Deficient	Range	Excess	
N%	2.5-2.9	2.2-2.6	1.6	1.6-2.8	3.0	2.2-2.6
P%	0.16-0.22	0.08-0.25	0.14	0.14-0.25	0.3	0.08-0.25
K%	1.0-1.2	0.75-2.0	0.9	0.9-2.0	3.0	0.7-2.0
Ca%	1.8-2.5	1.0-3.0	0.5	1.0-3.0	4.0	1.0-3.0
Mg%	0.5-0.7	0.25-0.8	0.15	0.25-0.8	1.0	0.25-0.8
S%	0.3-0.4	0.2-0.6	0.05	0.2-0.6	1.0	0.2-0.3
Fe ppm[1]	50-200	50-200	20-40	50-200		50-200
Mn ppm[1]	100-500	30-500	10-15	30-500	1000	30-500
Zn ppm[1]	60-100	40-80	10-20	40-80	100	30-150
B ppm[1]	40-60	40-60	10-20	40-80	100	50-100

[1]Minimum values; [2]Vock 2001, [3]The Avocado Botany, Production and Uses, [4]Salazar-Garcia 2002

Africa (Lahav and Whiley, 2002) but no published trials in New Zealand. In the absence of field trial information, which gives direct experimental evidence, a survey of orchards comparing yields to leaf test results must be used when there is no other information.

The leaf target levels in the Growers' Manual were calculated prior to the year 2000. In the past eight years the total hectares and number of orchards has increased considerably (New Zealand Avocado Growers' Association Annual Research Report 2008) allowing data from a large database on leaf test results and yields to be analysed. The Avocado Industry Council has been recording yields from all exporting orchards in a database since 2000. The greater number of orchards test results has meant that there is a sufficiently large data set of leaf test results from individual orchards across several years that can be matched to the industry yield data set. There is also data from a research trial on mulching where individual tree yields were collected along with leaf mineral values for groups of five trees. Leaf test results and the AIC yield data set have been combined to calculate average leaf target levels for specific yield classes. The values obtained have been used as standards for interpretation of leaf mineral content changes effect on yields. Such an analysis will calculate average leaf target levels for particular yield classes. These leaf target values will then be used as standards in calculating indices to relate leaf mineral content to tree yields.

MATERIALS AND METHODS

Data on leaf mineral content and orchard or tree yields were collected from a three year trial on the effect of mulch on avocado tree productivity (Dixon *et al.*, 2007), from the Avocado Industry Council database on yield and Hill Laboratories soil and leaf test database.

Leaf tests

Hass avocado leaves, free of lesions and physical damage, were collected either by avocado growers or consultants according to the Hill Laboratories protocol. The Hill Laboratories protocol utilises internationally recognised methods (Jones and Embleton, 1978; Banks, 1992) adapted to New Zealand conditions (New Zealand Avocado Growers' Association Growers' Manual, Nutrition Chapter, 2001).

The leaf test protocol for avocado orchards, in general, was: collection of the second to fourth leaf (blade plus petiole) from the terminal bud of a single shoot in April to May once the summer flush had ceased. Shoots were selected as being at shoulder height at both sunny and shaded positions that were not flushing or fruiting and boundary trees were excluded. Four to eight leaves from each of 20 trees were selected at random throughout the sampling area. Trees sampled were marked or noted so the same trees could be sampled each year. Leaf samples were for a single cultivar only.

For trees from the mulching trial, leaves were collected from seven groups of five trees on five orchards. There were a total of 35 leaf tests from 175 trees. The leaf sampling in the mulching trial used sample lots of five trees rather than from 20 trees.

Samples were analysed using internationally recognised laboratory methods (Anon) for basic plant nutrients: percentage of nitrogen (N), phosphorous (P), potassium (K), sulphur (S), calcium (Ca), magnesium (Mg) and sodium (Na); parts per million of iron (Fe), manganese (Mn), zinc (Zn), copper (Cu) and boron (B). Nutrient values were reported on a dry weight basis. Sodium levels in the samples were very low (0.0 to 0.01%) and copper levels in leaves can be strongly influenced by the use of copper based fungicides. Therefore these two minerals were excluded from the analysis.

Yield

Industry database

Yield in tonnes per hectare were calculated from the Avocado Industry Council database. Each harvest season the amount of fruit packed by a registered packhouse for each individual orchard exporting fruit is reported as export trays and kilograms of local market and processing fruit. These figures were converted to tonnes and divided by the orchard area, in hectares, declared on registration forms.

Mulching trial

For each individual tree the number of fruit and the mass of each individual fruit at harvest were recorded each year of the project. There were no statistical differences in the yield from trees in the different mulch treatments (Dixon *et al.*, 2007). The yield for each group of five trees was averaged across the trees and the equivalent per hectare yield, based on 184 trees per hectare spaced at 7m x 7m, calculated.

Data analysis

The yields and leaf test results each year from 2003 to 2006 were used in the analysis. The orchards used in the analysis were all located in the Bay of Plenty region of New Zealand. The number of orchards used in the analysis each year was: 151 in 2003, 183 in 2004, 195 in 2005 and 157 in 2006. In total the orchards represented 688 ha. When there was a leaf test but no yield reported for an individual orchard the yield was assumed to be zero for that year if a crop was reported in the following year. This represented those orchards where the trees exhibited severe alternate bearing. In the analysis all leaf tests were allocated a yield class. If a yield class could not be assigned to the leaf test the leaf test was excluded from the analysis. For analysis of both sets of data, yields were classified into yield classes of 5 tonnes/ha intervals. The yield classes were: 0 = no yield, 1 = >0-5 t/ha, 2 = >5-10 t/ha, 3 = >10-15 t/ha, 4= >15-20 t/ha, 5 = >20-25 t/ha, 6 = >25-30 t/ha and 7 = 30+ t/ha.

