

# FERTILISATION OF CITRUS

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## CONTENTS

1. INTRODUCTION
2. NITROGEN
3. PHOSPHORUS
4. POTASSIUM
5. CALCIUM
6. MAGNESIUM
7. SULPHUR
8. SODIUM AND CHLORIDE
9. COPPER
10. IRON
11. MANGANESE
12. ZINC
13. BORON
14. MOLIBDENUM
15. OTHER ELEMENTS
16. INTERACTIONS BETWEEN NUTRIENT ELEMENTS
17. NUTRITION AND DISEASES
18. NUTRITION AND QUALITY OF FRUIT
19. ACIDIFICATION OF SOILS
20. LIMING AND LIMES
21. ORGANIC MATERIAL
22. SOIL APPLICATIONS
23. FERTIGATION USING MICROJETS
24. FERTIGATION USING DRIPPERS
25. FOLIAR SPRAYS
26. LEAF, SOIL, WATER AND FRUIT ANALYSES
27. SOIL PREPARATION AND FERTILISATION OF NON-BEARING TREES
28. FERTILISATION OF BEARING TREES
29. USEFUL TABLES
30. REFERENCES.

## 1. INTRODUCTION

The most important environmental factors that influence photosynthesis, flowering, fruit set, fruit growth and fruit quality are light, water and nutrition. Inorganic nutrition of plants was raised for the first time during 1840 when Justus von Liebig published his book on this subject. Since then 17 elements were identified as essential for plant production. Fourteen of these elements, i.e. Nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), sulphur (S), chloride (Cl), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B) and molybdenum (Mo), are utilised and taken up from the soil and water. The other three, carbon, hydrogen and oxygen are utilised and taken up from the air and water.

The mineral component of plant material is small and variable and depends on the plant part, age and conditions in which they were produced. The mineral component of citrus is at the highest 17% of the total mass of plant material (Table 1).

**Table 1. Average mass of ash in citrus tissue**

Plant part	Ash content* (%)
Fruit	0.4 – 1.0
Leaves	6 – 17
Shoots	4 – 6
Wood	2 – 7
Roots	2 - 4

\*The ash content is the residue after all moisture and organic material are burned away. It contains all the nutritional elements except carbon, hydrogen, oxygen and nitrogen, and usually not sulphur and chloride.

Through the years, in the endeavours to increase plant production, a number of approaches have been tested for inorganic nutrition.

- Right at the beginning the main objective was to determine, which elements were necessary for plant production.
- The next step was to identify deficiency symptoms.
- Next it was endeavoured to improve production by manipulating the inorganic nutrition. The first attempt was based on the amount of minerals that are removed by the crop from the orchard (Table 2). The reasoning was that at least the same amount must be replaced.

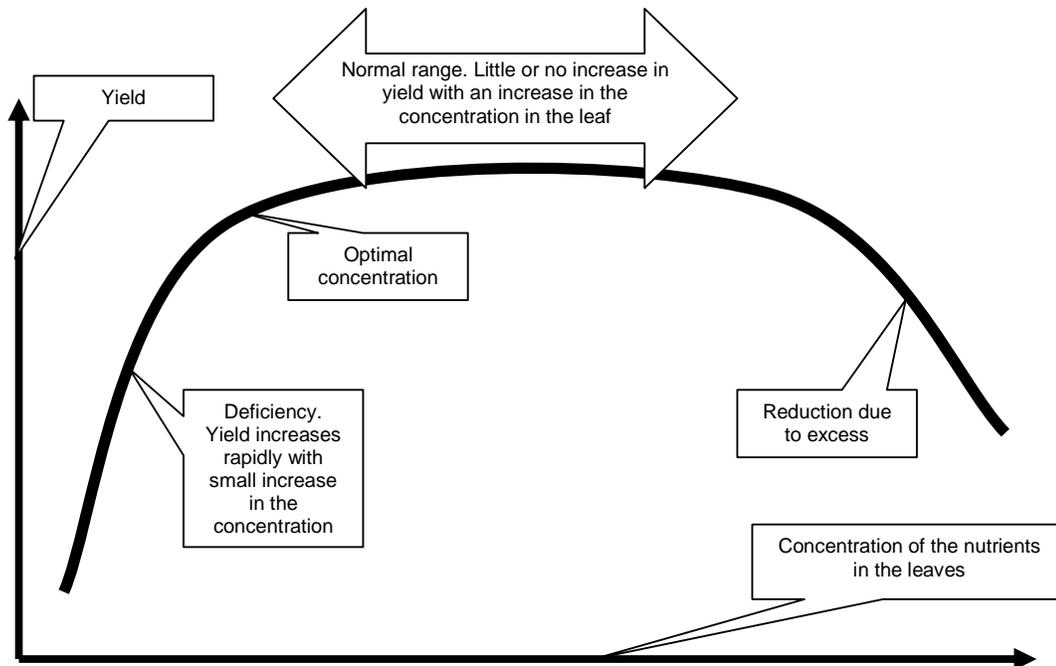
**Table 2. The average mass of some nutrients removed by the crop**

Element	Gram per ton of fruit	Adapted values in grams per ton fruit to compensate for fertiliser efficiencies.
Nitrogen as N	1900-2250 for lemons 1900-2250 for satsumas 2000-2250 for grapefruit 2000-2250 for navels 2000-2250 for the rest	2750-3000 for lemons 2000-2500 for satsumas 2000-2500 for grapefruit 2500-2750 for navels 2250 tot 2500 for the rest
Phosphorus as P	450-500 for satsumas 450-500 for the rest	500-650 for satsumas 400-500 for the rest
Potassium as K	2000-2250 for old clone Valencias 2000-2250 for the rest	2750-3000 for old clone Valencias 2250-2500 for the rest
Calcium as Ca	500-600	500-600
Magnesium as Mg	500-600	500-600
Sulphur as S	300-500	300-500

The values in the third column can be applied to determine the efficiency of the fertilisation program, especially that of nitrogen. An additional factor was incorporated to provide for manipulations that can be done on certain cultivars. E.g. with lemons the number of fruit can be increased to get smaller fruit according to the demands from the market.

- The main result of the use of removal figures was that plant analysis became important. Leaf analysis has come to the front and has received the most attention. The figures in Table 2 can be further refined by also taking the expected effectiveness of the fertilisers into consideration. The probability that 100% of any nitrogen source will be absorbed by the trees is zero. The efficiency of nitrogen sources is usually taken as 80%, phosphorus as 30 – 40% and potassium as 50%. Thus, when a crop removes 200kg N,  $200 \times 100 : 80 = 250$ kg N must be replaced.

- A logical result of leaf analysis was the developing of threshold values. According to this theory, production would increase if the mineral supply or the concentration of the nutritional elements increase till it reaches a level whereafter the increase in production ceases (Figure 1). Shortly thereafter leaf analysis was recognised as a diagnostic method.



**Figure 1. The relationship between the concentration of the nutrients in the leaves and yield.**

- The next step was to concentrate on certain plant parts and physiological processes. Fruit, vegetative growth, fruit set, cell division and cell growth and their relationship with mineral nutrients were investigated. Well known applications of this work are the timing of nitrogen and foliar sprays with potassium nitrate, zinc and boron.
- Nowadays we strive to manipulate physiological processes in order to increase the utilization of mineral nutrients. One example is the re-mobilisation of precipitated calcium oxalate to increase the calcium of the apple fruit.

No matter which method is used, plant analysis especially leaf analysis will form an integral part. Today it is necessary to evaluate the role of each nutrient element in production and to use the most effective method for effective supply. The best sustainable income will be generated when nutrients are supplied in the most economic way, which ultimately is the goal of a good fertilisation program.

In the following subsections, the role of each of the 14 elements will be discussed. Thereafter the practical application of this information on citrus production will be discussed. During the discussions distinctions between fertilising by conventional applications on the soil and fertigation will be highlighted. Fertigation is further divided into applications through microjets and drippers because different approaches are required. The differences are mostly related to the volume of the soil fertilised. With drippers the volumes of soil varies between 100 and 500 litre and with microjets between 2000 and 5000 (and even more) litres. An application of 10g N with drippers is effective because it represents a concentration of 20 and 100mg N per litre of soil. The same application is

not effective with microjets because the concentration is then only 2 to 5mg N per litre of soil.

In the list of sources those products that I am familiar with, are included. These sources are not necessarily recommended but are included in anyway. Trials with new sources should be done by treating only a few rows or half of the orchard. Take leaf samples from the two treatments to establish the value of the "new" product. Also look out for any visible symptoms on the trees, yield, fruit size, etc.

This publication is in no way complete and is never intending to be. The idea is to concentrate on the principals, which can be applied in practice and results and observations which can benefit production and quality. Aspects of nutrition and fertilising of citrus, which are discussed elsewhere and are readily available will not be repeated here. That includes aspects of physiology, leaf symptoms and standard practises. For more information regarding these, the following publications can be used.

Marschner, Horst. 1988. Mineral nutrition of higher plants. Academic Press. ISBN 0-12-473542-8 (HB) ISBN 0-12-473543-6 (PB)

Burt, C., O'Conner, K. & Ruehr, T. 1998. Fertigation. Irrigation Training and Research Centre. California Polytechnic State Univ. San Luis Obispo CA 93407. ISBN 0-9643634-1-0

Reuther, W., Batchelor, L. D. & Webber, H. J. 1968. Editors of The Citrus Industry. Volume 2

Reuther, W. 1973. Editor of The Citrus Industry. Volume 3

## 2. NITROGEN

### 2.1 Roll in citrus production

Nitrogen is present in the soil in a number of compounds and forms. The organic fraction in the soils contains the largest portion of the total nitrogen. The nitrogen is present in the form of amines (protein like compounds) which cannot be utilised by the trees. Once the organic matter is decomposed by the microbes, available nitrogen is produced which can be utilised by the trees. Of all the different nitrogen compounds in the soil, only ammonium- ( $\text{NH}_4$ ) and nitrate ( $\text{NO}_3$ ) nitrogen can be utilised by the plants in significant quantities.

Citrus expresses no voluntary uptake of nitrogen and the mass taken up depends on the temperature of the root zone (Chapman & Parker, 1942). To set the required number of fruit, the trees need to be forced feed with nitrogen during the late winter and early spring. During summer the conditions will support the utilisation well and if the concentration of available N in the soil is not reduced, excessive amounts can be taken up.

Uptake of nitrate is zero at 0°C but under mild conditions applied nitrogen is utilised within 8 to 15 days. Hardly any soils planted to citrus in Southern Africa ever reaches freezing point during winter. Uptake of nitrogen by the roots will therefore continue throughout winter and most of the N is stored in the roots until the ambient temperature rises and the demand for N by the vegetative parts increases. Uptake of nitrogen is less sensitive to low temperatures than that of Ca, Mg, K or P (Naude, 1958). Citrus trees can take up more nitrogen than required in air temperatures of -3 to 3°C provided the roots are still active. The microbes converting nitrogen are sensitive to low temperatures. However, at 15°C a mass of 325kg  $\text{NH}_4^+$ -N per ha can be nitrified completely within 4 weeks.

A mature Valencia tree contains at harvesting 700 to 900g N. Of this 40% is in the leaves, 20% in the fruit and 30% in the shoots, branches and trunk and 10% in the roots (Calculated from data supplied by Cameron & Appleman, 1934). When pruning is done as is a standard practise these days, the leaves might contain less than 20% of the total N.

Plants can directly absorb small amounts of urea (<25% as effective as nitrate) but, the uptake rate is very slow. On the leaf surface and in the soil, urea is converted by the enzyme urease to ammonium nitrogen. Absorbed ammonium and nitrate nitrogen are transported in the xylem vessels to the leaves and shoots. This nitrogen is transported to the organs with the highest activity. When the absorption by the leaves ceases, nitrogen is relocated from old to young active organs.

Eighty percent of all nitrogen in the plant is present as protein (80%),  $\pm 10\%$  as nucleic acids and the rest as amino and nitrate nitrogen.

### **Nitrogen deficiencies**

A nitrogen deficiency is most critical during the “pre-bloom, fruit set to fruit drop” stage.  $\text{CO}_2$ -assimilation is directly related to the concentration of nitrogen in the leaves (Syvertsen, 1989). In the absence of potassium the assimilated nitrates are not processed completely. A nitrogen deficiency reduces growth in general, limits the branching of roots, results in poor development of the chloroplast and reduces yield drastically.

When the nitrogen status of the trees is low, applied nitrogen is utilised more efficiently than plants with a high nitrogen status.

The first symptom of a nitrogen deficiency on lemons is the appearance of yellow areas on the leaves before it spreads to a total yellowing of the leaf. Yellowing of the veins is another symptom found on other cultivars. However, yellowing of the veins is also symptomatic of other problems like root diseases (Phytophthora) and too deep girdling. Leaves showing yellow veins contain low concentrations of nitrogen but the concentration of magnesium is within the limits.

When the supply of nitrogen through the root is too low to satisfy the demand, nitrogen is relocated from older to young developing plant organs. A mild nitrogen deficiency results in an even yellowing of the complete tree. As the deficiency progresses the yellowing of the older leaves intensifies and they are shed. This developed into bare twigs with only leaves at the tip and is quite specific for a continuous nitrogen deficiency (Smith, 1969). This is also referred to as a hidden nitrogen deficiency.

In comparison with healthy trees the hidden nitrogen deficiency symptom has the following characteristics.

- Leaves are dropped prematurely
- Trees appear sparsely foliated and contain about 50% less leaves than a normal tree.
- The general colour is slightly paler green.
- Leaves turn yellow shortly before they are dropped while “normal” leaves stay green when dropped. The N-content of the dropping leaves is < 1, 50%.
- No difference in tree size.
- No difference in the number or length of the shoots.
- The leaves that remain on the tips contain slightly less nitrogen than “normal”, (2,26 against 2,49% N).
- The twigs carry no leaves of the previous third and fourth cycle but only leaves of the last two cycles.

The danger of this phenomenon is that the appearance of the trees (intensity of the green colour) and leaf analyses do not reflect the true nitrogen status of the trees. When nitrogen is relocated from old to young leaves, these young leaves contain more nitrogen than young leaves on trees should the older leaves would have remained on the trees. The total mass of nitrogen is split between much less ( $\pm 50\%$  less) leaves.

Smith (1969) called this the hidden nitrogen deficiency syndrome and can be explained as follows. If a tree sheds 25% of its leaves due to a deficient nitrogen supply, the total mass of nitrogen is shared by the remaining 75% of the leaves. If the remaining leaves contain 2,00% N, the nitrogen

status reflected by this 2,00% is not all that deficient. However, if the mass of N in the tree was shared by all the leaves, including those dropped pre-maturely, the N content would have been only 1,50% which is deficient in any terms.

Therefore the nitrogen status of the trees can only be correctly assessed if the trees carry a “normal” number of leaves.

The reduced in branching of the roots also has a detrimental effect on the absorption of potassium and other nutrient elements.

Plants suffering from a nitrogen deficiency reach maturity quicker due to the lower production of growth hormones like cytokines. In the absence of nitrogen, plants produce indole butyric acid, rendering the plants more susceptible to water stress. The stomata will close sooner and reduce the period for optimal photosynthesis period considerably.

