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Preliminary Studies on Macro-Element Utilization by Hass Avocado Trees

P J C Stassen • B P H Janse van Vuuren • S J Davie
Institute for Tropical and Subtropical Crops, Private Bag X11208, Nelspruit 1200

ABSTRACT

A lot of uncertainty exists regarding the fertilization of avocado trees. Excessive vigorous growth, relatively low yields and fruit quality problems make it essential that these aspects be re-examined.

In this article six-year-old Hass avocado trees are used to explain the need to replenish quantities of N, P, K, Ca and Mg annually. Replenishing should not however be carried out automatically, but the tree condition and soil status should be taken into account.

Aspects that have to be considered are discussed. Further research is necessary to resolve the various shortcomings which exist.

INTRODUCTION

A source of concern when visiting many avocado orchards in South Africa is the tremendous tree growth. The inherent vigour of the tree (especially certain cultivars), high potential soils on which the orchards are planted, incorrect nutritional practices, as well as growth stimulating environmental conditions and cultivation practices may all contribute to the situation.

On the other hand there is often a phosphorus deficiency in most soils. Other soil problems such as pH adjustment and calcium supplementation which should receive attention before planting are often not done with long term goals in mind.

It must always be remembered that element deficiencies as well as element excesses can limit production.

The questions are:

- Do we know what the plant requires?
- Do we know when the plant needs it?
- Does the plant use macro elements effectively or does it stimulate unwanted reactions?

The importances of specific nutrient elements for plants are often stressed (Clarkson & Hanson, 1980; Mengel & Kirkby, 1972; Smith, 1982; Devlin & Whitham, 1983; Tisdale, *et al,* 1985). The more important functions are briefly summarised.

Nitrogen (N)

This element is an integral part of proteins, amino acids, nucleic acids, auxins, chlorophyll and coenzymes.

It is mainly the tempo of protein synthesis in the plant tissue that controls the uptake of N. On the other hand N-supply stimulates protein synthesis.

N deficiencies will result in protein hydrolysis in older leaves which will lead to collapse of the chloroplasts and general yellowing of the older leaves. These symptoms along with weak growth, early senescence and suppression of cytokinin synthesis and translocation are the result of deficiencies.

An excess of N on the other hand gives dark green leaves and excessive vigorous vegetative growth (especially water shoots) of the avocado (Embleton & Jones, 1966). This will be detrimental to fruiting. Excess N application and severe pruning will stimulate strong growth.

High N levels in vineyards are associated with fruit abscission as a result of excessive growth induction (Christensen *et al.,* 1978). Excess N shortens the storage life and increases the susceptibility of pome fruit to physiological problems (Faust & Shear, 1968).

Phosphorus (P)

This element is a constituent of the energy carriers ADP and ATP. The pyrophosphate compound is rich in energy which is released by means of the compound hydrolysis. It is also part of DNA and RNA and organic phosphates (phosphorylated sugars and alcohols e.g. fructose-6-phosphate).

Deficiencies will therefore seriously harm various metabolic processes. It will especially harm root growth, bud development, and give rise to poor fruit and seed development as well as small fruit.

It is necessary to enhance the phosphate status of the soil to establish a large labile pool of available P to be on hand for plant roots. An excess of P can however induce a K-deficiency (Kotzé *et al,* 1989).

Potassium (K)

This element has an osmo-regulatory role in plants and therefore a role in plant water utilization and control. It is involved in enzyme activation for the synthesis of protein and starch. It accelerates the translocation of assimilates and is involved in stomatal movement and therefore has a role in photosynthesis and the respiration process.

Deficiencies will harm important physiological and biochemical functions. Such plants react poorly to stress situations. Fleshy fruits are rich in K and a shortage will inhibit fruit development. In avocado trees deficiencies are manifested in narrow leaves and leaves show light brown patches (Embleton & Jones, 1966).

Calcium (Ca)

This element is a constituent of cell membranes and influences their permeability. It is involved in the translocation of compounds in the conducting tissues and also in cell lengthening and division.

Deficiencies lead to reduction and weakening of meristematic tissue and can lead to various forms of deformities. In fruit there are numerous physiological problems which can be coupled to Ca deficiency (Ferguson, 1984).

Magnesium (Mg)

This is of course the central element of the chlorophyll molecule and essential for photosynthesis. The element plays a role as enzyme activator with pyrophosphate phosphorylation processes, carbohydrate metabolism and nucleic acid synthesis.