The target level for each mineral was calculated as the average value of the mineral for each yield class. The coefficient of variation (CV) for the target value was calculated as the percentage of the mean represented by the standard deviation. The smaller the CV the less the values for a particular mineral were different from one another. A large CV indicates a large range of values for a mineral.

To relate leaf test values to target levels an indice for each mineral was calculated according to the following formula (Salazar-Garcia, 2002):

If sample > than target level p = sample/target*100, i = (100-p)*(CV/100), indice = p+i.

If sample < than target level p = sample/target*100, i = (p-100)*(CV/100), indice = p-i.

For comparative purposes the indices are presented in a bar graph format against expected variability ranges determined by each minerals CV. Mineral content was considered to be deficient (too little on the graph) at two standard deviations below the target value and excessive (too much on the graph) at two standard deviations above the target value.

Calculations of averages and other statistical values was made using Microsoft® Office Excel® 2007. The graphs were produced using Microcal™ Origin® version 6.0. The relationship between average mineral values and yield class was calculated using MINITAB 13.31. The leaf mineral values presented in the Tables 3 to 6 have been rounded to the nearest 0.1% for N, K, S, Ca, and Mg and the nearest whole number for Fe, Mn, Zn and B. Values for P have been rounded to the nearest 0.01%.

RESULTS

Relationship of leaf mineral content with yields in the same calendar year.

The range of mineral values was similar across the different yield classes (Table 2). The following trends were identified across the yield classes. At high yields of 20+ t/ha the low end of the range of potassium decreases while the upper end of the range increases for zinc and boron. For calcium and magnesium the upper end of the range increased up to 15 t/ha then was about the same. The low end of the range for boron values were in the mid to high 20's.

Regression analysis of yield class against average leaf mineral content revealed that as yield increased so did the average amount of calcium (r^2 = 0.5635, p = 0.032), magnesium (r^2 = 0.6904, p = 0.011), sulphur (r^2 = 0.7988, p = 0.003) and zinc (r^2 = 0.514, p = 0.045) (Figure 1). The increase in minerals was well described by a linear function. The boron content of leaves tended to increase with yield class (r^2 = 0.461, p = 0.064) while average leaf potassium levels decreased with increasing yield class (r^2 = 0.7578, p = 0.005). Average leaf nitrogen and iron levels showed a trend to be increasing at the highest yield classes. Phosphorous and manganese levels were similar at all yield classes.

Values from orchards and the trees from the Mulching trial carrying a 10-15 t/ha or 20-25 t/ha crops had average leaf mineral contents that, apart from nitrogen, were lower than those presented in the Growers' Manual (Tables 1, 3 and 4). The leaf target levels in the Growers' Manual more closely matched the leaf mineral values two standard deviations from the average where 19 out of 20 trees would be expected to have or exceed the average leaf mineral content shown in Tables 3 and 4. The recommended target leaf nitrogen levels in the Growers' Manual are close to the average leaf values and are between 0.4 to 0.6% lower than the two standard deviations above the average calculated here. By using a leaf target level two standard deviations above the average there will be only a small number of trees under fertilised as compared to half the trees when using an average as a target. This is illustrated in Figure 2 using data from the Mulching trial.

The average leaf mineral content of orchards that cropped each year compared to orchards that had no crop was greater in calcium, magnesium, sulphur, manganese and zinc and had lower phosphorous and boron while nitrogen, potassium and iron were similar (Table 5).

Table 2. Range of leaf mineral values (average plus or minus one standard deviation) of 'Hass' avocado trees with different yields taken from leaf tests in the same year as the harvest.

	Yield class (t/ha)						
Element	0-5	5-10	10-15	15-20	20-25	25-30	>30
N%	2.5-2.6	2.4-2.6	2.4-2.7	2.4-2.7	2.4-2.6	2.4-2.7	2.2-2.8
P%	0.15-0.16	0.14-0.16	0.14-0.16	0.14-0.16	0.13-0.16	0.15-0.18	0.13-0.16
K%	1.0-1.1	1.0-1.1	1.0-1.1	1.0-1.1	0.9-1.2	0.9-1.1	0.9-1.1
Ca%	1.3-1.4	1.3-1.5	1.4-1.6	1.3-1.7	1.2-1.8	1.6-1.7	1.1-1.7
Mg%	0.34-0.38	0.35-0.41	0.38-0.43	0.38-0.44	0.35-0.44	0.41-0.48	0.30-0.48
S%	0.24-0.27	0.24-0.27	0.26-0.29	0.25-0.28	0.22-0.31	0.25-0.28	0.21-0.29
Fe ppm	48-69	50-65	54-68	51-57	44-99	52-71	54-74
Mn ppm	146-192	140-237	117-234	127-196	124-233	120-192	73-186
Zn ppm	33-39	31-43	35-48	35-43	35-68	37-53	34-53
B ppm	29-33	25-35	30-39	26-42	21-44	28-39	29-49