A mild nitrogen deficiency results in less fruit that sets and therefore indirectly increase fruit size. If the severity of the deficiency increases, even fruit size will be reduced. A low nitrogen status results in less flowers but a higher percentage will set fruit. Likewise a high nitrogen status will induce more flowers but a smaller percentage will set fruit. Nevertheless, reducing the nitrogen status to a stress level is a risky way to reduce the number of fruit.

To reduce the nitrogen status without proper control in order to increase fruit size has serious limitations. When the potential of a tree is reduced to carry only 1000 fruit, the capacity to grow these fruit to optimal size is also restricted. However, if the potential of the tree is prepared to set 2000 fruit, and 1000 is removed, it's capacity to grow the remaining 1000 to an optimal size is so much better.

A mild nitrogen deficiency usually results in fruit with smooth skins but the internal quality is not much affected. Comparing fruit from a nitrogen deficient tree to that of a tree with a nitrogen excess, the appearance and quality differ considerably. Generally fruit from trees suffering from a mild nitrogen stress has better quality than that from trees with an excess of nitrogen. Note that the excess nitrogen status refers to the nitrogen content during January to June.

### **Nitrogen excess**

In it's simplest form, an excess of nitrogen manifested in trees with dark green leaves growing vigorously. An excessive supply of nitrogen will not necessarily reduce the number of fruit, but the first symptom is delayed colour break, thicker skins and fruit with a reduce shelf life.

When the nitrogen status of Valencia trees is increased from 2,00 to 2,75% the number of fruit will increase, fruit size will be reduced but the volume will remain about the same. This also applies to other cultivars although the nitrogen status will be different (not 2,00 to 2,75%).

High nitrogen levels during the late summer and autumn will have a detrimental effect on the dormant period and can reduce yield and quality of the next crop (Table 3). The results show little differences in yield between the three treatments but the major difference is in the mass (kg) marketable fruit and revenue. The main results of excess nitrogen are fruit with thick skins, low juice, high acid, low sugar content, delayed ripening, reduce shelf life and a reduction in resistance of fruit and tree against deceases.

**Table 3. The result of excessive supply of nitrogen on the marketable yield of citrus.**

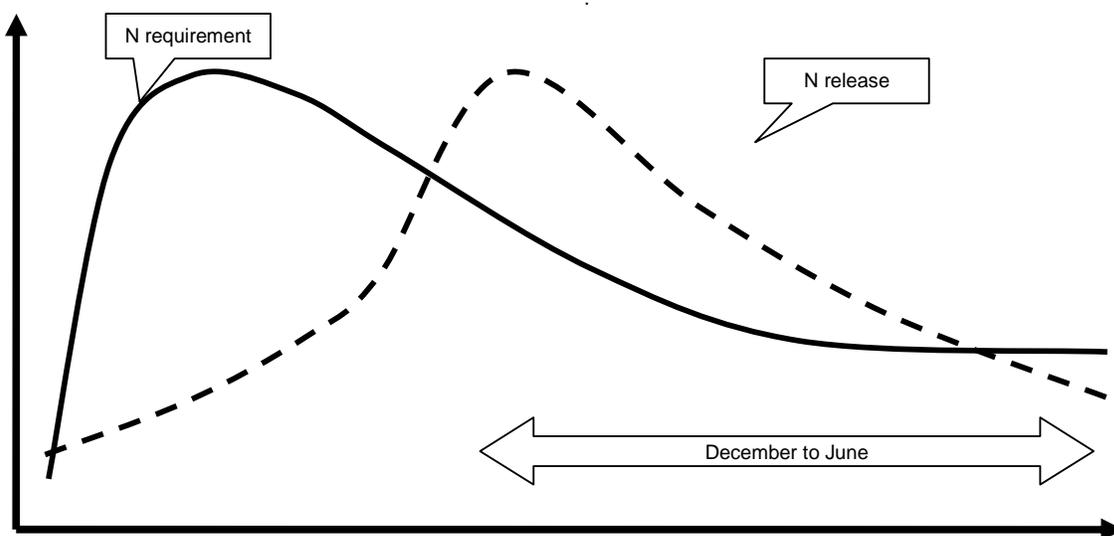
	<b>Nitrogen applied x gram per tree</b>	<b>Nitrogen applied 1,5x gram per tree</b>	<b>Nitrogen applied 2x gram per tree</b>
Number of fruit per tree	1801	2059	1395
Volume 15kg boxes	25,0	24,0	26,0
Average count	71,9	83,5	54,1
% > count 72	50,0	24,0	67,0
kg > count 72	900	494	935

% Marketable	80,0	65,0	34,0
kg Marketable	1441	1338	474

Nitrogen applications at the wrong time will have the same effect on yield and quality as an excessive status. If the required mass of nitrogen is applied during December to April, the trees will experience a nitrogen excess at the period when too much nitrogen will harm the crop. Both the current and the next crop will be jeopardised.

Depending on the cultivar, the nitrogen status of commercial orchards must vary between >3,50 (during bud break, blossom and fruit set) and <2,50% (during ripening) (Figure 3).

Release of nitrogen from the organic material (mineralization) in the soil, is controlled by the microbial activity of the soil. This activity depends on temperature and moisture and the mineralization seldom occurs at the required rate and time. The highest release of available nitrogen may occur during January to March at a period when the demand is low and additional nitrogen will ruin the crop (Figure 2). That will have a detrimental influence on the current and coming crop in the same way as an application of nitrogen at the wrong time.



**Figure 2. The nitrogen requirement of commercial citrus trees compared to the release of nitrogen from the organic fraction in the soil.**

Excessive nitrogen or nitrogen applied too late or a nitrogen deficiency will aggravate the incidence of cold damage (Maurer & Davies, 1994). This is very important for new plantings in cold areas. Plant organs receiving too much nitrogen are generally soft with large cells and thin cell walls, which are more prone to damage or infestations.

## 2.2 Sources of nitrogen

Plants can only utilise nitrogen in the form of nitrate ( $\text{NO}_3^-$ ) and ammonium ( $\text{NH}_4^+$ ) while organic forms and nitrites are only absorbed in very small amounts. A variety of nitrogen sources are available in RSA and they all contain ammonium- and/or nitrate nitrogen or compounds like urea or organic nitrogen that can be converted to these two forms. In the RSA the concentration of the nutrient element in the fertilisers are given in mass of the element per kg of fertiliser or % but on a mass-mass-basis (m/m)

**Table 4. Nitrogen sources**

Source	% nitrogen (m/m)
Urea	46

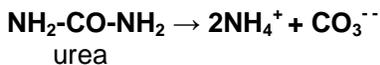
Ammonium nitrate	34
Urea ammonium nitrate	32*
Limestone ammonium nitrate	28
Ammonium sulphate nitrate	27
Ammonium sulphate	21
Ammonium nitrate solutions	19 tot 21*
Nitric acid	12 tot 14*

\*These fertilisers are liquids with a density >1,0. Therefore a litre of UAN contains 420g and one litre AN19 215g N and not 320 and 190g respectively.

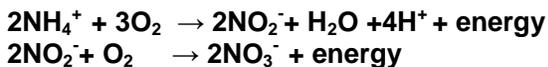
**Urea** is a synthetic organic nitrogen source. It is completely soluble in water and has no electrical charge. These two properties make urea very susceptible to be leached out of the root zone. The irrigation following a urea application should therefore be well monitored to apply only enough water to take the urea into the top 30cm layer of soil. With flood irrigation on sandy soils proper control is not possible.

In the soil, urea is converted (Hydrolysed) by the enzyme urease to form ammonium carbonate. The pH of the immediate surroundings will increase temporary but during this period of high pH, the ammonium part can be volatilized. If the urea is hydrolysed on the surface of the soil, volatilisation in the form of ammonia gas can be a major loss of applied nitrogen. Urea need to be washed into the soil shortly after application, to a depth of about 10 to 30cm without leaching it beyond the roots. The hydrolysis of urea is a biological process and temperature and moisture will determine the rate. In cold wet soil, the rate of hydrolysis is low and the plants may suffer a temporary short supply of nitrogen.

The hydrolysis of urea involves three steps. Firstly the urea is converted to ammonium carbonate by the enzyme in the soil. This reaction takes about 72 hours to convert almost all urea.



The ammonium is then converted by the nitrifying bacteria to nitrite and nitrate.



Urea is therefore a source of ammonium and nitrate nitrogen to the trees.

Due to the slow rate of hydrolyses of urea to ammonium and nitrate during the winter and under waterlogged (anaerobic) conditions, applications during July and August should not be done, especially in the winter rainfall areas. The trees cannot utilise urea directly and under these conditions, a nitrogen deficiency might be induced.

**Ammonium nitrate (34)** is a very popular source of nitrogen worldwide, but it is not available in RSA. It contains equal masses of ammonium and nitrate nitrogen in a fairly concentrated form. It is soluble in water and the nitrate part is more subjected to leaching than the ammonium part. In South Africa ammonium nitrate is available in various other formulations but also as a liquid containing 19 to 21% N (m/m).

**Urea ammonium nitrate (UAN)** is a fairly new product and is very suitable for fertigation with centre pivots and microjets. It contains urea and ammonium nitrate in a liquid formulation with 16.5% urea nitrogen, 7.8% ammonium nitrogen and 7.8% nitrates nitrogen on a mass per mass basis (m/m). In total 1kg UAN contains 320g N but remember that the density of UAN is 1,34. Therefore a litre of UAN will contain 428g N.

UAN are used quite extensively in the Sunday river valley. In some orchards the phosphorus, potassium and manganese status of the leaves increased without any application of these three

elements. About 70% of the orchard receiving UAN for three consecutive seasons shows this responds.

**Limestone ammonium nitrate (LAN)** contains 28% nitrogen of which 14% is present as ammonium and 14% as nitrate nitrogen. It also contains about 10% lime which is not meant to counteract the acidification caused by the ammonium nitrogen. The ammonium and nitrate is completely soluble in water but not the lime.

**Calcium ammonium nitrate (CAAN)** contains varying concentrations of nitrogen. This product is a combination of calcium nitrate and ammonium nitrate and is soluble in water.

**Ammonium sulphate nitrate (ASN)** contains 27% nitrogen of which 20.9% is present as ammonium and 6.1% as nitrate. It also contains 13.5% sulphur. The ASN is available as water soluble and a granular product suitable for fertigation and conventional applications.

**Ammonium sulphate (AS)** is one of the oldest nitrogen sources and contains 21% nitrogen all in the ammonium form. It also contains sulphur. AS is soluble in water and has a very high acidifying potential. It is well suited to alkaline soils.

**Nitric acid** is a source of nitrogen although it is mostly used to acidify irrigation water in hydroponics. Nitric acid *per se* is too expensive to be used as a source of nitrogen. The volume of nitric acid required to lower the pH of the water to 6,00-6,50 is calculated from the concentration of carbonates ( $\text{CO}_3$ ) and bicarbonates ( $\text{HCO}_3$ ) as follows;

- In the first step all the carbonates are converted to bicarbonates  
(me  $\text{CO}_3 \times 2$ ) = me  $\text{HCO}_3$  add this to the concentration of bicarbonates which is the amount to be neutralised.
- Now the volume of acid required can be calculated.  
me Total  $\text{HCO}_3 \times 74 = \text{ml HNO}_3^*$  per 1000 litre water. (\* based on nitric acid with a concentration of 13,7N and a density of 1,36).

Table 5 contains the ml nitric acid required to neutralise various concentrations of  $\text{HCO}_3$ . By removing the  $\text{HCO}_3$  in this way  $\text{NO}_3\text{-N}$  is added with little change in the electrical conductivity.

**Table 5. The volume nitric acid required to neutralised 0,50 to 5,00 me  $\text{HCO}_3$ .**

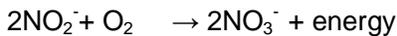
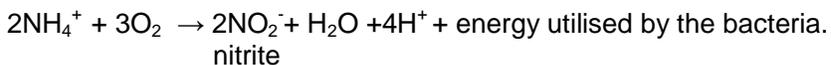
me $\text{CO}_3$ + $\text{HCO}_3$	ml $\text{HNO}_3$ per 1000 litre water
0,50	37
1,00	74
1,50	111
2,00	148
2,50	185
3,00	222
3,50	259
4,00	296
4,50	333
5,00	370

**Table 6. Sources of nitrogen suitable for most fertilisation programmes.**

Source	% N m/m	Form	Other elements
Calcium nitrate	12	$\text{NO}_3$	17% Ca
Magnesium nitrate	11	$\text{NO}_3$	9,5% Mg
Mono-ammonium phosphate	12	$\text{NH}_4$	22 - 26% P
Ammonium nitrate 19% solution	19	$\text{NO}_3$ $\text{NH}_4$	-
Ammonium sulphate	21	$\text{NH}_4$	24% S
Ammonium sulphate nitrate	27	$\text{NO}_3$	13,5% S

		NH <sub>4</sub>	
Limestone ammonium nitrate	28	NO <sub>3</sub> NH <sub>4</sub>	x% Ca
Ammonium nitrate granules	34	NO <sub>3</sub> NH <sub>4</sub>	-
Urea ammonium nitrate	32	NO <sub>3</sub> NH <sub>4</sub> Urea	-
Urea	46	Urea	-

**Ammonium nitrogen** is oxidised in the soil to nitrite and then nitrate by the nitrifying bacteria. Nitrification is a biological process through which ammonium (NH<sub>4</sub>) is oxidised by *Nitrosomonas* sp. to nitrite (NO<sub>2</sub>) and nitrite to nitrate (NO<sub>3</sub>) by *Nitrobacter* spp. During these oxidation processes, acid ions (H<sup>+</sup>) are produced which acidifies the environment. The origin of the ammonium has no bearing on the final result. All ammonium nitrogen, whether is from fertilisers or organic material will be nitrified by the bacteria. These processes take about 14 to 21 days to be completed.



Although nitrification depends on temperature, moisture and pH, a rate of 6% is possible at 7°C compared optimal conditions. At a pH of 4,0 the rate of nitrification is zero and at pH 5,0 only 50% of the rate at pH 7,0. The process requires a moisture content of 50 en 70% of field water capacity, a pH of 7.00 and temperature of 20°C for optimal conversion.

The 4H<sup>+</sup> in the equation is responsible for the acidification of the soil. Ammonium nitrogen moves fairly easily into the soil profile and is converted to nitrate in the subsoil. The subsoil is therefore more subjected to acidification. At existing orchards lime to counteract the acidity is applied to the surface. Lime is fairly insoluble and moves slowly into the subsoil. Therefore the hazard of acid sub soils should be monitored.

Acidification of the root zone is one factor that will reduce citrus production unnoticed. Smith (1962) showed that the production can be increased from 20kg fruit per tree to 110kg by increasing the pH from 4,00 to 7,00 (Table 7).

**Table 7. The result of soil pH on yield of citrus trees.**

pH	Yield Kg/tree	Surface area of the canopy in m <sup>2</sup> per tree	Mass roots in kg per tree
4,00	20	18,3	5,20
5,00	50	26,6	7,50
6,00	100	30,9	7,80
7,00	110	33,8	7,75

In acid soils the concentration of both the acid ion (H<sup>+</sup>) and aluminium increase with a decrease in the pH. Both these cations are phytotoxic and will damage the roots. The number of feeder root tips is the best correlated with production and is also reduced by acidic conditions.