Deficiency symptoms occur in old leaves. Shortages can detrimentally influence many metabolic processes and even inhibit CO_2 assimilation.

MATERIALSAND METHODS

Three selected Hass avocado trees (stem diameter about 57cm and tree volume about 38m^3) at the Nelspruit experimental farm were excavated and divided into their constituent parts for analysis in July 1995, October 1995, February 1996 and June 1996. In 1995 the trees were all in an off-phase with between 0 and 9kg fruit per tree. The trees harvested in June 1996 gave an average yield of 35kg per tree.

The trees received the normal recommended nitrogen of 300g LAN per application during March/April, July/August and December/January. As the P-content in the soil was 39,8g kg^{-1} (resin method), no P was applied in 1996. In April 1995 250g superphophate was applied. During April, July and December respectively 250g KCL was applied. During 1996 only 150g was applied during January, April and August. Although the Ca:Mg ratio was 4, the pH (H_2O) of 5,3 was not optimal. The orchard did not receive its maintenance application of one ton of dolomitic lime ha^{-1}. Zinc oxide and Solubor at 200g per 100 litre and 100g per 100 litre respectively was sprayed in September and October of each year.

RESULTS AND DISCUSSION

The different concentrations (N, P, K, Ca and Mg) for the four analytical periods are summarised in tables 1 and 2.

From the tables it appears that the highest concentration of N occurs in the leaves and varied between 1,57% in October to 2,16% in February. It must be remembered that analyses were only carried out at four periods (July, October, February and June) and that it therefore does not necessarily imply that peak values were obtained in February. The fallen leaves had lower N concentrations. This may indicate that there is a relocation of N from the leaves to the permanent structures before leaf drop. The N concentration was 1,23% in the fruit flesh and 0,45% in the seed at harvest. In the permanent structures the N concentration was highest in the bark followed by the roots and the wood.

The highest P concentration was in the fruit flesh at harvest (0,28%) while the P concentration in the new shoots was the highest in summer (0,24%) followed by the leaves. In the permanent structures low concentrations of between 0,04 and 0,07% were found in the wood, bark and roots.

The K concentration was especially high in the fruit flesh at harvest (3,05%). In new shoots the concentration increased from 1,26% in the winter to 1,62% in the summer. The roots and wood had low concentrations of 0,30 to 0,42%.

The Ca concentration decreased in the fruit flesh from 0,31% in October to a low 0,08% at harvest. In the fallen leaves the concentration was between 1,45 and 1,67% while the concentration in the leaves on the tree was between 0,75 and 1,16%. This seems to indicate a migration of Ca to the leaves before they fall. This is in agreement with the results obtained with apples (Terblanche, 1972). In addition there were relatively high concentrations of Ca in the bark, from 0,65 to 0,68%.

Table 1
N, P and K concentrations (%) in the various parts of a six-year-old Hass avocado tree at different phenological stages

Tree parts	*N*				*P*				*K*			
	Jul	*Oct*	*Feb*	*Jun*	*Jul*	*Oct*	*Feb*	*Jun*	*Jul*	*Oct*	*Feb*	*Jun*
Roots	0,32	0,33	0,35	0,44	0,05	0,05	0,06	0,05	0,37	0,31	0,39	0,42
Bark	0,52	0,55	0,48	0,52	0,06	0,06	0,06	0,07	0,73	0,71	0,71	0,82
Wood	0,21	0,22	0,20	0,19	0,05	0,05	0,04	0,04	0,37	0,34	0,42	0,30
Shoots	0,60	0,82	0,73	0,71	0,13	0,16	0,24	0,18	1,26	1,56	1,62	1,09
Leaves	1,79	1,57	2,16	1,83	0,11	0,10	0,16	0,10	1,02	0,84	1,20	0,75
Abscised leaves	1,04	0,78	1,26	0,90	0,06	0,05	0,06	0,05	0,14	0,47	0,28	0,20
Fruit	0,00	1,60	1,16	1,23	0,00	0,19	0,22	0,28	0,00	1,88	2,20	3,05
Seed	0,00	0,00	0,57	0,45	0,00	0,00	0,16	0,14	0,00	0,00	1,16	1,01

Table 2
Ca and Mg concentrations (%) in the various parts of a 6-year-old Hass avocado tree at different phenological stages