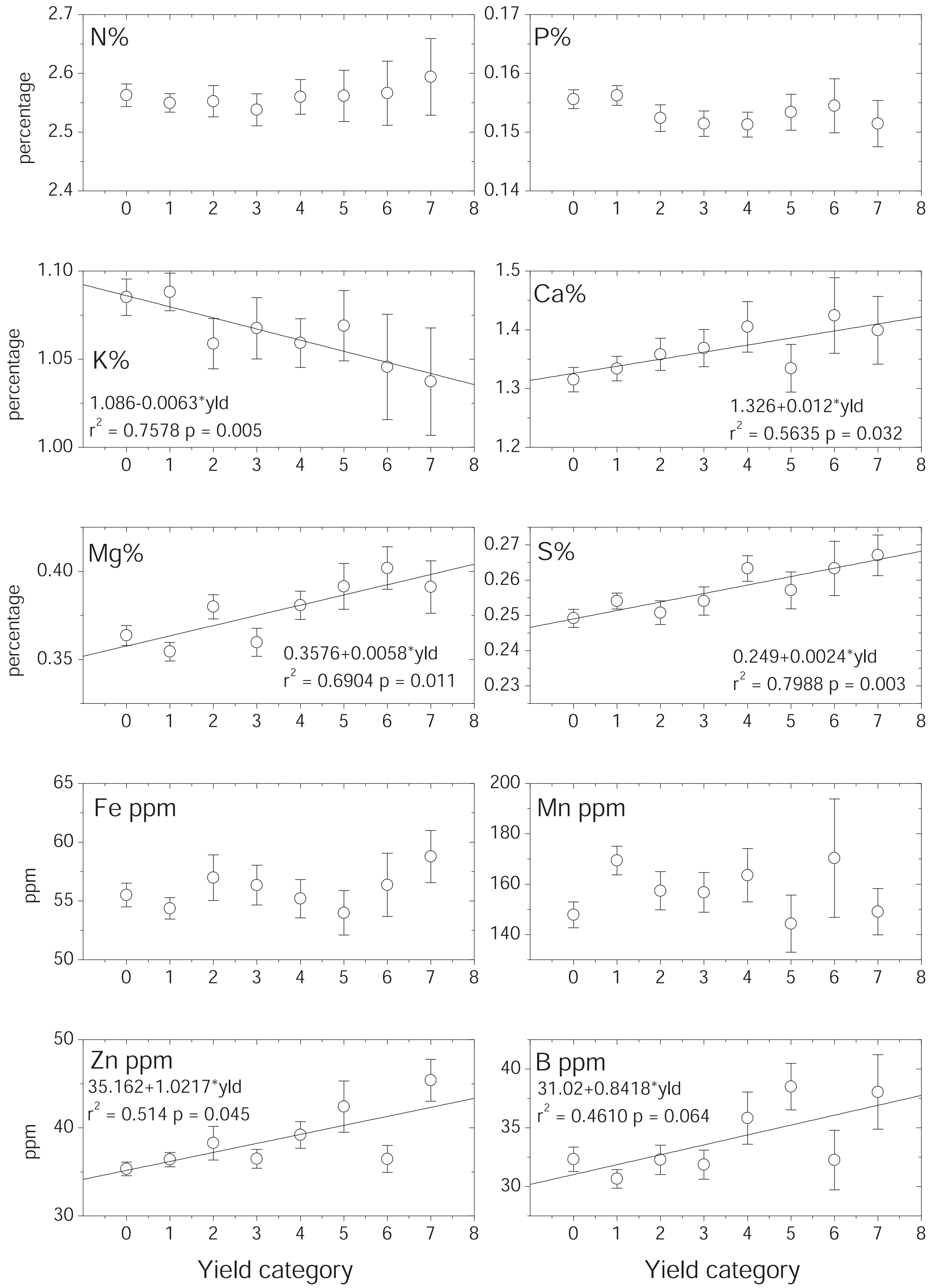

Figure 1. Average leaf levels of selected macro and micro nutrients across 5 tonne/ha yield categories for 'Hass' avocado trees for the years 2003 to 2006. Leaf samples were collected in April/May each year. The vertical bars represent the standard error of the mean.

Table 3. Calculated average 'Hass' leaf target levels from the Mulching trial and Orchards for a 10-15 t/ha crop on mature trees for leaf tests taken in the same year as the harvest.

	Mulching trial			Orchards		
Mineral	50% of trees target	CV	95% of trees target	50% of trees target	CV	95% of trees target
N%	2.8	7.5	3.2	2.6	9.6	3.1
P%	0.16	9.6	0.2	0.15	13.6	0.2
K%	1.0	10.1	1.2	1.1	13.6	1.3
Ca%	1.4	24.1	2.0	1.5	18.6	2.0
Mg%	0.4	19.3	0.5	0.4	16.1	0.5
S%	0.3	16.8	0.3	0.3	13.0	0.3
Fe ppm	56	19.8	78	59	26.9	90
Mn ppm	148	24.8	221	158	49.4	315
Zn ppm	32	18.7	44	39	31.1	63
B ppm	27	17.4	36	34	39.2	61

Table 4. Calculated average 'Hass' leaf target levels from the Mulching trial and Orchards for a 20-25 t/ha crop on mature trees, for leaf tests taken in the same year as the harvest.

	Mulching trial			Orchards		
Mineral	50% of trees target	CV	95% of trees target	50% of trees target	CV	95% of trees target
N%	2.6	8.9	3.1	2.5	9.6	3.0
P%	0.16	10.7	0.2	0.15	28.4	0.2
K%	1.1	8.9	1.3	1.0	16.9	1.3
Ca%	1.6	12.8	2.0	1.6	16.1	2.1
Mg%	0.5	9.1	0.6	0.4	16.1	0.5
S%	0.3	10.8	0.4	0.3	12.9	0.4
Fe ppm	65	28.8	103	64	38.9	113
Mn ppm	171	57.1	367	168	41.3	307
Zn ppm	40	15.2	52	46	42.7	85
B ppm	44	27.5	68	36	36.7	63

Table 5. Average 'Hass' leaf mineral values from Orchards for trees that had a crop each year and for trees that had no crop for the years 2003 to 2006 from leaf tests taken in the same year as the harvest.