Satsumas showed an increase of 25% in production when the pH(KCl) was increased from 4,2 to 5,3.

The only difference in a Marisol orchard between a good and a poor patch was the pH of the soil. The poor trees were planted in an area where the pH(water) was 5,20 against that of the good part's 6,34.

A low pH in the root system or soil shows no visual symptoms on the foliage. Nursery trees grown in pine bark at a pH(1:1,5) of 4,65 withered while trees in the same nursery at a pH(1:1,5) of 7,20 shown no signs of a water stress. Growth was also drastically reduced by a low pH in the root zone.

The acidification potential of nitrogen fertilisers differs due to the varying concentration of ammonium nitrogen, but also due to other contributing factors such as the sulphate present (Table 8).

**Table 8. The milli equivalent acid (H<sup>+</sup>) per kg N, generated from various nitrogen sources with the corresponding lost in Ca or base-ions.**

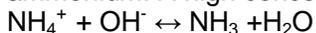
Source	me H <sup>+</sup>	kg Ca
Ammonium sulphate	180	-3,0
Ammonium sulphate nitrate	144	-2,0
Ammonium nitrate	36	-1,0
Urea		
Ammonia		
Limestone ammonium nitrate 26	17	-0,4
Limestone ammonium nitrate 22	0	0
Potassium nitrate	-28	+0,8
Calcium + sodium nitrates	36	+1,0
Calcium cyanide	-60	+1,7

Acidification is perceived as negative when the pH(water) of the soil is lowered to below 6,00, but it has a positive side. In alkaline and calcium rich soils, acidification will mobilise nutrient elements. Acidification by 100kg ammonium sulphate will mobilise about 40kg calcium and make it available for the trees to utilise. This acidification is seldom measurable with the techniques we use in soil analyses. It happens in a micro volume of soil and also makes Ca, Fe and manganese available to the plants.

Another negative property of ammonium nitrogen is the potential losses due to volatilisation. Losses occur when ammonium nitrogen is left on the surface of alkaline soils. Volatilisation occurs at pH(water) values greater than 7,00

Volatilisation of ammonium nitrogen is a chemical process influenced by pH, humidity, wind speed, moisture, clay content, organic material present, temperature and the type of ammonium compound (Stevens, 1989). Losses from MAP are much less compared to DAP under the same conditions. Losses from DAP can be as high as 50% (Fertiliser Research 1986).

Even in acid and neutral soils, volatilisation can happens and is driven by the concentration of ammonium. A high concentration of ammonium will force the reaction below to the right.



In alkaline soils the presence of carbonates will be responsible for the reaction to shift to the right, forming NH<sub>3</sub> which is a gas and will escape into the atmosphere.



Aeration is at its maximum on the surface of the soil and formed ammonia will be removed rapidly. If the soil is moist volatilisation will be driven by the pH of the soil. Table 9 shows the magnitude of losses of ammonium nitrogen, under laboratory conditions, due to volatilisation at various pH levels.

**Table 9. The influence of soil pH on the % nitrogen lost by volatilisation from applied ammonium.**

pH(water)	% lost
7,0	< 1
8,3	12
9,0	47
10,5	95
11,3	100

Ammonium nitrogen ( $\text{NH}_4^+$ ) is utilised in a passive manner by diffusion and needs to be “detoxified” in the plant. The pH of the cytoplasm is  $\pm 7,5$  and will convert all  $\text{NH}_4^+$  to  $\text{NH}_3$ . The  $\text{NH}_3$  is phytotoxic (poisonous to plants) and must be detoxified. In this process carboxyl groups from carbohydrates are utilised to bind the  $\text{NH}_4^+$ -N. This means less energy remains for fruit and vegetative growth. During periods of high temperatures, lots of carbohydrates are required by respiration and little can be spared to detoxify ammonium. Applications of ammonium nitrogen through drippers should therefore be avoided during periods of high temperature (Kafkafi, 1990). Application of ammonium nitrogen may however be advantageous during periods of low temperatures.

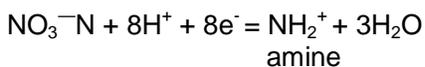
Ammonium nitrogen is utilised by plants best at a neutral to slightly alkaline pH of the soil. At elevated pH levels, nitrification is also much faster than at acid pH levels.

When nitrification of ammonium is inhibited by low temperatures, plants will absorb more ammonium. This can lead to yellowing of the leaves, a decrease in absorption of potassium (due to competition by ammonium) and a decrease in the formation of sugars. In the presence of an already low potassium status, starch may accumulate in the leaves resulting in yellowing of the leaves. Temperatures  $< 12^\circ\text{C}$  will reduce the uptake of K and yellowing can also develop. Therefore, a yellow leaf can be the result of too little N, K or too much starch and too much ammonium nitrogen.

**Nitrate nitrogen** is the final product of mineralization (conversion of organic nitrogen to ammonium) and nitrification in the soil. Nitrate nitrogen is stable under normal agricultural conditions and is not subjected to any further changes. It can however again be utilised by the microbes and build into organic nitrogen. Nitrates are more subjected to leaching than ammonium nitrogen.

Nitrates are the driving force in many physiological processes and join forces with the ever present potassium in transporting organic products.

Energy is required to absorb nitrate. That is one reason why the absorption is not suppressed by chlorides ( $\text{Cl}^-$ ) or sulphates ( $\text{SO}_4^{2-}$ ). The absorption is an active process supported by the presence of  $\text{Ca}^{2+}$  and  $\text{K}^+$  and suppressed by the presence of  $\text{NH}_4^+$ . Nitrates are converted to amine nitrogen (protein) in the leaves before it can be utilised. This process like nitrification requires molybdenum.



Nitrate can be used to control the pH in the root zone and importantly on the surface of the roots. When  $\text{NO}_3^-$  is absorbed an  $\text{OH}^-$  ion is excreted to balance the charges in the medium. This  $\text{OH}^-$  is responsible for increasing the pH. An increase in the absorption of  $\text{NO}_3^- \text{N}$  increases the concentration of organic acids within the plant to neutralise the charges of the increase in cations absorbed (Kirkby, 1981). Also see Table 53 in Chapter 24.

The absorption of water is also higher when  $\text{NO}_3^- \text{N}$  compared to  $\text{NH}_4^+ \text{N}$  is supplied.

The absorption rate of nitrates is usually high (active process) but the further processing of nitrate involves passive processes. The absorption process is also dependent on air and soil temperatures. At  $0^\circ\text{C}$  absorption almost ceases but even then some absorption happens. As long

as the trees absorb water, nitrates will be absorbed.

At low soil pH levels, nitrate nitrogen is absorbed fairly quickly but nitrification is slow at such pH levels and the supply of nitrates will be reduced. Ammonium will then accumulate in the root zone which will inhibit the absorption of nitrate.

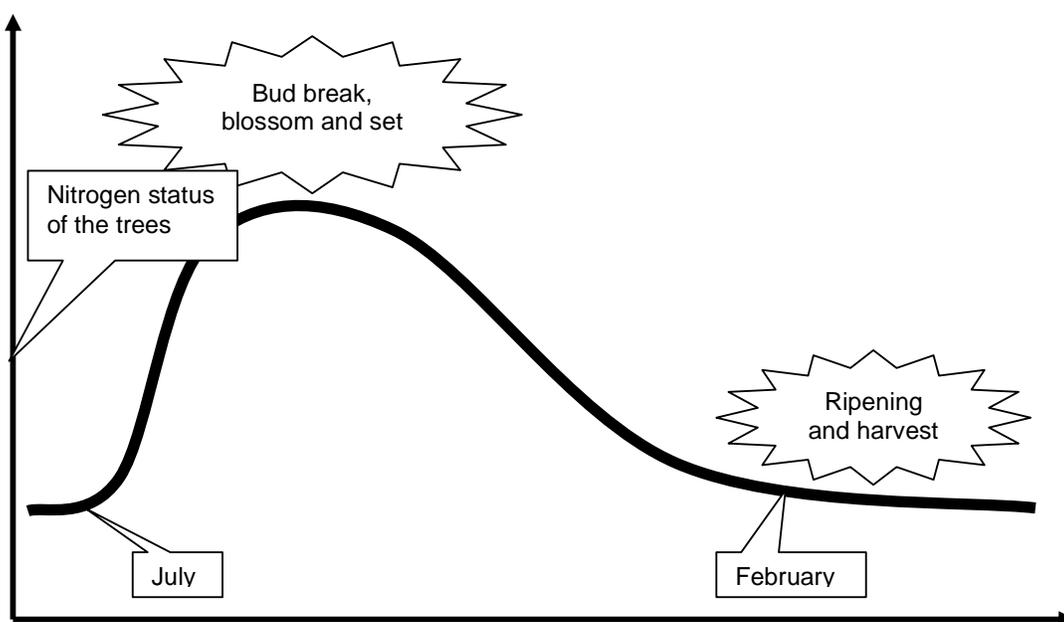
### 2.3 Nitrogen fertilisation of citrus.

Nitrogen is the most important nutrient element in fertilisation of citrus and many other crops. Not because it is required in large amounts but because of its involvement in yield and quality and because the form, the time and quantity applied are all important. The nitrogen status of citrus must be managed to be at its highest during bud break, blossom and fruit set and at a minimum during ripening and harvest. Diurnal absorption of nitrogen also confirms that the rate is at a maximum during blossom and a minimum during the dormant period (Legaz et al, 1981).

Nitrogen applied prior to blossom is equally distributed between the foliage and new flowers and enhance fruit set (Kato et al, 1982). During bud break, blossom and fruit set the demand for nitrogen is high but the supply is still low due to the low temperatures in the soil. It is therefore important to give the trees enough time to utilise the nitrogen during adverse conditions.

Nitrogen applied during blossom has no influence on fruit set. It is too late to influence this process. Nitrogen enhances the distribution of products from photosynthesis to flowers and young fruit. Nitrogen applications after October have almost no effect on the fruit and are partitioned between vegetative activities. For these reasons it is important to apply at least 50% of the nitrogen requirement 6 to 8 weeks prior to the 50% bloom stage. A fertilisation program that does not incorporate these principles will not be successful.

This manipulation of the nitrogen status of the trees is very important. The high status during flowering and fruit set will ensure high quality flowers and a decent fruit set. The low nitrogen status during ripening and harvest will ensure quality fruit of the current crop and accumulation of energy for the coming crop (Figure 3).



**Figure 3. The seasonal variation in the nitrogen status of the trees to ensure yield and quality.**

Whatever nitrogen source is applied, the nitrogen status of the trees must be according to these requirements. Therefore the majority of the nitrogen is applied before blossom. During July and

August (before blossom) soil temperatures are still low but absorption of nitrogen can even be active at temperatures as low 2-3°C (Kato et al, 1982), albeit at low rates. At -4° (minimum) to 9°C (maximum) ambient temperature, the absorption rate of nitrogen is about 10% compared to summer times. Absorbed nitrogen is stored in the roots until the ambient temperature rises followed by an increase in the demand, and then the nitrogen is transported to the flowers and new leaves. To overcome the slow absorption rate, nitrogen must be applied before bud break to enable the roots to accumulate enough nitrogen.

Applications during summer (after December) will mostly go to the skins and new leaves.

Applications during autumn end up in the roots, leaves and shoots where it remains until it is relocated to the buds, flowers and fruit.

### **Soil applications of nitrogen.**

Absorption of nitrogen is directly related to temperature but low a temperature reduces the absorption less than it reduces the absorption rate of P, K, Ca and Mg. Even during the winter enough nitrogen is absorbed provided long enough time is available. The absorption rate during winter exceeds the requirement and N can be stored in the roots awaiting transport to the tops.

Applications of nitrogen must therefore be executed to fit the curve in Figure 3. The type of fertiliser (solutions, granules, organic) and the method of application (hand, machine or fertigation) are less importance. To manage the nitrogen status according to the requirement, nitrogen needs to be applied in one single dosage in July or several smaller ones over an extended period (July to September/October). The splitting of the nitrogen application is based on the properties of the soil, the method of application and the properties of the nitrogen carriers.

Due to the low temperature in the soil during July/August, the applications must be managed to ensure that the nitrogen remains in the root zone. Although root growth ceases at temperatures <15 and >35°C the roots remain alive and active. As soon as the soil temperature exceeds 10°C, applied nitrogen will reach the tops within 25 days.

Splitting of the nitrogen application in conventional systems (all but single line drippers and open hydroponics) is primarily based on the clay content of the soil. Even with fertigation with microjets and sometimes double line drippers, the spitting is based on the clay content. In general, as the clay content decreases, the number of applications increases. Table 10 serves as a guideline for the application of nitrogen by means of hand applications, mechanical spreaders and microjets. The distribution applies to all inorganic sources, organic enriched sources but not for organic material such as compost and kraal manure.

**Table 10. Guidelines for the distribution of nitrogen given as a % of the total requirement.**

<b>Clay content of the soil (%)</b>	<b>% N to be applied in July/Aug</b>	<b>% N to be applied in August/Sept</b>	<b>% N to be applied in September/Oct</b>	<b>% N to be applied in Oct/Nov</b>
< 10%	35	25	25	15
10 tot 15	50	25	25	
16 tot 20	50	50		
21 tot 25	75	25		
> 25	100			

The above mentioned schedules only serve as guide line and can further be refined by considering the effectivity of the nitrogen application, leaf status, colour of the leaves and local conditions. The purpose of the distribution is to get the supply to match the requirement as shown in Figure 3. Clay soils have a natural storing capacity for nitrogen and will be able to follow the demand curve with only one single application of nitrogen. A sandy soil has less of a storage capacity and needs more frequent replenishment to supply according to the demand. Further more, when more than 500g LAN per tree is applied at once to a sandy soil (<5% clay), the created salinity might scorch the roots and leaves and result in a decrease in yield of up to 50%.

Fertigation via microjets requires the same approach as applications by hand. The volume of soil treated by both methods is about the same. Using hand application the fertilisers must be applied where irrigation is applied; making the volumes of soil treated the same. Since Hoagland formulated the first nutrient solution for citrus in 1919 (Hoagland, 1950) no evidence was presented to prove that citrus requires the nutrients in a narrow concentration range. Only with single line drippers and open hydroponic systems (OHS) the concentration and ratios need to be within certain limits

The efficiency of applied nitrogen varies and efficiencies of 12 to 85% have been reported. The efficiency depends on a number of factors and decreases as the application rate increases. If the efficiency rate is 75% at an application rate of 150kg N per ha it will be less (say 60%) at an application rate of 300kg N per ha. The reduction in efficiency can be the result of many factors. High applications of nitrogen can damage the roots and reduce the number of feeder roots. Acidification is another limitation created by high applications of nitrogen. It is therefore also important to measure the efficiency of a nitrogen application. Such information will help to optimise the final fertilisation program. The acceptable efficiency for nitrogen is 70 to 80%. To calculate the efficiency the mass of N removed by the crop is expressed as a percentage of the mass applied. In Table 11 the removal figures are given as 2250 to 3000g per ton of fruit, which can further be refined as follows.