Tree parts	*Ca*				*Mg*			
	Jul	*Oct*	*Feb*	*Jun*	*Jul*	*Oct*	*Feb*	*Jun*
Roots	0,17	0,17	0,17	0,17	0,06	0,06	0,07	0,06
Bark	0,65	0,68	0,67	0,68	0,13	0,11	0,16	0,11
Wood	0,09	0,10	0,05	0,09	0,05	0,05	0,03	0,04
Shoots	0,55	0,75	0,43	0,54	0,27	0,36	0,25	0,27
Leaves	0,91	1,16	0,75	1,09	0,56	0,58	0,52	0,54
Abscised leaves	1,54	1,67	1,45	1,60	0,55	0,58	0,55	0,59
Fruit	0,00	0,31	0,07	0,08	0,00	0,22	0,13	0,14
Seed	0,00	0,00	0,03	0,05	0,00	0,00	0,06	0,08

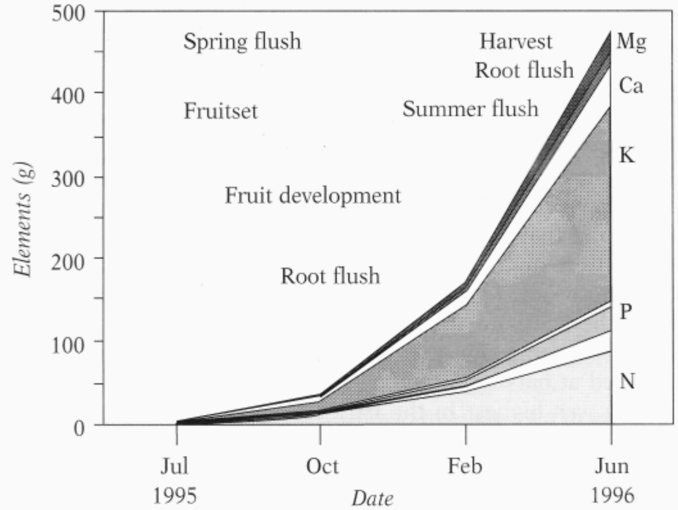

Figure 1
Accumulation of N, P, K, Ca & Mg in fruit (shaded areas) and seed (blank areas) of six-year-old Hass avocado trees producing 35kg fruit per tree.

Magnesium concentrations were the highest in the leaves (0,52 to 0,58%). The concentration was the same in the fallen leaves which means that no movement of Mg takes place before abscission. The new shoots have concentrations of Mg between 0,25 and 0,36%. In the fruit flesh the Mg concentration decreases from 0,22 to 0,14 at harvest.