	Crop each year			No crop	
Mineral	50% of trees target	CV	95% of trees target	50% of trees target	CV
N%	2.6	7.0	3.0	2.6	9.8
P%	0.15	8.2	0.2	0.16	12.5
K%	1.1	8.4	1.3	1.1	13.0
Ca%	1.4	12.8	1.8	1.3	25.8
Mg%	0.4	13.9	0.5	0.3	20.6
S%	0.3	9.3	0.4	0.2	12.5
Fe ppm	56	16.4	74	55	41.6
Mn ppm	156	41.4	285	149	61.6
Zn ppm	40	19.6	56	36	36.2
B ppm	33	25.3	50	36	46.8

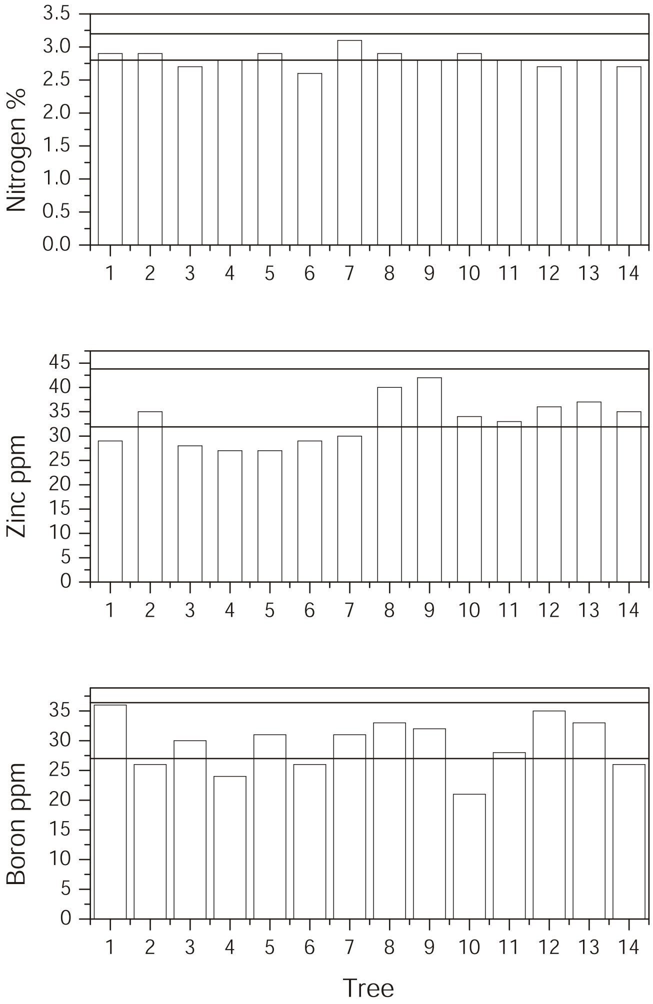

Figure 2. Leaf values from composite samples of five 'Hass' trees from two orchards, samples 1 to 7 and samples 8 to 14, respectively. The lower horizontal line in each graph represents a leaf target value from Table 3 above as an average value where only half of the samples meet leaf target levels. The top horizontal line in each graph represents the average leaf target value needed where at least 95% (19 out of 20) of the samples meet leaf target levels.

Examples of presenting leaf test results using indices

Leaf test results converted to indices using 50% of trees leaf target levels from Table 3 for the Mulching trial for two different sets of trees are presented in Figures 3 and 4. In Figure 3 the average yield for the group of five trees was low going from an average of 1 kg per tree in 2003 to 22.6 kg per tree in 2004. Comparing the leaf test results between the years showed that there were clear differences between the leaf samples. These differences were an increase in leaf nitrogen from 2003 to 2004 taking the leaves from the normal range to the above normal range. Of the other elements phosphorous and zinc, although in the normal range, were greater. Calcium, magnesium, iron and boron remained in the below normal range while manganese levels continued to be very high. Potassium and sulphur levels were unchanged.