**Table 11. The mass nitrogen removed by 1000kg fruit for various citrus cultivars.**

Cultivar	g N per ton fruit
Lemons	3000
Minneolas	3000
Navels	2750
Satsumas	2250
Grapefruit	2250
All other	2500

To estimate the efficiency of a nitrogen application, apply the following steps;

- A crop of 40 tonnes navels has been harvested
- Therefore  $40 \times 2750 \text{g N} = 110\,000 \text{g}$  is removed by the crop.
- Assume that 200kg N per ha (200 000g N) was applied during the previous season.
- N efficiency is therefore  $= 40 \times 2750 \div 200\,000 \times 100 = 55\%$

An efficiency of 55% is too low and is indicative of problems related to the type of N applied, the method of application or factors that restricted fruit set. A simple calculation can therefore be used to evaluate a number of production factors.

An efficiency exceeding 100% indicates that the trees received nitrogen from another source. This can be detrimental unless this source can be controlled. Two major "other" sources can be involved. Irrigation water containing in excess of 20mg N per litre can cause production problems during the second half (January to June) of the season. The second uncontrollable source is releasing of N from the organic component.

### **Fertigation by microjets.**

With fertigation via microjets the same basics principles as hand applications are applicable. The volume of soil treated is exactly the same and the guidelines given in Table 10 also apply to fertigation with microjets. Do not split the nitrogen applications into too many portions simply because it can easily be done. The efficiency will be reduced.

The nitrogen should be applied during the last quarter of the irrigation cycle followed by just enough water to wash the fertiliser into the top 10 to 20cm layer of soil. Another important aspect is the next irrigation. Due to low temperatures in the soil the absorption rate is slow and the remainder of the N must not be leached beyond the roots by the following irrigation.

The advantage of fertigating nitrogen via microjets is the labour cost. However, if the distribution of the water is poor, then the distribution of the fertilisers will also be poor. With hand application, rainfall can still correct the effect of poor irrigation on fertilisation.

### **Fertigation via drippers**

Distribution of nitrogen via drip systems is based on other principles. With drippers the volume of soil treated varies from 100 to 500 litres and with microjets from 2000 to 5000 and even more. An application of 10g N is effective with drippers because it creates a concentration of 20 to 100mg N per litre soil. The same application with microjets represents a concentration of only 2 to 5mg N per litre.

Small masses of fertilisers are applied with every irrigation and the distribution is based on physiological processes (See Tables 47 to 52 in Chapter 24)

Acidification of the root zone is more rapid due to the smaller volume of soil and the impact of the ratio  $\text{NH}_4^+:\text{NO}_3^-$  directly on the surface of the root. Liming is not effective. The simplest way is to control the pH is to change the ratio of  $\text{NH}_4^+:\text{NO}_3^-$ . The higher the  $\text{NH}_4^+$  component, the more acid will be generated and the lower the pH. A ratio of 20 $\text{NH}_4^+$  to 80 $\text{NO}_3^-$  will keep the pH fairly stable around 6,5 to 7,0. Nitrogen is the only essential nutrient element available to the plants as an anion and a cation and can thus be used in nutrient solutions to manipulate the pH.

By using more ammonium, less other cations will be absorbed and the pH will decrease. By using more nitrate nitrogen, more cations will be absorbed and the pH will increase. When all nitrogen is supplied as nitrates, double the mass of  $\text{K}^+$ ,  $\text{Ca}^{++}$  and  $\text{Mg}^{++}$  will be absorbed compared to all ammonium nitrogen.

Ammonium nitrogen ( $\text{NH}_4^+$ ) is absorbed in a passive process and needs to be "detoxify". Growth is reduced, chloroses appear due to excessive ammonium, reduced starch formation, reduction in the concentration of other cations and acidification are the results when plants receiving only ammonium nitrogen under conditions where nitrification is limited.

In areas with cold winters, it is advisable that the plants be harden-off before the cold spell is experienced. The hardening-off-process needs to be started in February by removing all ammonium from the solution and supply potassium nitrate as the source of nitrogen until March and perhaps April.

## **2.4 Foliar sprays**

Foliar applications with urea are the most successful of all foliar sprays. The absorption rate is highest with urea, followed by nitrate and certain amino acids (Furuya et al, 1999). The rate of absorption decreases as the molecular weight of the amino acid increases. The best absorption is at pH 5,50 to 6,00 and absorbed urea is distributed throughout the entire citrus tree within 30 days (El-Otmani et al. 1999). Apple leaves hold on average 24mg urea-N per  $\text{m}^2$  irrespective of the age of the leaves (Tosselli et al, 1999).

Foliar sprays with urea are used to improve the intensity and quality of the flowers. The sprays increase the  $\text{NH}_4\text{-NH}_3$ -content of the leaves resulting in a number of physiological reactions. The final product is ethylene which has the same effect on the trees as a water stress. In response to this stress applied, as much as double the number of flowers can be produced (Lovatt et al 1989).

Due to this induced stress no urea or potassium nitrate must be applied during the period 6 weeks prior to the 50% bloom stage until 100% petal drop. This is very important for Deltas, Midknights and clementines. Applications with urea or potassium nitrate on the flowers reduce fruit set by as much as 35% (Van Rensburg personal contact).

Apical leaves (leaves on the tips) absorb urea better than basal leaves (Tosselli, 1999).

Tomatoes absorb 70% of the applied urea within 10 hours and after 24 hours all urea has been absorbed.

Foliar sprays can substitute soil applications but the same mass of nitrogen needs to be applied. Using urea, phytotoxicities might arise due to the biuret in the urea. If 100g of N needs to be applied, 217g urea per tree is required. With a soil application it can easily be done but three foliar sprays of 1% solution and 10 litres per tree will be required.

Foliar sprays with urea are also used to stimulate a strong flower following a heavy crop or when the fruit was left on the trees for too long, especially the seedless types.

Foliar sprays with urea at rates of 1% to 1,4% are used to improve the nitrogen status of the trees in general. These sprays can be applied as late as January/February where trees are showing yellowing due to lack of nitrogen. The residual effect of foliar sprays is much less than a soil application and should not retard colour break of the current crop.

Although urea *per se* can also be phytotoxic to plants, it is the biuret in the urea that causes the problems. Urea containing less than 0,5% biuret is safe to use as a foliar spray. Urea containing more than 0,80% biuret is not suitable for foliar sprays (Albrigo, 1999). Biuret can also be toxic if too much is applied to the root zone. This can happen if too much urea is applied.

### 3. PHOSPHORUS

#### 3.1 Roll in citrus production.

The reaction of tree crops on fertilisation with phosphorus is less spectacular than that of annuals. Trees have the ability to absorb phosphorus (P) almost all year round. When the demand is less than the absorption, P is stored in the leaves and wood for later use. Plants can only utilise about 10 to 20% of the P in the soil. The rest is present in an unavailable form (Figure 4) which is continuously supplemented from the unavailable pool.

When the P in the available pool is absorbed the replenishment comes from the unavailable pool but the rate can restrict the supply to the trees.

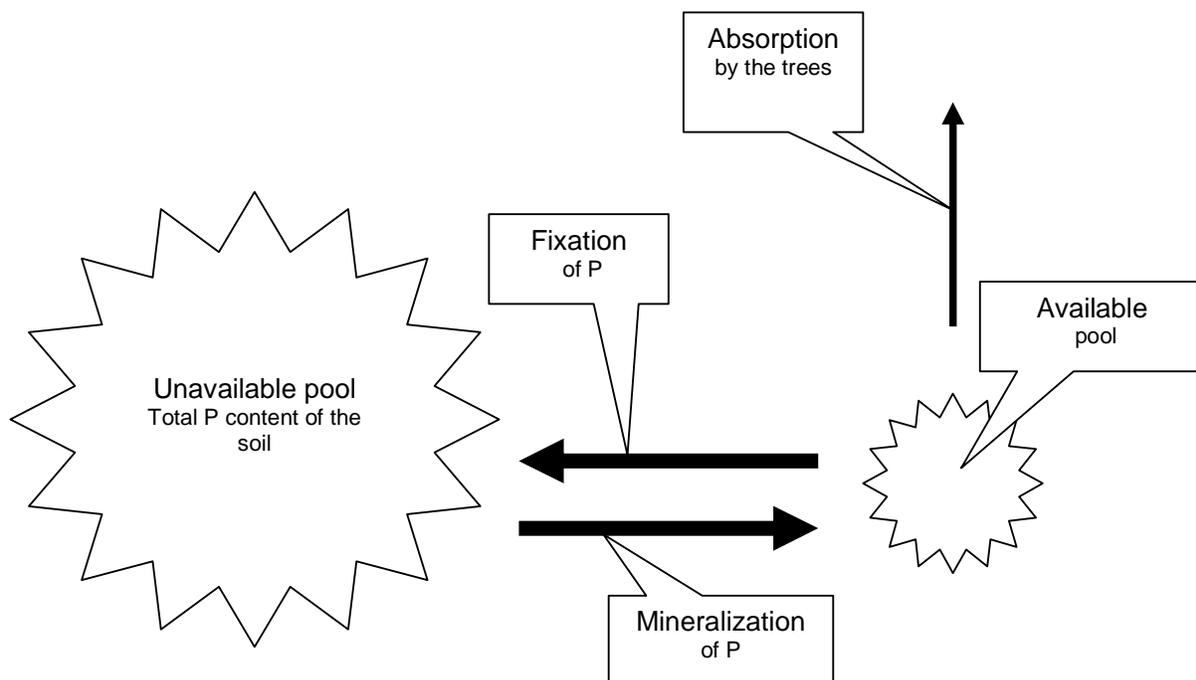


Figure 4. Illustration of the interaction between the available and unavailable pools of

### **phosphorus in the soil.**

This accumulated or P reserve is available to the citrus tree. With radio active P it was determined that the trees still utilised P that was applied 28 years ago (Citrus Industry Vol 3 p139).

The most important ionic species of P are  $\text{HPO}_4^{2-}$  and  $\text{H}_2\text{PO}_4^-$  and the specie dominating is determined by the pH of the soil. At a pH(water) of <5,5 in the soil, the majority of the P will be fixed as aluminium, iron and manganese phosphate which are insoluble in water. When the pH of the soil is increased to pH(water) >7,5 the available P will be fixed as tricalcium phosphate which is also insoluble in water. Liming acid soil or acidifying alkaline soil will mobilise the fixed P.

Although the concentration of P in the soil solution is low, plant roots can utilise this P and accumulate P in the cell sap at concentrations exceeding 1000 fold that in the soil. P is absorbed almost year round with the exception of perhaps the two coldest months. More P is sometimes absorbed than is required. This P is stored and utilised when the demand exceeds the absorption. P does not move readily in neutral to alkaline soils. After 28 years applied P was restricted to mainly the top 30cm layer of soil (Citrus Industry Vol 3 p139).

Absorbed P is quickly incorporated in the metabolic processes. The organic forms of P in the plant are very mobile and can be transported up and down in the trees. Young leaves and other organs are supplied with P from older plant organs including the roots as well as freshly absorbed P

Phosphorus forms an integral part of the most important physiological processes without which the trees cannot survive and produce.

#### **Phosphorus deficiency.**

The most dramatic effect of a phosphorus deficiency is the poor quality fruit produced long before yield is reduced.

A phosphorus deficiency inhibits a number of processes like the production of energy rich compounds and components of the electron transfer chain. Without these compounds energy transfer is not possible.

A low P-status results in poor cells in the fruit. These fruit has a coarse texture, low juice high acid content and appears soft and over mature.

Leaf symptoms of a P deficiency will only appear in the advanced stage but the symptoms on the fruit are distinct and manifested already at mild deficiencies.

#### **Excess phosphorus.**

Excessive supply of P has little influence on the condition of the trees or the fruit. The major problem is that excessive levels of P will have a negative effect on the availability, absorption and utilisation of copper, zinc, boron, iron and nitrogen. The effect of too much P was well demonstrated on tomatoes where zinc deficiency was induced by leaving the application rate of P too high at the end of the season.

A high P status reduces skin thickness and acid level in the fruit. Due to the thinner skins, creasing is more prominent when the P status is high.

The influence of P on fruit quality is only of any importance when the P status is increased from deficient to excess. The effect of a change in the P-status within the optimal concentration range (0,10 to 0,16% P) on the quality is small and variable. A change in the P status from 0,06 tot 0,16% P will however improve quality in most respects.

Excessive applications of P will damage feeder roots, reduce TSS, delay colour break and

enhance the incidence of regreening (Citrus Industry Vol 3 p158).

The lack of symptoms and responds to excess P are unfortunately misused to promote the sales of phosphate fertilisers.

### 3.2 Sources of P

In RSA virgin soils contain hardly any available P. However, many phosphate containing deposits are available. This give rise to a variety of phosphate fertilisers (Table 12). The concentrations of water and citric acid soluble phosphates are used to evaluate the potential of these products for South African agriculture.

Water soluble P is immediately available to plants. Citric acid soluble P needs to be dissolved by the acids in the soil and from the root before it becomes available.

**Table 12. Phosphate fertilisers available in Southern Africa.**

Source	P content* %		
	WS	CAS	Total
Super phosphate (single)	10,5	10,5	10,5
Super phosphate (double)	19,6	19,6	19,6
Rock phosphate	0	3,0	12,6
Calmafos	0	9,0	9,5
Phosphoric acid	31,0	31,0	31,0

WS = water soluble phosphorus

CAS = Citric acid soluble phosphorus

\* The actual concentrations of the various P sources may differ a bit from these values.

**Super phosphate** is a very popular source of P because it contains all the P in a water soluble form and can be applied to all soil types and all pH levels. The phosphorus is present as mono- and di-calcium phosphate. In water it will supply the available forms of  $\text{H}_2\text{PO}_4^-$  and  $\text{HPO}_4^{2-}$  to the plants.

Single super phosphate also contains calcium (21% Ca) and sulphur (11% S).

When mono calcium phosphate dissolves in water, the pH of the immediate surroundings drops to 1,80. This acidic condition will harm the roots. If the surrounding soil contains copper, the copper will dissolve and poses another thread. The pH of the acidified area will gradually increase to its level prior to the application.

**Table 13. Solubility of calcium phosphates.**

Form of calcium phosphate	Formula	Solubility mg/100ml
Tri-calcium phosphate	$\text{Ca}_3(\text{PO}_4)_2$	2,0
Di-calcium phosphate	$\text{CaHPO}_4$	31,6
Mono-calcium phosphate	$\text{Ca}(\text{HPO}_4)_2$	1 800

**Calmafos** is a source of P for acid soils and especially when magnesium is also required. It can however not be banded or spread on the surface. For a good reaction this P source must be mixed with the soil.

**Rock and marine phosphates** like Langfos can only be used on acid soils and must be mixed with the soil. These sources cannot be banded or spread on the surface.

**Phosphoric acid** is a liquid and is the ideal phosphate source for fertigation with drippers. It can also be applied to reduce the pH of the irrigation water. The volume of phosphoric acid ( $\text{H}_3\text{PO}_4$ ) required to lower the pH to 6,00-6,50 will be determined by the concentration of carbonates ( $\text{CO}_3$ ) and bicarbonates ( $\text{HCO}_3$ ) in the water. The volume acid required can be calculated as follows.

- In the first step all the carbonates are converted to bicarbonates  
(me CO<sub>3</sub> x 2) = me HCO<sub>3</sub> add this to the concentration of bicarbonates which is the amount to be neutralised.
- Now the volume of acid required can be calculated.  
me Total HCO<sub>3</sub> x 28,6 = ml H<sub>3</sub>PO<sub>4</sub>\* per 1000 litre water. (\* based on phosphoric acid with a concentration of 36N and a density of 1,69).