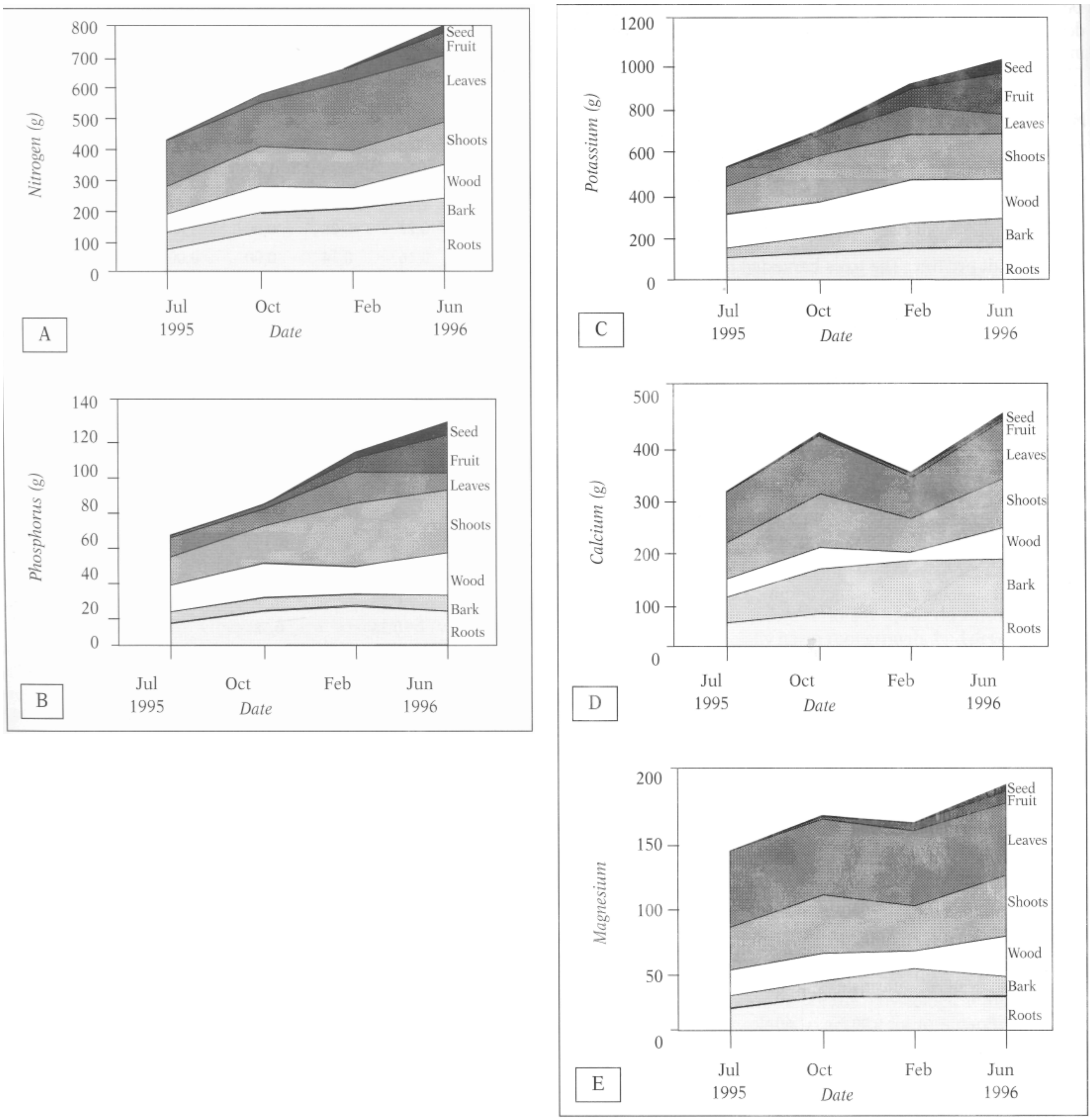

Figure 2

Total amount of N, P, K, Ca & Mg in tree tissues of six-year-old Hass avocado trees producing 35kg fruit per tree

In figure 1 the actual increase (g) of N, P, K, Ca and Mg in the fruit and seed is shown from fruit set to harvest.

The bigger demand for K by the fruit and seed (289,27g) at harvest, followed by N requirement (125,15 g) is shown. The demand for P (29,23g), Mg (15,Og) and Ca (8,43g) was much lower. Potassium in particular was taken up by the fruit during summer until harvest. The increase of Ca in the fruit was exceptionally low, if the important role of this element in membrane structure is taken into account.

In figure 2 the quantities of N, P, K, Ca and Mg in the plant parts of six-year-old Hass trees with an average yield of 35kg fruit are illustrated for a full season. The figure clearly shows the capacity of each part relative to the other parts as well as seasonal uptake tendencies. Along with this figure the percentage spread of the elements in the different plant parts are shown (table 3) and discussed.

Table 3
Percentage distribution of each element in the different parts of the tree at harvest based on the total amount in the tree as a whole

Tree parts	*Elements (% of tree)*				
	N	*P*	*K*	*Ca*	*Mg*
Roots	19,4	14,6	14,4	13,4	11,3
Bark	9,6	7,0	11,9	25,5	9,0
Wood	14,9	22,0	19,7	12,8	16,4
Shoots	15,3	24,1	18,2	20,4	24,4
Leaves	25,1	9,0	7,9	26,1	30,9
Fruit and seed	15,7	23,4	28,0	1,9	7,9
Tree	100,0	100,0	100,0	100,0	100,0

From figure 2A and table 3 it is clear that the greatest quantity of N is found in the avocado leaves i.e. 25,1%. The roots are next with 19,4% N. Nitrogen increase in the leaves takes place mainly in summer. In the post-harvest period there is an increase of N in the roots. In the summer/autumn period in particular N accumulates in the fruit and green shoots as well as in the roots and wood. Except for the fruit and leaves there is a period during early summer when little N is accumulated. It must be remembered that analyses were only carried out during July, October, February and June. Peak periods could be slightly different if samples were taken more regularly throughout the year.

From the preliminary results it would appear that the avocado tree requires N in the post-harvest/spring period as well as the autumn/harvest period but less in the summer period. The first period coincides with bud and flower development and a spring flush. The second period coincides with fruit development and root growth. In the summer period there is mainly summer growth and water shoot development and N applications must be avoided as far as possible. More research is required to establish the relationship between frequency of N applications during these different periods and growth flushes, fruit development and fruit drop. Single large applications during any particular period may be too stimulating and smaller regular doses may make N management easier. Potentially the reactions may be manipulated e.g. by withholding applications of N depending on the growth response of the tree. These aspects must be examined in more detail. Nitrogen can be the cause of poor yield in avocado trees (Embleton & Jones, 1966). It may indirectly cause various physiological problems (Whitney *et al.,* 1986) as the Ca content of the fruit of vigorously growing trees is negatively affected.