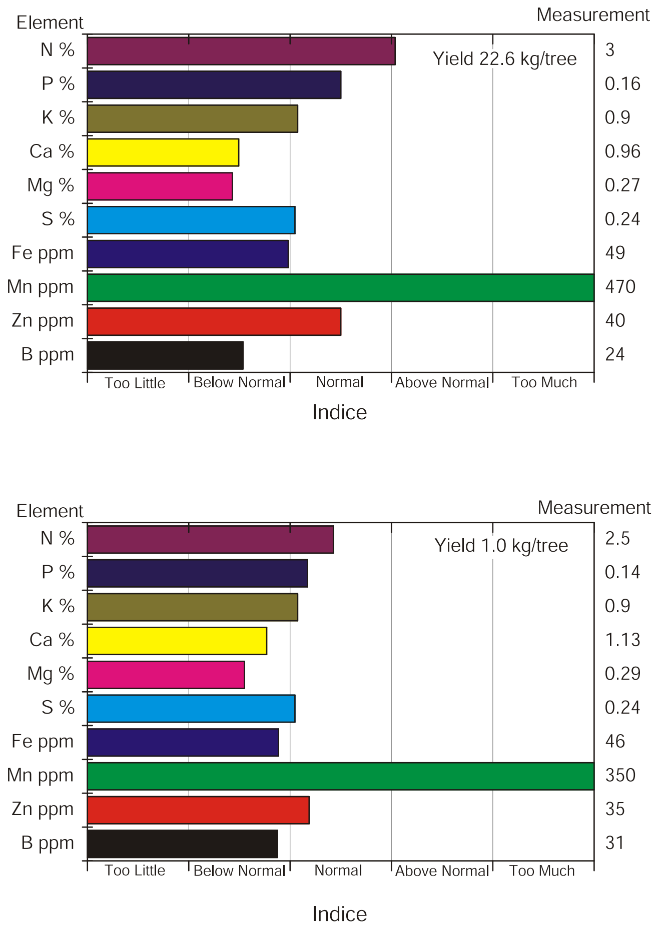

Figure 3. Indices of leaf mineral content against leaf target levels in Table 3 for five trees of the minimal mulch treatment in the mulching trial in 2003 (bottom graph), yield 1.0 kg/tree, and 2004 (top graph), yield 22.6 kg/tree.

In Figure 4 the average yield for the group of five trees was 73.9 kg/tree in 2003 and fell by 40% to 44.4 kg/tree in 2004. Comparing the leaf test results between the years showed clear differences between the leaf samples, most notably that there was a general reduction in minerals when the yield was reduced. In particular zinc levels fell from above normal to below normal and boron fell from normal to below normal. Calcium levels fell from above normal to the low end of the normal range. Iron fell from normal to the below normal range and manganese fell from too much to the above normal range. The nitrogen levels remained the same.

In Figure 5 the yield and indices calculated from Table 3 using the 50% of trees leaf target values, for the leaf test results each year from 2003 to 2006 for a single orchard are presented alongside each other for comparison. The leaf tests were taken in the same year the fruit were harvested. The yield in the years 2003, 2004 and 2006 were very poor with a very good yield in 2005. There was a clear difference in the indices for 2005 to the indices in other years. In 2005, apart from manganese, the minerals were in the normal to above normal range. In the other years some of the minerals were in the below normal range. The amounts of zinc and phosphorous were highest in 2005 compared to the other years. Although the boron levels were above normal in 2003 and too much in 2004 the yield was very low.

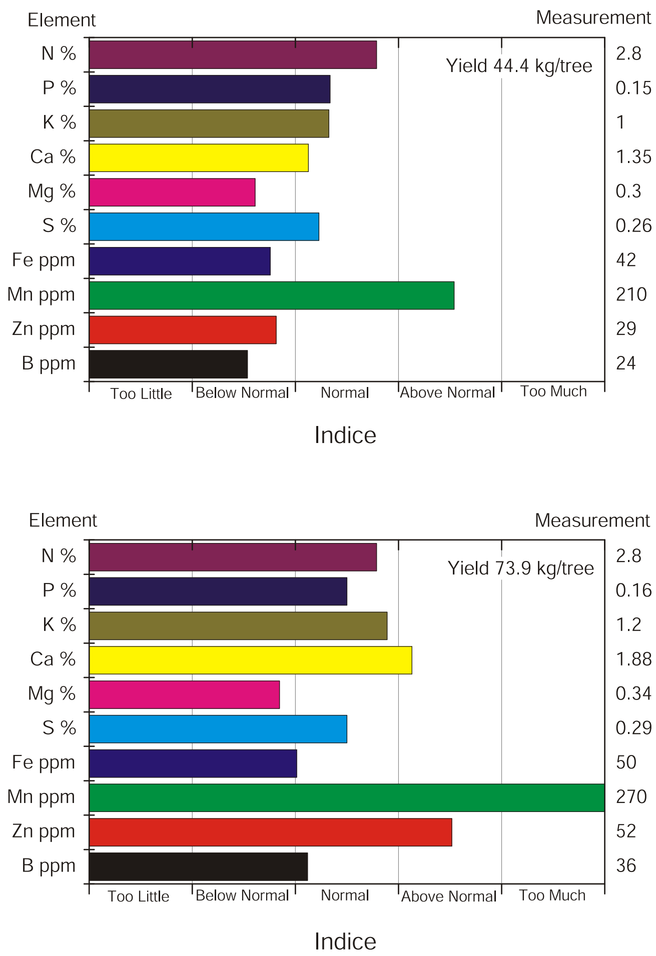

Figure 4. Indices of leaf mineral content against leaf target levels in Table 3 for five trees of the minimal mulch treatment in the mulching trial in 2003 (bottom graph), yield 73.9 kg/tree, and 2004 (top graph), yield 44.4 kg/tree.