This calculation was used to generate the figures in Table 14.

**Table 14. Volumes of phosphoric acid required to neutralised 0,50 to 5,00 me HCO<sub>3</sub> in the water.**

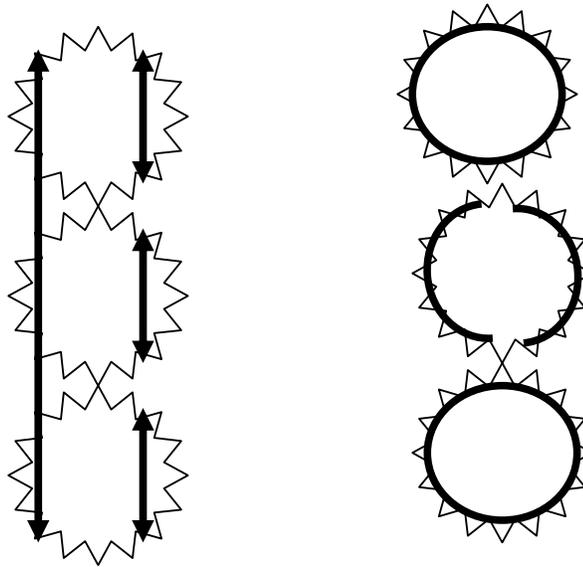
me CO <sub>3</sub> + HCO <sub>3</sub>	ml H <sub>3</sub> PO <sub>4</sub> per 1000 litre water
0,50	14
1,00	28
1,50	43
2,00	57
2,50	72
3,00	86
3,50	100
4,00	114
4,50	129
5,00	143

It is important to note that the density of phosphoric acid is 1,69 and that one litre does not contain 210g but 350g P.

### 3.3 Fertilisation with phosphorus.

#### Soil applications

The efficiency of soil applications of phosphates is restricted by the pH and clay content of the soil. Fixation by the clay and amorphous materials in the soil is also governed by the pH. One method to reduce the fixation is to apply the phosphorus in a narrow strip of about 10cm wide, below the drip line of the trees where the irrigation water is also applied. This is also called band placing or banding of fertilisers. The supers can also be placed in a circle below the drip line. Do not mix the supers with the soil. Only single and double supers can be banded. Ammonium phosphates (MAP and DAP) contains too much ammonium which will scorch the roots when banded. Likewise for potassium phosphates where the potassium is the limiting component. Ammoniated supers can also not be banded



**Figure 5. Illustration of the various methods of banding super phosphates.**

If the phosphate is spread out evenly over the surface the mass is so diluted and it will be fixed in the top few mm of the soil. Banding is about 80% successful and can be used on alkaline and acid soil and on clayey and sandy soils. On white neutral sands (<5% clay) supers can be spread out. Under all other conditions spreading is less than 20% effective. To correct the P status of the trees one or sometimes two applications are required and the residual effect last for 3 to 5 years.

Phosphates that contain no water soluble fractions cannot be band placed. This includes all the marine deposits and rock phosphate. For these sources to be effective they must be mixed with the soil which is impractical and unwanted in an orchard.

#### **Fertigation by microjets.**

Application of water soluble phosphates like MAP and phosphoric acid are not effective when applied through the microjets. The mass/volume is spread over an area of 8 to 15m<sup>2</sup> and will be fixed in the top few mm of soil. It is exactly the same kind of problem experienced with hand applications. Successful spreading of phosphates is restricted to neutral sandy soils.

#### **Fertigation by drippers.**

An important principle with fertigation and drippers is that phosphorus must be applied continuously. If the wetted volume is less than 500 litres, P should be applied every day for at least 8 months per annum.

By using drippers it could be possible that the P status of the trees can be increased during certain physiological stages to manipulate the quality of the fruit. For instance, foliar sprays with MKP are used to increase the TSS of fruit. Perhaps this can be done through drippers.

The combination of  $\text{NH}_4^+$  and  $\text{H}_2\text{PO}_4^-$  apparently has a stimulating effect on root growth. Therefore the season should kick-off applying P in this form.

The density of phosphoric acid is 1,69 and serious errors can be made if the calculations are based on mass and the applications are done in litres. One kg of phosphoric acid contains 210g P but one litre contains 350g P, about 50% more.

$\text{Ca}(\text{NO}_3)_2$  and MAP cannot be mixed and will form a precipitate.

### **3.4 Foliar sprays**

Foliar sprays to improve or maintain the P status of citrus are not done commercially. Partly due to the number of sprays required to increase the P level and partly due to a lack of positive responds. Also refer to Table 62, Chapter 25).

The research on foliar sprays with phosphorus was concentrated on ways to improve fruit quality by increasing the P level at certain critical times. Foliar sprays with 1,0 to 1,5% MKP at intervals of 6, 4 and 2 weeks prior to harvest apparently can increase the TSS by as much as 1% (from 11 to 12%). Concentrations as high as 5% have been applied but locally 1,5% is the maximum to avoid damage to the fruit.

Sprays of 0,22 to 0,88% P have increased the P content of guava trees significantly (Natale, et al, 1999). In other trials with MKP (Rabe, personal communication) and MAP (Coetzee, unpublished data) the attempts to increase the P status significantly, failed. The P content of citrus leaves could only be increased from 19 to 20mg P per kg, two hours after the application. Thereafter the increase was diluted, probably by relocation of the P.

A foliar spray with 1% MAP is used to reduce the acid level of fruit. This is a substitute for calcium arsenate sprays and is done 6 weeks after full bloom.

## 4. POTASSIUM

### 4.1 Roll in citrus production.

Potassium (K) is involved in activation of many enzyme reactions in the biology of the plant. More than 60 enzymatic reactions require potassium for optimal functioning.

One distinct roll of potassium is in the transport of products of photosynthesis from the leaves to the roots. In contrast to Ca, K is completely mobile within the plant. Potassium is present in plant tissue in fairly large concentrations and a deficiency will lead to malfunctioning of many physiological and biochemical processes. Potassium is strongly absorbed by the roots and is easily transported to the meristem tissue. Relocation of K from old to young tissue occurs commonly. That is why it is quite difficult to identify a responds to a foliar spray. Soon after absorption the K is removed to other tissue. Potassium is also involved in the synthesis processes of protein, cytokinin and hence the growth rate of plants.

Translocation of potassium is best when the nitrogen status of the plants is optimal. Translocation also occurs in the phloem vessels and potassium can move up and down in the plant.

Absorption of potassium is being reduced by high concentration of H<sup>+</sup>, (low pH in the soil), calcium (Ca), magnesium (Mg), sodium (Na) and ammonium (NH<sub>4</sub>).

Potassium plays an important roll in the activities of the stomata. Plants that are well supplied with potassium require less water for the same mass of synthesised organic material compared to plant lacking potassium. The transpiration rate is reduced and the opening of the stomata better regulated when potassium is in sufficient supply.

Potassium cannot be substituted by other mono-valent cations in these functions. When potassium is in short supply the stomata will take much longer to close but also to re-open once it in responds to climatic factors.

Potassium improves the assimilation of CO<sub>2</sub> (photosynthesis) and the relocation of the formed products.

The potassium requirement for maximum number of citrus fruit is reached at fairly low levels. However whenever fruit size become an issue, much higher levels of potassium is required. A leaf concentration of 0,75% K is optimal for number of fruit but a K status of 1,00 to 1,50%, depending on the cultivar is required for optimal fruit size.

## Potassium deficiency

Plants suffering from a short supply of potassium do not show visual symptoms. The first symptom is a decrease in growth rate followed by chlorotic (yellow) and eventually necrotic (dead) tissue. Symptoms develop firstly on the old but not the oldest leaves. Plant resistance against diseases, drought and cold decrease when the supply of K is deficient. This alone is another good reason to apply potassium nitrate to young trees during February to May, prior to an expected frosty winter.

Sometimes the leaves of K deficient trees show a bronze colour with a leathery touch.

In practise, a K deficiency is first of all expressed in a decrease in fruit size followed by a decrease in number of fruit. Fruit tend to change colour earlier with little change in the juice and acid content.

The cation exchange capacity (CEC) of the roots has a distinct influence on absorption of K and is also related to growth rate. The CEC of the roots of rough lemon rootstock is  $\pm 40$  and that of trifoliolate only 16 me/kg. Rough lemon rootstocks absorb K much stronger than trifoliate.

Potassium is the element that has a major impact on the manufacturing of sugars and starch. A lack of K will harm these processes.

Nematodes reduce the absorption of K more than that any other element. It is even possible that K can leach out of damaged cells. Usually young citrus trees utilise the potassium in the soil very efficiently but in replant soils not treated to control nematode, the potassium status of the trees were low. "Symptoms" of nematode infestation are a reduction in K status and an increase in the concentration of chloride in the leaves.

Normally the potassium status of citrus trees decline with age. When the concentration in the leaves is allowed to decline below 0,50% K, it is almost impossible to correct the level. Therefore, it is very important to prevent the K status from declining to an irreversible level.

## Excessive potassium

Potassium is utilised very efficient by young trees and an excess of K is usually only a problem with young trees during the first or second year of bearing. As the trees aged, the K status will decrease and less symptoms of excess K is present. Therefore it is important to be cautious with the application of potassium on young trees, especially grapefruit and navels.

Excessive absorption of potassium results in large fruit with coarse and thick skins, except in lemons where the skins will tend to be smoother. Fruit size will, like with other cultivars, increase when the K status of lemons increased.

Potassium and magnesium react antagonistic during absorption and even as a responds to foliar sprays. It is important to watch the magnesium status when focussing on increasing the K status to improve fruit size. Foliar applications of potassium usually result in a decrease in the concentration of magnesium in the leaves.

An excessive concentration of potassium will result in large fruit with less juice, delaying colour break, less TSS and an elevated acid content.

## 4.2 Sources of potassium

The most freely available sources of potassium in Southern Africa are potassium chloride (50% K) and potassium sulphate (45% K). Both are also used in preparing mixes.

Potassium chloride is the cheapest source but cannot be used on chloride sensitive crops and crops that require chloride free conditions. In some circles citrus is regarded as sensitive to

chlorides but no proofs are available that citrus is harmed by moderate applications of potassium chloride.

Potassium sulphate can be used as a source of both K and sulphur (S) and on soils where the application of chloride is unwanted.

Potassium nitrate is also freely available but is mostly used in foliar sprays and hydroponic mixes. The combination of K and NO<sub>3</sub> enhances the absorption of K by the roots and this formulation is an excellent source of both K and N in hydroponics and fertigation with drippers. Due to the cost potassium nitrate is seldom applied by conventional systems to the soil.

Potassium magnesium is a double salt of K and Mg and can be used when both K and Mg need to be applied. It contains 22% potassium and 6% magnesium.

### 4.3 Fertilisation with potassium

The reaction to soil applications of potassium is faster/easier on sandy than clayey (20-25% clay) soils. The volume of the root hairs has a direct relationship with the mass of K absorbed by the roots.

#### Applications to the soil.

One method to evaluate an application of K to the soil is to calculate the potassium saturation. K-saturation is the %K in terms of the total cations namely K+Ca+Mg+Na. The %K should ideally be 5 to 7,5. In soils containing more than 20% clay, levels of >10%K may suppress growth (Citrus Industry Vol 3, p 141).

When applying potassium chloride or sulphate by hand or mechanically, the fertilisers should be spread out evenly below the canopy where the water is applied.

The total application can be split into one or more applications depending on the clay content of the soil. Not more than 250g potassium chloride should be applied to soils containing less than 10% clay. Even if it is spread over 6 to 8m<sup>2</sup> around the tree. The increase in the concentration of soluble salts due to potassium chloride or sulphate will damage the roots, could scorch the leaves and cause leaf drop. The maximum for soils containing 15 to 20% clay is 500g per tree per application. Soils containing more than 25% clay can handle up to 750g potassium chloride per application.

Potassium chloride or sulphate cannot be banded. Temporary salinity created by the concentrated application will damage the roots, leaves and even shoots.

#### Fertigation by microjets.

Both potassium chloride and sulphate can successfully be applied through the microjets. Even on soils with properties that limit the absorption of K, fertigation can be effective. However, the requirements are low concentrations of K applied over the entire length of the irrigation cycle during the day. During the day when the trees utilise the water enriched with K, the K is absorbed before it is subjected to all the negative forces in the soil. This approach was applied in the Sundays River valley with a positive response (Table 15).

**Table 15. The improvement of the potassium status of the trees over 6 seasons when 1600g potassium chloride per tree was applied in dosages of 100g per tree during irrigation periods of 5 hours.**

Year	% K
1996	0,56
1997	0,74
1998	0,91
1999	1,24
2000	1,29

2001	1,44
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This is a low-dosage-high-frequency application. However, the concentration should not be less than 100mg K per litre water.

#### Fertigation with drippers.

Potassium salts are potentially more saline than calcium salts. This limits the application of potassium chloride and sulphate to fairly low concentrations. Solutions of potassium salts have higher EC's than calcium salts at comparative concentrations (Table 16).

**Table 16. Comparative EC's of 0,10% solutions of some fertilisers.**

Salt	EC mSm <sup>-1</sup>	pH
Potassium nitrate	105	5,25
Potassium sulphate	140	5,35
Potassium chloride	185	5,50
Calcium chloride	150	5,55
Calcium nitrate	120	5,25

Due to the mobility of potassium in the plant, continuous applications are not required. This can therefore be utilised to control the EC of the nutrient solution. For instance if more calcium is required in spring, the concentration of Ca can be increased during this critical period without increasing the EC, by lowering the concentration of K in the solution. To ensure that the trees will not lack K during this period, K can be stored in the trees for use when the concentration is lowered.

#### 4.4 Foliar sprays

Reactions to foliar sprays with potassium are much faster than to applications to the soil. With soil applications the time required to notice an increase in the K status can be months or years while it shows within seconds after a foliar spray. Being so mobile K will be removed from the site of absorption (leaf) after a few hours resulting in a concentration not much higher than before the foliar spray. The rate of relocation depends on the initial potassium concentration in the leaves. With trees having a K status of <0,70%, the increase in the leaf status could be disguised by the relocation of K, but the results on the crop is still significant (Table 17). To obtain a permanent increase in the concentration of K in the leaves the status must be lifted to between 1,00 to 1,25%K when relocation is limited.

**Table 17. The apparent lack in responds of the concentration of K in the leaves following a foliar spray, compared to the response in crop performance.**

Treatment	Fruit diameter in mm	% < 62 mm ø	%K in leaves
0	64	29,7	0,36
2x4%KNO <sub>3</sub>	68	7,30	0,36
3x4%KNO <sub>3</sub>	69	6,70	0,40

According to SRCC Tech Dept 1977

Foliar applications of 9 to 10% KNO<sub>3</sub> acidified with phosphoric acid to pH 4,5 to 6,0 (in the retail known as Bonus-NPK) on fruit with a diameter of 18 tot 22mm did however increase the concentration of K in the leaves and skin and increased fruit size by 28% (Achilea, 1999).