The role of N retention properties and mineralization in certain soils, as well as the contribution of thunder storms to N replenishment, must be given attention. The necessity for planting N-fixing cover crops must be questioned. Growth control of the avocado is vital and N can play an important role.

Figure 2B shows that the new shoots have the highest concentration of P representing 24,1% of the total in the tree at harvest (table 3). The fruit and seed at 23,4% are also high in P. In the roots, bark and wood P accumulation takes place in the post-harvest/spring period. In the green shoots and leaves P uptake continues until the summer. During the autumn period the fruit and the wood in particular accumulate P.

Phosphorus is the one element that moves poorly in the soil and P replenishment in soils with a low analysis can be corrected before planting. According to Oliver and Woodridge (1990) the optimal replenishment for deciduous fruit is about 30 mg kg^4 (Bray2 extraction method). Annual applications as top dressing will only take place if leaf analyses indicate deficiency (Kotzé & Olivier,1989).

From figure 2C and table 3 it is clear that fruit are the biggest sink for K (28,0%). This is followed by the wood, shoots and roots. Potassium uptake in the permanent parts continues from post-harvest to the next harvest and in the leaves and shoots until the summer. Annual applications should be unnecessary in most soils with reasonable clay content if the soil levels are sufficient. Replenishment can easily be done in spring if a leaf analysis indicates deficiencies. An imbalance of K in relation to Ca will resultin ion competition (Kirby & Pilbeam, 1984) which can adversely affect Ca uptake. Excess K application without taking the mineral balance of the soil into account will be detrimental to fruit quality.

The Ca pattern of uptake and the demonstration of the capacity of the different tree a part is given in figure 2D. In table 3 the percentage distribution in the tree as a whole at harvest is summarised. From this it would appear that most of the Ca is found in the leaves (26,1%), followed by the bark (25,5%) and green shoots (20,4%). The Ca content of the fruit is very low, 1,9% of the tree as a whole. This compares closely with the 1,2% found in apples (Terblanche, 1972). With apples, Ca deficiency in the fruit is an important factor which results in physiological disorders (Ferguson, 1984). Chaplin and Scott (1980) found that higher levels of Ca in the fruit led to a reduction in cold induced problems in avocados. Kirby and Pilbeam (1984) showed that fruit and leaves are in competition for Ca and that Ca will preferentially move to terminal buds such as developing shoots.

In the tree as a whole the Ca diminished during the early summer. This can be ascribed to leaf drop where Ca from the leaves and shoots migrate to the leaves before abscission and in this way is lost by the tree. In the permanent parts Ca is especially taken up during the spring. As indicated earlier large concentrations of Ca is found in the bark. The role and importance of Ca in the avocado fruit should again receive attention. Quinlan (1969) found that with apples the Ca is taken up rapidly by fruit in the first six weeks. Bower (1985) found the same for avocados.

Correction of pH during soil preparation will in most cases increase the Ca in the soil to the right levels. Where the Mg content of the soil is sufficient, calcitic lime should be used. Where Mg additions are required, dolomitic lime should be applied. In the case where pH is correct but Ca levels are still low gypsum could be applied.

Soil preparation is therefore not only important for correcting physical soil defects but also for the chemical correction with regard to soil reserves so that nutrient management at a later stage will be simplified. According to Du Plessis and Koen (1987) the purpose should also be to reduce the aluminium levels in the soil to below 20mg kg^{-1}. With leaf and soil analysis, maintenance additions of most elements can then be done as required. It is of utmost importance that a knowledgeable person makes the recommendations as imbalances can lead to serious quality deviations and ripening problems. Incorrect applications can cause toxicity or deficiency symptoms. Fouché (1981) found that the optimum pH (H_20) for avocados is between 5,8 and 6,5. According to him imbalances between K, Ca and Mg in the soil will increase the incidence of pulpspot in avocados.

As expected most of the Mg occurs in the leaves (30,9% of the Mg in the tree as a whole) and this is shown in figure 2E and table 3. Magnesium uptake occurs mainly in spring but in the new shoots and leaves it also accumulates in autumn. The new shoots contain 24,4% of the total Mg content and the fruit only 7,9%.