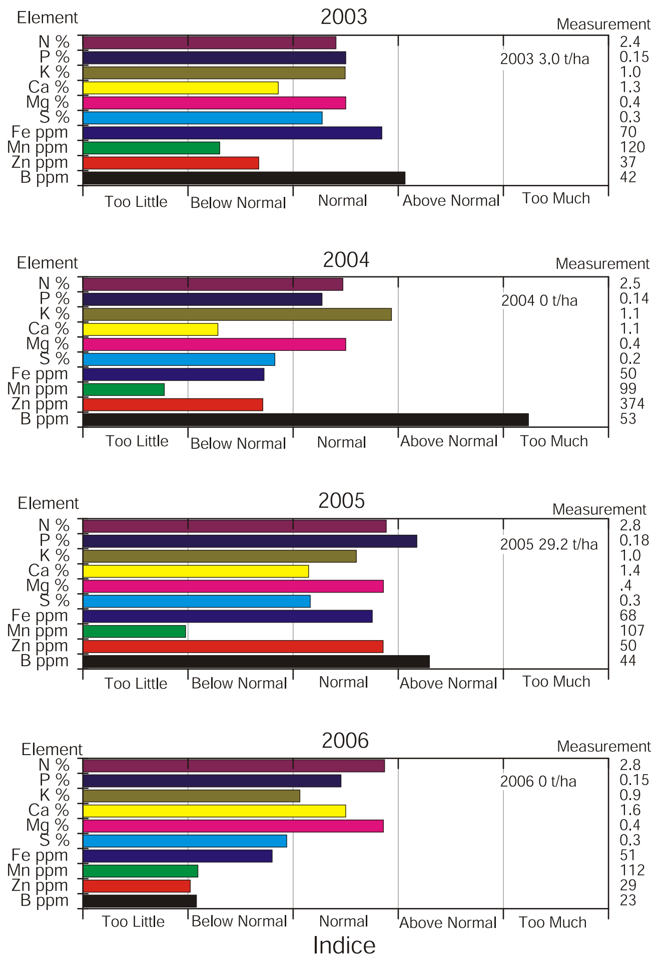

Figure 5. Leaf mineral content of 'Hass' avocado trees sampled in 2003 to 2006. Leaf target levels for calculating indices taken from Table 3 above, yields in the panels are for the same year as the leaf test for an orchard located near Katikati.

Relationship of leaf mineral content with yields in the following year

Calculating average leaf target levels using the leaf mineral values for the year preceding the harvest (Table 6) resulted in very similar leaf target values to the average leaf target values in the same year as the crop were harvested (Table 5). For a 10-15 t/ha crop an average value based on the crop in the following year the 50% of trees target levels were slightly lower for nitrogen and calcium with the other minerals either the same or the values were within 2 to 3 ppm or each other. For a 20-25 t/ha crop an average value based on the crop in the following year the 50% of trees target levels were slightly higher in nitrogen, potassium, iron and manganese with slightly lower calcium.

In Figure 6 the yield and the indices, calculated from Table 6 using the 10-15 t/ha 50% of trees leaf target values, for the leaf test results each year from 2003 to 2006, for a single orchard are presented alongside each other for comparison. The leaf tests were taken in the year before fruit were harvested. There was tendency for the years where the yields were very low, 2004 and 2006, for the indices to be, generally, higher than in the years when there was good yields, 2005 and 2007. The minerals sulphur and iron appeared to follow a pattern of being lower in the years when the yields

Figure 6. Leaf mineral content of 'Hass' avocado trees sampled in 2003 to 2006. Leaf target levels for calculating indices taken from Table 6 above, yields in the panels are for the following year for the same orchard located near Katikati in Figure 5.

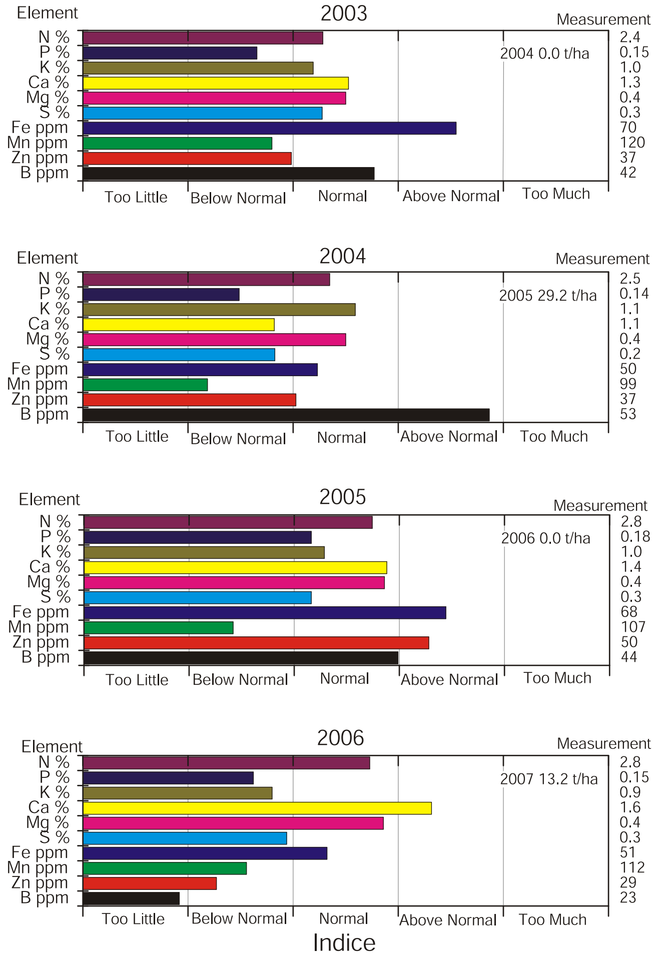

Table 6. Calculated average 'Hass' leaf target levels for selected minerals from Orchards for a 10-15 t/ha and 20-25 t/ha crop for mature trees for leaf tests taken in the year preceding the harvest, *i.e.* values from the leaf test taken in April/May 2003-2006 compared to yields in 2005-2007.

	10-15 t/ha			20-25 t/ha		
Mineral	**50% of trees target**	**CV**	**95% of trees target**	**50% of trees target**	**CV**	**95% of trees target**
N %	2.5	9.2	3.0	2.6	10.0	3.1
P %	0.15	9.0	0.19	0.15	12.0	0.19
K %	1.1	14.0	1.4	1.1	10.9	1.3
Ca %	1.4	19.7	1.9	1.3	18.5	1.8
Mg %	0.4	17.0	0.5	0.4	19.3	0.6
S %	0.3	11.3	0.4	0.3	10.3	0.4
Fe mg/kg	56	25.7	85	54	20.7	76
Mn mg/kg	157	42.6	291	144	46.5	278
Zn mg/kg	37	24.6	55	42	41.0	76
B mg/kg	32	33.1	53	39	30.0	62

were very low. There were no other patterns in the mineral contents with yield.