The concentration of the potassium in the spray solution is less important than the mass actually applied to the trees. It appears that the volume of water applied per ha can be reduced but then the concentration must be increased to apply an equal mass of the nutrient. This can only be done if the higher concentration is safe and the contact period is not reduced. Up to 10% potassium nitrate has been applied without detrimental effects. An increase in concentration or a decrease in volume requires better climatic conditions to allow for absorption.

Potassium nitrate should not be applied within 3 weeks following an application of Corasil-E<sup>R</sup>. This could aggravate drying out in certain mandarins.

The efficiency of foliar sprays with potassium nitrate can be improved by adding urea or fulvates to the mix. (Table 18, Coetzee unpublished data). Adding urea will also increase the nitrogen content of the mix which will not always be acceptable.

**Table 18. Increase in the potassium status of the leaves following foliar sprays with potassium nitrate, with or without fulvates and urea.**

Treatment	%K in leaves	% Efficiency*
0	0,93	-
4% Potassium nitrate	1,87	30
4%+0,1% Fulvates	2,23	40
4%+0,5% urea	1,99	33

\* 152g K was applied per tree and  $1,87-0,93 \times 4750 \div 100$ g was detected in the leaves. A mature tree carries 4750g dried leaf material (Embelton in Citrus Industry Vol 2).

The limiting factor with foliar applications of potassium nitrate is the nitrogen component. The nitrates restrict the applications to periods 6-8 weeks prior to blossom and after fruit drop. It is therefore so important that the formulations of potassium that contains no available nitrogen should be tested independently. These formulations have the potential to be applied during cell division when extra K could have a major impact on fruit size. These formulations are chelates of K and some of the available ones are K-Charge, Only K, K-metalosates etc. However, EDTA-chelated K contains a lot of N.

An application of about 50g K per mature tree is required. Also note that a concentration of 5000mg K per litre is required to be successful, when potassium nitrate is the carrier. This means 500g K per 100 litre water.

## 5. CALCIUM

### 5.1 Roll in citrus production

Calcium and strong cells and hence shelf life are synonymous. The roll of calcium (Ca) can be compared with that of cement in a brick wall. In the absence of Ca the cells loose their cohesion and sturdiness and the structure collapsed. Calcium is required in processes involving cell division and cell growth and plays an important roll in the activities of biological membranes. When Ca is substituted by H<sup>+</sup> in the nutrient solution, these membranes loose their permeability, organic compounds leak from the cells and the cells die.

The concentration of Ca in the soil solution is 10 times as high as that of potassium, but less Ca is absorbed than K. Calcium is absorbed by a passive process where it enters the plant and is translocated to the fruit and leaves via the flow of the stream of water. The transpiration of young leaves is much higher than that of young fruit and more water and thus more Ca will end-up in the leaves.

Climatic conditions have therefore an over riding effect on the supply of Ca to cells of trees in commercial orchards. Any element of climate that reduces the flow of water from the roots to the fruit, leaves and shoots can induce a Ca deficiency. Therefore too high temperatures will result in closing of the stomata resulting in stopping the flow of water. With no water flowing through the plant no Ca is delivered to the fruit.

Calcium only moves upwards in the trees. Therefore Ca applied to leaves will not be relocated to other parts of the plant. Only the leaves sprayed with Ca will benefit and only at the time of contact. Ca that are not utilised will be precipitated as calcium oxalate. Calcium oxalate is not soluble in water and is, for all practical purposes lost to the tree and fruit.

Plants require fairly small amounts of Ca for normal functioning, but under field conditions, the

absorption of Ca is inhibited by other divalent cations of metals. Calcium is also involved in the detoxification of heavy metals and higher concentrations of Ca can be required under field conditions to satisfy the demand.

Calcium absorption is best in combination with nitrate and absorption is most active in the area just behind the root tip.

No relocation of Ca is possible and no Ca will be transported from old to young leaves or fruit. However, during the night when the humidity is high and temperature is not too low, the roots will keep on absorbing water. Pressure is building within the plant and some Ca can be forced backwards in the phloem tissue to the fruit.

Calcium is also very important for the development of roots. In the absence of Ca, the roots tips will die within days.

When high levels of nitrogen increases vegetative growth, fruit will receive less Ca. Fruit cannot compete with young leaves for water and hence Ca.

Calcium fulfils an even important roll in the soil. There it is also responsible for building and maintaining the structure. A proper structure of the soil will enhance root efficiency through better aeration and water penetration. Calcium is also involved in detoxification of high concentrations of B, Cl and the acid soil complex. By applying only Ca without increasing the pH of the soil at pH 4,0, an improvement in production of Valencias of 500%, was achieved. When the soil pH was 6,00 the improvement in yield with additional Ca was 56% (Anderson, 1972).

#### **Calcium deficiency.**

A lack of calcium needs only to last for a few hours to have an impact on quality. If the transpiration rate is reduced for a few hours by clouds, all cells formed during that period are potentially at risk to show calcium deficiency. Plants rely on a low but constant supply of Ca every hour of the day. Freshly absorbed Ca cannot correct previous short supplies nor can it be stored for future use.

Because Ca can not be relocated, a Ca deficiency will first of all affects the growing cells like root and shoot tips, meristem and storage organs. It is also involved in leaf drop but has apparently no function in enzyme reactions.

Sporadic deficient supplies of calcium are more prevalent in commercial orchard than can be appreciated. The cause of creasing is most probably an interruption in the supply of Ca to the fruit. Factors that induce or aggravate the incidence of creasing are also those that limit the flow of water through the plant.

Calcium absorbed during the first 5 to 6 weeks after blossom is primarily channelled to the young leaves and little enters the fruit. This is also the period when the incidence of creasing is determined. Fortunately Ca is absorbed more strongly during the 5 weeks following flowering.

The relationship between the climatic conditions that aggravate the incidence of creasing and that restrict the flow of water are summarised in Table 19.

**Table 19. The relationship between factors that increase creasing and climatic conditions that restrict flow of water.**

<b>Factors that &gt; the incidence of creasing</b>	<b>Factors that reduce the supply of Ca.</b>
Large number of fruit	Fruit set was improved by mild climatic conditions like overcast and cool weather.
Inside fruit	Transpiration is less on the inside of the canopy than on the outside
Inner half of the fruit	Transpiration is less on the side shaded by

shows more creasing	the tree than on the exposed side of the fruit.
Low temperature	Cell division is less affected by lower temperatures than transpiration.
Very high temperature	Stomata close and respiration is reduced.

Calcium is supplied to the soil based on parameters that have no bearing on the physiological processes in the plant. When the soil analyses indicate a low pH or low calcium saturation, lime and/or gypsum are applied. Calcium is also present in single super phosphates and LAN and is applied indirectly. However, even when enough Ca is present in the soil, sporadic short supplies to the fruit is still possible.

The ratio between the cations, Ca+Mg and Na (sodium adsorption ratio) will also influence the infiltration rate (IR) of water into the soil. A sodium adsorption ratio (SAR) of <2,00 will reduce the IR. Other factors like precipitation rate of irrigation water or rain, mulches and organic material are also involved. Soils containing more than 10-15% clay should have a calcium saturation of 70 to 75% in order to maintain the structure.

In soils planted to avocado, less problems with *Phytophthora* infection is experienced when the Ca content in the soil is high. The higher the Ca contents the less root rot.

Absorption of Ca is also determined by factors like light intensity, humidity, temperature of the air and salinity.

Gypsum is a cheap and abundant source of Ca. Although it is only slightly soluble in water, it can also be applied where drip irrigation is used. When gypsum is applied it is important to watch the concentration and saturation of potassium. Ca will displace the K on the clay complex and the displaced K is subjected to leaching. When K is applied again at a later stage, the reverse reaction will adsorb more K leaving less K available for absorption by the plants.

### **Excess calcium**

Excessive Ca is not commonly found in plant tissue. The high concentration sometimes reported on leaf analyses is more often than not due to the leaves being older than the diagnostic leaf, than an over supply.

The absorption of elements like K and manganese (Mn) is reduced by very high concentrations of soluble calcium. In alkaline and saline soils the poor performance of trees is more likely due to the other complicating factors like high concentrations of sodium and chloride and poor aeration than to the high concentrations of Ca.

In general excess Ca is less detrimental than a deficient supply. Plants grown in soils containing high concentrations of Ca but moderate to low concentrations of the other cations, experience less problems than when grown in soils where one or more of K, Mg and Na are in excess.

“Peteca spot” in lemons is apparently due to damage caused by calcium oxalate crystals in the cells. Calcium oxalate is precipitated in the cells when the supply of Ca exceeds the demand.

### **5.2 Sources of calcium**

Calcium is generally supplied to the soil to improve or maintain the structure of the soil (lime and/or gypsum) or to correct the pH (only lime). Acid soils usually have low calcium saturation and this can be corrected by applying dolomitic, calcitic, hydrated or slaked lime. Also refer to Chapter 20.

On alkaline soils, gypsum is the best source to correct low calcium saturation. For all practical purposes, gypsum has no effect on the pH of the soil. When the pH(water) of the soil >8,30,

dolomitic or calcitic lime can also be applied to supplement the low calcium saturation. The pH of these two limes is 8,30 and by applying them, the pH of the soil will not be increased. Dolomitic and calcitic limes are much less soluble than gypsum and the residual effect creates the impression that is better than gypsum.

Super phosphates also contain Ca.

### 5.3 Fertilisation with calcium

#### Soil applications.

The lime applied to increase or maintain the pH of the soil, is also the main source of Ca. In alkaline soils gypsum is the number one choice due to price and availability. As mentioned above dolomitic or calcitic lime can also be used on alkaline soils provided the pH(water) exceeds 8,3. Where the calcium saturation exceeds 80%, little of the applied K will be available (See above).

#### Fertigation with microjets

Calcium nitrate is about the only soluble source of Ca and can be used with microjets. However the application of gypsum or lime is more effective methods to add Ca to the soil and the nutritional program. Calcium nitrate is too expensive to use with microjets.

#### Fertigation with drippers.

The most important feature of fertigating Ca with drippers is that it must be supplied for every day light hour during the 6 weeks during and after flowering. Calcium nitrate can be used and will also supply all or part of the nitrogen required. Calcium chloride is very seldom used. Gypsum can also be used but must be placed in a small basin below each dripper. Limes cannot be used in this manner. Lime will precipitate elements like P, Cu, Zn, Mn and Fe.

When the irrigation water is acidified to pH 6,00 to 6,50, all the calcium in the water will be available. If the concentration exceeds 50mg Ca per litre it should be enough to meet the demand. However, extra Ca during the critical period during and after flowering will do no harm.

### 5.4 Foliar sprays.

Due to the physiology of calcium, Ca cannot be stored for later use nor can an existing deficiency be corrected, and foliar sprays will have limited value. Only during the actual application period will a foliar spray be of any use. This renders foliar applications of Ca an impossible logistic task.

Apparently apples have a different mechanism. During the first part of the season (up to December), apples can utilise the Ca effectively to satisfy all growth and quality requirements. However, during the second part the absorption is too little and foliar sprays can supplement the shortfall to improve quality (Wojcik, 1999). With citrus it is quite the opposite. Creasing develops during the early stages of development when the supply of Ca to the fruit is too low.

Calcium citrate and calcium acetate can also be used with drip systems but no work has been done with these two sources.

## 6. MAGNESIUM

### 6.1 Roll in citrus production

Magnesium (Mg) is the central ion in the molecule of chlorophyll but more  $\pm 70\%$  of the total Mg content of plants is in a mobile form. The rest is present in chlorophyll, pectin and oxalates. .

The main roll of Mg is its participation as co-factor in enzyme reactions in the processes of phosphorylation. It acts as a bridge between the pyro-phosphate structure during energy transfers. Magnesium is therefore important in the energy management of the plant. The involvement with

enzyme reactions is similar to that of manganese but differ from that of Ca and K.

The Mg status of the trees can therefore also be misinterpreted by using leaf analyses data without orchard information. Due to its mobility, the Mg is relocated from old to new leaves. The old leaves are being shed too early leaving the trees sparsely foliated. The analytical result will reflect the content of magnesium of a tree with a low leaf density. Please refer to the hidden deficiency symptom of nitrogen in Chapter 2.

### **Magnesium deficiency**

A magnesium deficiency will reduce the assimilation rate of CO<sub>2</sub> and other processes long before the chlorophyll per se is reduced. Assimilation of nitrogen into protein is also reduced by a lack of magnesium.

Magnesium deficiency symptoms will develop on old leaves. The magnesium is relocated from the old leaves and symptoms usually appear during autumn or early spring when the demand from new growth is highest. These deficient leaves are shed prematurely and photosynthetic capacity is lost.

Magnesium deficiency can induce an alternate bearing pattern. This is more possible with certain mandarin types, especially the seedy varieties.

Magnesium deficiencies occur country wide and are aggravated when potassium nutrition is emphasised to improve fruit size. Absorption of magnesium is suppressed by potassium applications to the soil and foliar sprays.

To correct a magnesium deficiency might take a number of years. It is therefore essential to increase the potassium applications with caution while the magnesium status is monitored closely. A magnesium deficiency will also result in too small fruit and can mask the effects of an increased potassium status.

### **Excess magnesium**

An excess of magnesium can substitute Ca in the cell walls but the resultant compound has the same qualities.

An excess Mg is mainly of importance due to its inhibiting effect on the absorption of potassium. This will therefore also result in too small fruit.

In soils excess magnesium might acts as sodium in destructing the soil's structure. It can also aggravate crusting and all other negative resulting from an excess of sodium.

## **6.2 Sources of magnesium**

Magnesium can be supplemented by applying any of the following sources (Table 20). Other factors like pH of the soil and additional elements required, will dictate the most suitable source.

**Table 20. Magnesium sources for use in citrus orchards.**

<b>Source</b>	<b>% Magnesium</b>
Magnesium oxide	50 – 54
Magnesium hydroxide	40 – 45
Magnesium sulphate	10
Dolomitic lime	15 – 30
Magnesite	20 – 30
Magnesium carbonate	15 – 25
Calmafos	11

Magnesium nitrate	5.3 – 9.6
Potasmagnesium	6
Mixtures	Varying

**Magnesium oxide** and hydroxide are excellent sources of magnesium and can be used on virtually all soils (especially on sandy soil) as a slow release form of magnesium. These two materials are both alkaline and can also be used as liming material. The application rate to increase or maintain the magnesium status is not more than 500kg per ha. Such an application will not increase the pH of neutral to slightly alkaline soils too much. Both are slightly soluble and the particle size is therefore important.

Both are more effective on soils with a pH(water) <6.5 but can also be applied to soils with a pH(water) up to 7,5.

Table 21 illustrate the response of citrus trees and the soil to applications of magnesium oxide. One application of 208kg magnesium oxide was applied to a soil containing 11% clay. The samples were taken 7 months before and 5 months after the application.

**Table 21. The result of magnesium applications on the soil and trees**

	Before	After
pH(water) of the soil	7,15	7,33
Available magnesium in the soil mg/kg	74	107
Leaf content % Mg	0,28	0,40

**Magnesium sulphate** is very soluble in water but is not a good source of magnesium when using conventional systems. It is a good source of Mg and sulphur for dripper systems and hydroponics. Applications of magnesium sulphate like dolomitic lime and magnesite cannot correct magnesium deficiencies but is useful to maintain a satisfactory status in the soil and leaves.