In table 4 the annual losses and fixation of N, P, K, Ca and Mg are given. Losses are the quantities removed by harvesting or leaf drop. Fixation represents that portion of the element content that forms part of the tree structure. For the six-year-old trees the quantities represent the cumulative amounts over the six year period. The annual increase was therefore calculated. In the case of the leaves, the increase was calculated over a three year cycle as this more or less represents the period of leaf replacement. Leaching of N, Ca and Mg is estimated at 20% for soils with about 20% clay. Leaching of P and even K is regarded as negligible in such soils.

Table 4
Annual losses and fixation of N, K, Ca and Mg by various parts of a six-year-old Hass tree with a yield of 35 kg

Tree parts	*Elements (g/tree)*				
	N	*P*	*K*	*Ca*	*Mg*
LOSSES					
Harvest	125,2	29,2	289,3	8,4	15,0
Abscised leaves	51,3	2,6	11,6	59,2	22,6
FIXATION					
New shoots	20,3	5,1	31,2	15,4	7,7
Leaves	66,2	3,8	27,1	39,4	19,6
Permanent parts	58,2	9,1	78,9	39,0	11,6
Total/free	321,2	49,8	438,1	161,4	76,5

Table 4 gives a summary of the requirement of a six-year-old Hass avocado tree to produce 35 kg of fruit. This is a preliminary study but it must be clear that sufficient information of this kind for the different circumstances can, along with other fertilization recommendations, help to better understand the requirements of the avocado tree. It may also help to establish guidelines such as those summarised in table 5. It was felt that leaching losses in most cases were negated by the contribution of abscised leaves.

CONCLUSIONS

It must be emphasised that this is a preliminary study giving information on six-year-old Hass avocado trees under less vigorous growth conditions at Nelspruit. The quantities that these specific trees require annually as replenishment, is purely a guideline example which must be adapted according to differing conditions. More extensive studies over a range of conditions and varying growth rates will be investigated. At this stage it is only necessary to take note of the seasonal trends. More information will be gathered in order to get a clearer picture.

Excess nitrogen application can negatively influence avocado fruit production and quality. With the application of nitrogen to the avocado trees, the guidelines given and leaf analysis results must be taken into account. Judging the growth rate of the tree is, however, essential before making a final decision. Where water shoot development in the trees is excessively vigorous and the leaves dark green and large, nitrogen application must of necessity be withheld. When planting avocado orchards, high potential soils with accumulated nitrogen levels must be avoided. Such orchards will reach the encroachment stage even before they have produced an acceptable crop. It would be preferable to diminish the nitrogen levels in such orchards by first planting a suitable crop before planting avocado trees.

Research with regard to the time and frequency of nitrogen applications must be completed. In addition fruit set of potentially large and strong fruit that can compete with reasonable growth must be encouraged. The control of strong summer growth must be regarded as a priority and must not be sabotaged be unjudicious applications of nitrogen. It must also be borne in mind that thunder storms release a considerable amount of nitrogen which must be taken into account. The management of vegetative and reproductive development will provide the foundation for regular yields and research should concentrate on these aspects.

If soil reserve fertilization with P was done during soil preparation then P need only be applied if leaf analyses should indicate a shortage. If the soil pH and the K, Ca and Mg balance was adjusted before planting then K will be managed in most soils with a clay content of more than 20% according to soil and leaf analysis. Maintenance liming annually or bi-annually will maintain the Ca and Mg and be controlled by soil and leaf analyses.

Although K is important in the development of the avocado fruit an excess K can cause problems with regard to Ca uptake and correct Ca:Mg:K ratios must be maintained.

The low Ca level in the fruit is disturbing and may influence numerous post-harvest problems and adversely affect the keeping quality of avocado fruit. This aspect should be further investigated.

The trace elements B and Zn were not part of this study but the interrelationship between Ca: Mg: B and K must be clarified. A possible synergistic activity between B and Ca must be examined.

Table 5

Quantity guidelines for the elements needed per annum by a six-year-old Hass tree with a yield of 35 kg

	Elements				
Tree parts	*N*	*P*	*K*	*Ca*	*Mg*
Element tree^{-1} (g)	321,2	49,8	438,1	161,4	76,5
Fertilizer tree^{-1} (g)	1 147	440 Super	876 KCI	403 Calcitic 807 Dolomitic	637 Dolomitic
Element (kg yield)$^{-1}$ (g)	9,2	1,4	12,5	4,6	2,2
Element (cm trunk circumference)$^{-1}$ (g)	5.6	0,9	7,6	2,8	1,3

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