DISCUSSION

We report for the first time the range of mineral content of leaves from New Zealand Hass trees over a range of yields, from 5 t/ha to 30 t/ha. The Growers' Manual lists the target ranges of minerals in leaves from high performing orchards (Cutting and Barber, 2001) that is greater than those calculated in the analysis presented here. Even at the highest yield classes of over 20 t/ha the Growers' Manual values for leaf target levels start at the high end of the target ranges. The values of minerals then appear to be too high in the Growers' Manual and may seldom be achieved on New Zealand avocado orchards. Using the results of this analysis the leaf target levels could be lowered slightly and be more specifically aligned to a yield class rather than use a generic set of target values for high yielding trees for trees with low yields. The leaf target values presented here are for avocado trees grown in the Western Bay of Plenty and may not be suitable for avocado trees in other regions of New Zealand. To determine if leaf target levels may be different in Northland and other growing regions a similar study to the one reported here would be needed using leaf test results from other regions.

There were positive trends of the minerals calcium, magnesium, sulphur, zinc and boron with increasing yield class. There was a negative trend for potassium with increasing yield class. For the minerals nitrogen and iron there appeared to be a trend for an increase in leaf content when the yield class was 25 t/ha and above. Although the trends were approximated well by a linear function the magnesium and calcium levels appeared to have a decreasing trend from yield class 6 (25-30t/ha) to yield class 7 (30+ t/ha). For zinc and boron there was an unexplained dip in the average levels between yield class 5 and 6. This may have been due to a quirk in the data as there was less data at the higher yield classes than at the lower yield classes. The dip in average values at yield class 6 was not seen for the other minerals indicating that there may have been an unknown factor in those orchards. Some minerals can be relocated from leaves to other parts of the trees while others once in the leaves are fixed and not re-mobilised. The trends of increased mineral content of leaves for some minerals with increasing yield indicates that supporting a heavy fruit crop it is necessary for the leaves to accumulate a certain concentration of minerals by April/May. It is reasonable to assume that trees with heavy crops have a greater demand for minerals and more fertiliser is needed than when there is a light crop. In this study it is difficult to determine if the trend of increasing mineral content in leaves is due to application of more fertiliser or an intrinsic tree factor. Using only the yield class as the basis for setting leaf targets does not take into account important aspects of tree phenology that require certain nutrient levels for good cropping potential each year.

It was possible in this study to calculate average leaf mineral values for trees without fruit. There was little difference in the mineral content of leaves between trees with and without fruit (Table 5). Leaf test results do not appear to be useful in determining the appropriate fertiliser needs of trees when there are no fruit on the trees. A further limitation of this study was that each mineral was considered individually whereas interactions between minerals are possible and that ratios of one mineral to another could influence yield.

The leaf test values represent an average value within a range of values. In the bar charts describing individual leaf test results the values are

Table 7. Calculated values for deficiency levels of 'Hass' avocado leaf minerals

Mineral	Value	Mineral	Value
Nitrogen	1.43	Iron	32.5
Phosphorous	0.11	Manganese	96.5
Potassium	0.56	Zinc	27.8
Calcium	0.81	Boron	22.3
Magnesium	0.24		
Sulphur	0.17		

presented in relation to the average. The normal range of values is considered to be plus or minus one standard deviation and above or below normal two standard deviations from the average. Three standard deviations from the average can be used to identify deficiency or excess. Values calculated as three standard deviations from the average could then be thought of as one way to define the levels of deficiency for each mineral. The calculated deficiency levels (Table 7) are based on the values from the leaf test data set.

These values have not been established using nutrient exclusion trials so may be too low or high when trialled in an experimental system in the field. To begin identifying possible deficiency levels of New Zealand grown Hass avocados, the calculated values are a useful start. Future research could examine if the deficiency levels reported here have an effect on the yields of the avocado trees. Compared to leaf target levels in other countries (compare Table 1 to Table 2), New Zealand Hass leaf targets for zinc and boron are low. The other minerals sit within the normal range of leaf values found overseas. Leaf boron levels in New Zealand trees appear to be very low but are not quite at what could be considered deficient levels. It would be worth investigating if these low zinc and boron levels can have a negative effect on yields.

The leaf target levels are reported in two ways, as the average for the yield class (50% of the trees meet or exceed the target) or where 95% of the trees meet or exceed the target. For a high performing orchard all the trees need to receive good nutrition. Within an orchard individual trees often carry different amounts of fruit. This implies that the fertiliser needs of the individual trees will be greater or less than the average. With leaf mineral targets based on the average of all trees half of the trees will not be getting enough fertiliser in relation to their crop load. For almost all of the trees to have good nutrition the trees can be either fertilised individually for their specific crop load or the leaf targets be based on a greater percentage of the trees meeting or exceeding the target levels. The approach here has been to calculate leaf target values that are two standard deviations above the average on the assumption that the trees crop load is a normal distribution. This results in a leaf target level that will meet 19 out of 20 trees (95%) needs. Apart from nitrogen levels, the target values for 95% of trees meeting leaf target levels are more closely aligned to the leaf target values published in other countries. It is possible that the leaf target values reported overseas are not based on averages but on the levels needed to be sure that almost all trees in the orchard are well fertilised. The 95% leaf target levels would therefore be the most suitable values that should be met in the tree to ensure good cropping levels.