**Magnesium nitrate** is a good source of magnesium in drip and hydroponic systems and can be used on all soil types. It is also an excellent source of magnesium for foliar sprays.

### 6.3 Fertilisation with magnesium

#### Soil applications

The magnesium content of the soil expressed as a % of the four cations, Ca, Mg, K and Na, should be between 15 and 25%. Deficiency levels of magnesium in the soil are usually related to acid soils and can be corrected with dolomitic lime. However, deficiencies in the trees as indicated by foliar analyses and visual symptoms can also be found on soils containing enough magnesium.

#### Fertigation with microjets.

Although magnesium sulphate can be applied through the microjet, applications of magnesium oxide or hydroxide or even dolomitic lime are preferred. The application of magnesium sulphate through microjets has not been tested properly.

#### Fertigation with drippers.

Magnesium sulphate and nitrate are the most popular sources for application through the drippers. Because Mg is very mobile in the plant, it can be “accumulated” to be utilised when supply is insufficient. Therefore the application of magnesium can also be postpone to control the EC and applied at a later/earlier stage when the demand for Ca is less. It is not required to apply the magnesium continuously every day.

### 6.4 Foliar sprays

A number of magnesium chelates are available. However, magnesium nitrate is still a popular and effective product. Two sprays with 125g Mg as magnesium nitrate per 100 litres water is about

80% effective in correcting mild magnesium deficiencies. Magnesium nitrate can be applied in July with or without urea to correct serious deficiencies before flowering.

## 7. SULPHUR

### 7.1 Roll in citrus production.

Notwithstanding the fact that citrus and many other crops require more sulphur than P, fertilisation with sulphur did not receive its rightful measure of attention. Sulphur is applied indirectly through compost, manures and quite a few inorganic fertilisers and is seldom in short supply. However, when highly concentrated fertilisers were being applied extensively, sulphur deficiencies developed and started to draw attention.

Plants absorb sulphur as the sulphate ( $\text{SO}_4$ ) and this process does not depend on the pH of the soil. Sulphur moves mainly upwards to the tops and is hardly being relocated. Therefore young tissue is supplied with sulphur from the roots and not from older tissue. Sulphur dioxide in the atmosphere can be utilised by some plants but the majority of plants must be supplied through the roots.

Sulphate is reduced in the plant to the thiol-group and then incorporated into sulphur-containing amino acids (Cysteine and methionine). Sulphur is also involved in the condensation of peptides into polypeptides and protein.

Sulphur is an important part of the thiazole ring in the structure of vitamin B-complex.

When S is in short supply, the protein content of plants and seeds is reduced. Many processes involved in photosynthesis require sulphur. Sulphur deficiency results in yellowing of leaves and can be mistaken for a nitrogen deficiency by the untrained eye. Leaf analyses can solve this confusion. Leaf symptoms appear at concentrations of <0,12% S in the leaf, but the deficient range starts at 0,15% S.

However, the symptom of a S deficiency is quite specific. Contrary to nitrogen, sulphur deficiency develops on the new growth. The new leaves have a "rich" yellow colour on a background of green leaves from the previous flush. Trees with a S deficiency flower poorly and hardly set any fruit.

It is therefore important to ensure a minimum S content in the leaves of 0,15% prior to blossom.

### 7.2 Sources of sulphur.

Additional sulphur can be supplied by changing the nitrogen and/or potassium source to one that contains sulphur. Table 22 contains a list of the most available sources of S. In all these listed sources except elementary sulphur, sulphur is present as the sulphate ( $\text{SO}_4^-$ ) which is directly available to the plants. Elementary sulphur, also known as flowers of sulphur, needs to be converted by the microbes to the sulphate.

**Table 22. Sources of sulphur.**

Product	% S	Applied *
Ammonium sulphate	24	C, H and F
Potassium sulphate	18	C and H
Calcium sulphate (gypsum)	19	C and H
Single Super phosphate	11	C
Magnesium sulphate	13	C, H and F
Elementary sulphur	95-100	C

\* by means of; C = conventional fertilisation, H = hydroponics and F = foliar sprays.

### 7.3 Fertilisation of sulphur

#### Soil applications.

The sulphate ion moves easily through the soil profile and is subjected to leaching. Applications of sulphur to the soil are very effective to correct a deficiency or to maintain the optimal status.

When a deficiency of S is detected by means of leaf analyses (leaf level of <0,15%) it will be advantages to correct it before flowering. Applications of gypsum in May to July can be used to correct a deficiency without any precaution or disruption of the fertilisation program. Gypsum supplies Ca and  $\text{SO}_4^-$  and can be applied at any time. Maintenance of the status can be done by applying any of the sources mentioned above, at the appropriate time for the accompanying ion (ammonium, potassium, magnesium, phosphorus or calcium).

#### Fertigation by microjets.

Fertigation of ammonium sulphate or potassium sulphate will be as effective as applications by hand or mechanical spreaders.

#### Fertigation by drippers.

The sulphates of ammonium, magnesium and/or potassium are used in the program to supply nitrogen, magnesium and potassium but also sulphur. In many instances, the sulphates are used to balance the N and P requirement and more than the required concentration of  $\text{SO}_4^-$  is applied. Nutrient solutions should contain not less than 30 and not more than 600mg S per litre. Remember to incorporate the concentration of S in the irrigation water into the final concentration in the nutrient solution.

#### Foliar sprays.

Foliar sprays have not being researched but based on the immobility of S in the plant, has little potential to correct a deficiency. It could perhaps be applied to maintain the optimal status.

## 8. SODIUM EN CHLORIDE

### Sodium ( $\text{Na}^+$ ).

Sodium is an essential nutrient element but is better known for the toxic effects on plants and destructive habits in soil. Due to the abundance of sodium in soils and waters too little sodium or sodium deficiency is not regarded as a problem in agriculture.

Sodium can substitute potassium to some extent in a number of physiological reactions but has never received much attention as a nutrient element. Sodium is too abundant to have any influence on production due to too low supplies.

When sodium nitrate is applied as the nitrogen source, the influence of sodium per se is neglectable. The devastating effect of too much sodium in the soil and the indirect effect of that on the plants have a greater impact on production and received more attention.

An excess of sodium is usually associated with salinity. When the sodium saturation exceeds 3%, the structure of the soil is harmed and aeration and water penetration negatively affected. This usually results in poor and inefficient roots with subsequent loss in production.

When too much sodium is absorbed by the plants the tips of the leaves will turn necrotic (dead tissue). Chlorotic (yellow) spots of irregular shape will appear on the edges of the leaves with occasional interveinal chlorotic spots. Sometimes the impression of manganese and/or zinc deficiency is present. The chlorotic spots are however not symmetric as those due to manganese and zinc deficiency and appear all over the leaf.

However, before this stage is reached, conditions in the soil have deteriorated to such an extent

that production is reduced due to a decrease in root activity as a result of poor aeration and ineffective irrigation.

Excess sodium in the soil is mostly due to applications of sodium rich water and/or poor drainage. Water with a high concentration of sodium, usually also contains a high concentration of chlorides and total salts. The osmotic effect of salty water exceeds that of the individual ions. When the electric conductivity (EC) of the water is  $150\text{mSm}^{-1}$  the osmotic pressure (OP) is 50kPa. A water stress of 50kPa is the maximum beyond which a plant needs energy to utilise the water. With salty water the trees will experience a water stress whilst the roots standing in water, the so called physiological drought.

Under saline conditions the concentration of N and chloride in the leaf will increase and suppress the absorption of K.

### **Chloride ( $\text{Cl}^-$ )**

The element chlorine is present in agricultural soil, irrigation water and fertilisers as the chloride ion ( $\text{Cl}^-$ ) and is utilised by the plant as such. Chloride is an essential nutrient element and deficiency symptoms of  $\text{Cl}^-$  resemble that of iron deficiencies. However, applications of iron chelate will not get rid of the symptoms. Plants require between 0,2 and 0,4 mg  $\text{Cl}^-$  per kg for optimal performance. Chloride is involved in splitting the water molecule during photosynthesis and apparently also in the functions controlling the stomata.

However due to its abundance in waters and soils, chloride excesses are more important. At high concentrations, chloride will suppress the absorption of other anions like nitrate and sulphate.

The source of  $\text{Cl}^-$  is of no consequence and  $\text{Cl}^-$  from potassium or sodium chloride has the same effect on the absorption of nitrate. The effect of chloride can be countered by adding more nitrates. For instance 30mM  $\text{Ca}(\text{NO}_3)_2$  will reduce the detrimental effects of 60mM  $\text{Cl}^-$  (1200mg Ca vs. 2100mg Cl) if the osmotic effect is not considered. A ratio of 1:2 me nitrate: chloride will reduce and a ratio of 1:1 will remove the effect completely. The limitation of this approach is the total mass of N applied which should not exceed the requirement of the trees. However, this can better be used in hydroponics to offset the effects of chloride.

Chloride per se is also phytotoxic. An excess of  $\text{Cl}^-$  will reduce photosynthesis and the ability to regulate the stomata. Excess sodium has no effect on these processes. Salinity caused by sodium and chloride reduces the concentration of N, K, Ca and Mg in the leaves.

As mentioned above, high concentrations of chloride and any other salts will cause a physiological drought. At an OP of 100kPa shoot growth ceases with a drastic reduction in root mass, diameter of the trunk, total leaf area and length of the roots if compared to growth at an OP of 50kPa.

Citrus rootstocks differ in their sensitivity towards high concentrations of chlorides. Sour orange is the most sensitive, followed by Volckameriana, Swingle citromello and Rangpur the least sensitive. Resistance of rootstocks like Cleopatra mandarin against salinity could be the ability to exclude chloride. When Ca is added to the nutrient solution the advantage of Cleo rootstock diminishes and leaf scorching and leaf drop are reduced on sensitive cultivars. With Troyer citrange, Ca will also reduce the translocation of sodium.

It is important to realise the difference between chlorine and chloride. Chlorine is the active ion and is used to disinfect while chloride is the other component of table salt. In moderate concentrations chloride will not kill organic life. At high concentrations it will retard microbial life due to the osmotic effect like in the process of making biltong.

## 9. COPPER

### 9.1 Roll in citrus production

Copper is involved as a catalyst in many enzymatic reactions including the reduction of molecular oxygen. Copper is also involved in the metabolism of protein and carbohydrates where it fulfils the roll of a co-factor in enzyme synthesis. Without enough copper certain enzymes will not be manufactured.

About 70% of the total copper in the plant is present in the chloroplast. It is part of the chloroplast protein and therefore involved in photochemical systems of photosynthesis.

Copper is only slightly mobile in the plant and the relocation rate from old to new tissue can cause a temporary deficiency in fast growing shoots and leaves. The copper status also influences the rate of relocation. The lower the Cu status the lower the relocation rate. Copper moves in the plant as an organic copper complex.

The absorption rate of copper depends on the concentration of copper in the soil, which in turn depends also on the pH.

#### **Copper deficiency.**

Copper deficiency is quite common country wide and need to be supplemented from time to time. The reduction in the application of copper compounds to control fungi, put more emphasis on foliar sprays to maintain an adequate Cu status in the trees. Acute Cu deficiency results in gumming on shoots and in the albedo of the skin. However, gumming in and on shoots is also an indicator of other forms of stress. Another well know symptom which is very specific for copper deficiency, is the abnormal large and dark green leaves. The large leaves frequently appear on fast growing shoots where a single growth flush exceeds 40cm in length. Another specific symptom of a copper deficiency is shoots that are bending sideways in an S-shape

When a single growth flush exceeds 40cm the mass of copper required at the tip exceeds the supply rate from the roots. The leaves typically contain less than 3mg Cu per kg. However, six weeks later, the supply had caught up with the requirement and the concentration of copper in the leaves in crease to optimal levels of >5 mg per kg. This phenomenon is frequently found in young trees.

In practise it is quite difficult to prove the importance of micro nutrient elements because of the many sources of contamination. However under controlled conditions, deficiencies of any of the micro nutrients have an impact on the number, quality and size of the fruit.

#### **Excess copper.**

In the past copper was used extensively to control diseases and caused accumulation of copper in the soil. Copper toxicity can develop especially in neutral and acid soils. When the pH of the soil decreases for some or other reason, the toxicity will be aggravated. The most recognisable symptom of copper excess is damage to the roots. The roots show symptoms resembling aluminium toxicities where the roots form multiple branching which do not developed.

When products like copper oxychloride and copper hydroxide are applied as foliar sprays, the copper concentrations reported by leaf analyses might be excessively high. Most of the detected Cu is trapped in the waxy layer on the surface of the leaves. Washing according to the standard program will remove only some of the copper and the rest will be added to the copper in the leaf. The "outside" copper does not form part of the bio-active copper and high concentration need not be harmful. When the waxy layer is removed the copper concentrations are within acceptable and safe levels.

Excessive soluble copper in the soil can be reduced by liming.

**Sources of copper.**

Copper oxychloride is one of the oldest sources and is still an effective method to correct copper deficiencies by foliar sprays. It is also used in disease control and when it forms part of the pest control program, can be omitted in the nutritional program.

Copper hydroxide is used in the same manner and for the same purpose as -oxychloride with similar effects.

Other formulation of copper includes copper carbonate, copper sulphate and organic copper complexes.

Copper chelates can be used as foliar applications.

**9.2 Fertilisation with copper****Soil applications.**

Any reaction that will acidify the soil will increase the concentration of soluble copper. For this reason, applications of copper to the soil are risky. Precipitated copper (at high pH levels) can accumulate and cause damage whenever the pH drops. That is why stem applications of copper oxychloride increase the concentration of Cu in the leaves of trees on acid soils but not on alkaline soils. Copper applied to the stems will wash down to the soil. If the pH is low enough it will dissolve and be absorbed by the trees. Stem application is only successful in raising the copper status if the soil has a pH of <6,00, contains less than 20% clay and less than 1% organic carbon. Organic materials fix Cu easily and in peat rich soils could induce a copper deficiency.

Stem applications are not recommended to supply nutrient Cu because of the risk of accumulation and subsequent toxicity when the pH drops.

**Fertigation with microjets.**

Applications of copper products through microjets are not recommended for the same reasons as stem applications.

**Fertigation with drippers.**

Low concentrations of soluble copper are required in the nutrient solution. Concentrations of >0,1 mg Cu per litre water can reduce root growth. Accumulation of copper on the perimeter of the wetted volume has the potential to intoxicate the roots when the pH drops. With drippers this is a real threat because the pH can drop substantially over a short period.

Sampling and analyses of the perimeter is therefore a good idea to monitor the development of copper accumulation. More than 30mg Cu/kg soil extracted with 3N acid is potentially dangerous. The copper content of soils should not exceed 2,00 mg/kg when extracted with 0,1N acid.

Damage or symptoms caused by excess Cu is seldom visible in the top growth because the damage is done to the roots.

**Foliar sprays.**

As from 2006, the European Union limits the application of copper to 6000g Cu per ha per annum. At a rate of 2500 litres per ha and 150g copper oxychloride per 100 litre water, 1875g Cu per ha will be applied.