When leaf test results are presented to avocado growers it is useful to have the values compared to target levels so that the grower can see if their fertiliser programme is meeting the needs of the trees. It is also useful to see the leaf test results in the context of the range of expected mineral values as the target values are not absolute markers of the correct mineral content. This is due to interactions between minerals and other components of the tree that may be limiting yield. Therefore a lower value of one mineral may be counteracted by the value of another mineral being higher or lower. Each mineral is present in the leaves at a different range of concentrations and variability and needs to be considered separately. Displaying the leaf test result against the range of values that show if the minerals are around the target level or are acceptably close enough above or below target values could be a good aid in interpreting the mineral status of the tree. The bar chart using indices for showing the results of the leaf test is relatively easy to read and interpret and can when used for different years or crop load identify differences in the leaf mineral content. Interpreting the meaning of the changes in terms of the effect on tree growth, crop load, interactions between minerals and the fertiliser needs of the trees remains the domain of a specialist nutrition advisor.

The coefficient of variation when used to establish the ranges normal, below normal, above normal, too much and too little in the absence of experimental data was a reasonable estimate of where leaf mineral values had an effect on the tree. When using survey data, as in this study, statistical calculations are necessary to define potential limits when setting standard values. The values identified here could be used as the starting points for nutrition trials to better define the fertiliser needs of avocado trees. Following this analysis, field trials based on the leaf mineral targets reported here, could be conducted to confirm the suitability of the targets to achieve high yields.

Ensuring that the leaves contain enough nutrients is the reason why the leaf test is considered of prime importance when determining fertiliser needs. The assumption is that the leaves are a good indicator of the pool of mineral reserves that can be drawn down by the tree as needed. Therefore when the demand for minerals is high when there is a big crop there should be greater amounts of minerals in the leaves. This then forms the logical basis for using the leaf test result as a guide for the fertiliser needed to meet the trees estimated fruit load. The leaf test is then not used as a predictive tool but as a check on the trees potential to meet its nutrition needs. In other words, the fertiliser programme is geared to supporting the current crop on the tree rather than targeting a particular yield in the future. Using leaf test results to establish if the nutrition level of trees is sufficient appears to be the best use of leaf tests. Leaf test results were poorly related to the yield in the following year when using the indices method of examining changes in leaf minerals from year to year. Leaf target values calculated for the future cropping potential of the trees were very similar to the leaf target values calculated using the yields in the same calendar year suggesting that the leaf mineral levels need to be at specific levels relevant to the crop being carried by the tree. Based on the graphs of the indices high yielding trees also have their leaf mineral content close to or in the above normal range. These are the levels of minerals needed to be present by April/May so that the estimated crop will be realised. This method of utilising leaf test results when considering the crop load on the tree runs the risk of not taking into account the need to support key phenological stages such as flower induction/initiation or to promote shoot growth when needed. Therefore the leaf target levels calculated using the yield of the trees should only be one item to consider when designing a fertiliser programme. The values reported here for leaf target levels have been calculated using the best information available and could be regarded as setting the baseline for Hass avocado trees in the Western Bay of Plenty.

CONCLUSIONS

Leaf target levels for individual minerals have been calculated for different yield classes. To ensure most of the trees (95%) on an orchard have adequate fertiliser leaf targets based on the average plus two standard deviations from the mean could be used. Presenting leaf test results on a graph categorising values against an average and the variability around the average could make it easier for avocado growers to interpret their leaf tests.

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REFERENCES

Abercrombie, R.A. (2001). Fertilization. In: *The Cultivation of Avocado* (E.A. de Villiers Ed.). Institute for Tropical and Subtropical Crops pp. 183-191.

Anon. Hill Laboratories Crop Guide Avocado. www.hill-laboratories.com/file/fileid/15805

Banks, A. (1992). Growing avocados in Queensland. Department of Primary Industries, Brisbane.

Cutting, J.G.M. and Barber, R. (2001). Avocado Nutrition. In: *New Zealand Avocado Growers' Association Growers' Manual* (J.G.M. Cutting and J. Dixon Eds.) Third Edition December 2001. ISBN 0-473-07071-5.

Dixon, J., Elmlsy, T.A., Fields, F.P., Smith, D.B., Mandemaker, A.J., Greenwood, A.C. and Pak, H.A. (2007). What, when, where and how much mulch should be applied to 'Hass' avocado trees in the Western Bay of Plenty. *New Zealand Avocado Growers' Association Annual Research Report* **7:** 49-72.

Jones, W.W. and Embleton, T.W. (1978). Leaf analysis as a guide to avocado fertilisation. In:*Soil and Plant-Tissue Testing in California* (Reinsenauer, H.M. Ed.). Division of Agricultural Science, University of California.

Lahav, E. and Whiley, A.W. (2002). Irrigation and Mineral Nutrition. In: *The Avocado Botany, Production and Uses* (A.W. Whiley, B. Schaffer and B.N. Wolstenholme Eds.). CAB International, Oxon, UK pp. 275-281. ISBN 0-85199-357-5

Salazar-Garcia, S. (2002). *Nutricion del Aguacate, Principios y Aplicaciones*. Instituto de la Potasa y el Fosforo, A.C. ISBN: 968-5512-00-0 (In Spanish).

Vock, N. (2001). Growing the Crop. Fertilising. In: *Avocado Information Kit* (N. Vock co-ordinating author). Section 3 pp. 31. ISBN 0-7242-6724-7