Foliar sprays containing > 200mg Cu per litre water are potentially dangerous and could be toxic, causing leaf burn and leaf drop. However on crops other than citrus, copper sulphate is

successfully applied as a foliar spray at a rate of 100g per 100 litres water (250mg Cu per litre). A fairly safe application rate of copper sulphate is 90-100g  $\text{CuSO}_4$  (25% Cu) per 100 litre (225 to 250mg Cu/litre). Copper Count N, a fungicide is applied safely at a rate of 500ml per 100 litre (400mg Cu/litre) water.

Cu, Zn and B in combination give better results than single sprays.

Any copper product can darken blemishes on the skin. The process that gives rise to the darkened blemish is the reaction of the cell sap with the copper to give a dark brown to black organic copper complex. When a small fruit is injured the blemish will be darkened by any copper product and grow larger with the fruit and will be more visible. When copper is sprayed on mature fruit, only sap from a fresh injury will react with the copper. At this stage an injury will be a culling factor with or without the copper. Copper will not react with old injuries. It needs the sap from the cells to form a dark complex. With the suspensions, copper oxychloride and copper hydroxide, much more copper in total is applied to the trees than with the soluble and chelated products. The potential danger of darkening blemishes is therefore much higher with the suspensions. With copper oxychloride 1875g and with copper sulphate 625g Cu per ha are applied.

For these reasons copper products should be applied prior to blossom even on mature fruit. Copper sprays do not damage the fruit but will accentuate any fresh blemish.

Copper oxychloride contains 50% total copper of which < 2% is soluble in water. However, if the suspension is acidified by buffers or for instance zinc or magnesium nitrate, more copper will dissolve and toxicities are eminent. This will not happen to the soluble products like copper sulphate which is completely soluble and an increase in the concentration on acidification is not possible.

## 10. IRON

### 10.1 Roll in citrus production

Plant roots are in contact with at least three ion species of iron in the soil namely  $\text{Fe}^{++}$ ,  $\text{Fe}^{+++}$  and Fe-chelates. Plants utilise  $\text{Fe}^{++}$  and sometimes also Fe-chelates directly.  $\text{Fe}^{+++}$  is insoluble in water and need to be reduced before plants can absorb it.

Absorption is governed by the metabolism of the plant and can be influenced by other cations. Iron chloroses are frequently induced by other factors such as poor aeration and high pH. Absorption of iron is also suppressed by high concentrations of bicarbonates and phosphates. Bicarbonates are absorbed by the plants and react with the iron already absorbed by the plant rendering it inactive inside the plant, for physiological processes. The total iron content in the plants is therefore not necessarily in the active form. Under such adverse condition iron will accumulate in the leaf but the leaf might still suffer from a deficiency. Deficiencies induced by bicarbonate cannot be corrected by applying iron chelates. Only lime induced chloroses can be corrected by chelates.

Over irrigation results in accumulation of bicarbonates and will induce iron deficiencies.

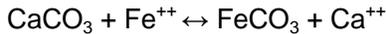
Iron is fairly immobile in the plants and reduction does not occur readily. Symptoms of an iron deficiency therefore develop on young and shaded leaves. Chlorotic leaves do not necessary contains low concentrations of total iron.

Due to the ease of conversion of  $\text{Fe}^{++}$  to  $\text{Fe}^{+++}$ , and visa versa, iron is involved in many oxidation reduction reactions in the plant. The most important functions are in the electron transport chain and in cytochrome synthesis.

#### Iron deficiency

Most soils contain ample iron but a deficiency in available iron can be induced by many factors.

Free lime will induce an iron deficiency due to formation of insoluble iron carbonate. This is called lime induced iron chloroses. The reaction can be written as follows.



The  $\text{FeCO}_3$  will be oxidised further to form  $\text{Fe}_2\text{O}_3$  (iron oxide) a reddish completely insoluble product, which cover soil particles.

The concentration of available iron can be reduced in the soil solution but also in the plants. This is caused by bicarbonate. Bicarbonate is present in alkaline soils but can also accumulate during water logged conditions caused by poor drainage. Under water logged conditions the partial pressure of  $\text{CO}_2$  in the soil increases and more  $\text{HCO}_3$  is formed and absorbed. This could also happen when the irrigation water contains too much  $\text{HCO}_3$ .

A complete lack of iron is restricted to white, acid and sandy soils where all the Fe has been dissolved and leached.

Iron deficiencies limit production of citrus by reducing both the total mass and fruit size. Fruit formed under deficient conditions are flat with a light yellowish colour.

Foliar application of iron is not effective in correcting a deficiency. Soil applications are more effective and economically justifiable permitted more than 20% of the canopy is chlorotic. However, it is more often better to treat the conditions (drainage and pH) that induced the iron deficiency.

Therefore it is important to establish the cause of the iron deficiency in order to select the most effective treatment.

Symptoms of iron deficiency appear during winter and usually first on the shady or inside of the canopy. The new leaves have a normal size and the veins, even the very fine ones are green on a light green to yellow back ground of the blade (lamina).

### Excess iron

An excess of iron is rare and like all other heavy metals will damage the roots before it influence the leaves. Excesses are limited to reducing conditions like water logging as well as acidic conditions.

## 10.2 Sources of iron.

Applications of iron chelates to the soil are very effective. The chelates can be applied by hand or through microjets and drippers. Iron deficiencies are usually associated with alkaline conditions and treatment includes the selection of the appropriate chelate (Table 23). Some iron chelates are not stable at the high pH conditions of alkaline soils.

**Table 23. The most suitable chelate at different pH values of the soil.**

Chelate	pH(water)
DTPA	7,50
EDTA	6,00
HEEDTA	5,90
EDDHA	8,50

## 10.3 Fertilisation with iron.

### Soil applications

Applications to the soil are very effective and should be done during August. Apply 30g Fe-EDDHA per  $\text{m}^2$  to total not more than 300g per tree. This one application should correct the deficiency and increase the number of fruit economically. This chelate is sensitive to sunlight and should be washed into the soil soon after application.

**Fertigation with microjets.**

The same application rate and conditions as mentioned above are applicable. Apply 30g Fe-EDDHA per m<sup>2</sup> to total not more than 300g per tree during a short period, followed by enough water to wash it into the soil. This one application should correct the deficiency and increase the number of fruit economically. This chelate is sensitive to sunlight and should be washed into the soil soon after application.

In sandy soils the application can be split and both applied in August.

**Fertigation with drippers.**

If the pH of the nutrient solution is kept between 6,00 and 6,50 any chelate can be applied, even iron sulphate. The concentration of iron in solution is much lower namely 2,5 to 5,00mg per litre water. Chelates must not be mixed with acids or solutions if the pH is below 5,00. The organic component might be disrupted.

**10.4 Foliar sprays with iron.**

It is claimed that 500g citric acid per 100 litres water, can correct iron deficiencies. The precipitated iron in the cytoplasm will be dissolved by the acids and mobilised rendering it available for physiological processing. A combination of organic acids (citric acid + malic acid + sorbitol) plus iron sulphate also gave good results (Rambola et al, 1999). The acids form chelates with the iron in iron sulphate but the cost of these mixtures are higher than the commercial products.

The lack of relocation of iron in the plant makes foliar sprays an ineffective method to maintain or correct the iron status of the plants.

**11. MANGANESE****11.1 Roll in citrus production.**

Manganese is absorbed as a cation (Mn<sup>++</sup>) and in the same form transported in plant tissue. Manganese (Mn) is not very mobile in the plant and moves with difficulty from old to new tissue.

The functions of Mn in the plant are biochemically about the same as that of magnesium. It is involved in many complexing reactions of enzymes and oxidation-reduction reactions in the photosynthetic transfer of electrons.

**Manganese deficiency.**

Only under very unusual conditions will a deficiency of Mn being the result of a total lack of manganese in the soil. Manganese deficiency develop due to adverse conditions in the soil like high pH, free lime, or water logging that reduce the concentration of available Mn in the soil.

Deficiency symptoms of manganese appear on normal size leaves as mottles between the veins. The symptoms resemble that of a zinc deficiency but less clear and somewhat diffused. .

When lime is applied the manganese status of the leaves decreases. Therefore if the Mn status was on the lower end of the optimal range before liming, a foliar spray with manganese sulphate or nitrate will help to maintain an optimal status after liming.

**Manganese excess**

Excess soluble manganese is common in red acid soils. Like with copper and iron is the roots more subjected to damage by excess manganese than the top part of the tree.

Manganese toxicity had been confirmed on lemons which received a number of sprays with manganese based fungicides. The leaf symptoms resemble that of a magnesium deficiency

although the yellowing is more intense. The chemicals used contain 16 to 21% Mn, probably in a very available form which is much better utilised than the other component, 2 to 23% Zn. The chlorotic sections of the leaves contain on average 950mg and the green parts 450mg Mn per kg.

Excess Mn does not limit the absorption of Fe but the utilisation thereof.

### **Sources of manganese.**

Manganese sulphate contains 23 to 32% Mn depending on the degree of hydration and is the most common source of manganese. Manganese sulphate is used in foliar applications and as a source of Mn in hydroponics. To reduce the incidence of phytotoxicities not more than 250g manganese sulphate should be applied per 100 litres water. Certain fungicides (Dithane) contain enough Mn to satisfy the nutritional requirement. If such products are used in the pest control program, nutritional sprays with manganese can be omitted.

## **11.2 Fertilisation with manganese.**

### **Soil applications**

The requirement for manganese applications is due to the conditions in the soil that reduced the concentration of available Mn. Therefore it makes no sense to apply Mn to the soil under conventional fertilisation and irrigation systems. Chelates of manganese can be use but is normally expensive. Most available chelates are EDTA formulations which is unstable at pH levels where Mn deficiencies are to be treated.

### **Fertigation with microjets.**

The same argument applies to this approach and foliar applications are the preferred method to correct Mn deficiencies.

### **Fertigation with drippers.**

Manganese as the sulphate or nitrate can successfully be applied through the drippers. If the pH of the nutrient solution is kept between 6,0 and 6,5 chelated formulations are not required.

## **11.4 Foliar applications**

Sprays containing 200g manganese sulphate per 100 litres water are usually successful. Other compounds can also be used, provided its efficiency is comparable to that of manganese sulphate. Manganese nitrate is also available and can be applied at the same concentration than the sulphate. Foliar sprays with manganese are applied in October but if the Mn status is very low, applications prior to blossom are justified. Manganese sulphate is compatible with zinc nitrate, magnesium nitrate, sodium borate and urea. Manganese nitrate can also be applied as a foliar spray.

## **12. ZINC**

### **12.1 Roll in citrus production.**

Zinc (Zn) is involved in the metabolism of nitrogen and a zinc deficiency will let to a reduction in the RNA produced and thus in cell division.

Zinc is required to produce serine a precursor of tryptophane. Tryptophane is converted to the growth hormone indole acetic acid that governs the growth rate. Hence the short internodes and small leaves when zinc is deficient.

Like Mn and Mg, zinc is also involved in the binding of substrate and enzyme.

Zn is most probably also involved in the functions of the stomata and like K fulfils a regulatory function.

A very important function of Zn is in maintaining the integrity of the membranes and can reduce the impact of stress (Swietlik, 1999). During adverse conditions like heat or cold, the membranes are damaged and may lose their ability to function properly. If Zn is in short supply the impact of the adverse condition is much larger. For instance, in the absence of enough Zn, P may leak from the membranes. The damage is not reversible and it is therefore important to maintain an optimal Zn status. A Zn spray after the event will be of little use. This could be the reason why Zn and boron sprays onto the flowers of macadamia, mango and avocado improve pollination and fruit set.

Zinc is fairly immobile in the plant and the degree of relocation depends on the current Zn status of the tree. Zinc applied to the soil will accumulate in and on the roots and a small portion is translocated to the tops. With  $^{65}\text{Zn}$  applied to the leaves, less than 1% was relocated to other plant organs (Boaretto et al, 1999).

### **Zinc deficiency.**

The concentration of zinc in the soil is not related to the zinc status of the trees. Zn has to be applied as a foliar spray at least once per annum. Citrus trees utilise the Zn in the soil very inefficiently although Zn accumulates in the roots. Therefore, while the roots may contain enough Zn, deficiencies might still develop in the leaves.

Symptoms of a Zn deficiency are very specific. The leaves are small, the internodes are short and the chlorotic areas between the veins are clear and defined. The chloroses resembles a manganese deficiency but the leaves are about half the normal size.

Zinc deficiency symptoms also appear as a side effect of virus infections, like in the greening disease.

A zinc deficiency will also reduce the root mass of grains and losses of up to 300% have been reported.

### **Excess zinc.**

This is a very rare phenomenon in the leaves but not in the soil. Excessive Zn in the soil will have a negative effect on the translocation of P to the top parts of the trees. Zinc phosphate is insoluble in water.

## **12.2 Sources of zinc.**

Zinc nitrate and zinc oxide are the most used sources of Zn. Zinc oxide is only applied as a foliar spray but zinc nitrate can also be used as a source in hydroponics.

Zinc oxide is effective to improve or maintain the Zn status of the trees but the suspension is corrosive on the spraying equipment. To minimise the corrosion a very fine grade (95% of the particle having a diameter of less than one micron) should be selected.

Zinc chelates are also available.

Zinc sulphate is not used extensively in citriculture.

## **12.3 Zinc fertilisation**

### **Soil applications.**

Nursery trees can utilise Zn from the soil or growth medium effectively. This ability diminishes with age. Application to the soil is very ineffective. On a neutral (pHwater = 6,93) sandy soil (14% clay) 75kg zinc sulphate or 2,50 kg Zn-EDTA were required to mature trees to increase the Zn status of the leaves substantially.

### **Fertigation with microjets**

Only young trees will respond to fertigation and this method is not recommended.

### **Fertigation with drippers.**

Fertigation with Zn through the drippers is possible and is successful with young trees. However, the Zn status in the leaves and soil need to be monitored properly. Due to the poor transportation of Zn via the roots to the leaves, the Zn status of the trees and the efficiency of the applications will demand higher applications. This could lead to accumulation of Zn as zinc phosphate on the roots or as the carbonate in the perimeter of the wetted zone.

It is claimed that the roots developed properly even below the drippers if all the micro-nutrients are supplied through the water. Therefore at least part of the Zn requirement should be supplied with the water. Foliar sprays should be used to supply the rest of the required mass.

### **12.4 Foliar sprays.**

Zinc nitrate is widely used as source of Zn for foliar sprays. It is available in various concentrations. The application rate of 150ml per 100 litres water of a product containing 5,5% Zn is quite successful. Any other formulation can be used as long as the concentration is  $\pm 82\text{mg Zn per litre spray solution}$ .

The movement of foliar applied Zn in the plant depends on the Zn status at the time of spray. At a low status, no Zn will move out of the treated leaf to nearby tissue. Only when the status is high, limited movement can be expected.

Due to the poor movement of Zn, timing the sprays is important. Zinc sprays should therefore be applied when a poor supply will have the highest impact on production. This will be during fruit set and even during flowering. It can also be applied during any stress period. Where Zn deficiencies are present, the applications should be done as soon as possible before blossom.

## **13. BORON**

### **13.1 Roll in citrus production.**

Boron (B) is also fairly immobile in the plant and a continuous supply is required. Boron is involved in carbohydrate supply to the growing tips (meristem), lignifications of cell walls, nucleic acid synthesis and rate of respiration. Boron is therefore involved in reproduction, growth and maintenance of plant organs.

When reproduction, growth and maintenance are inhibited by a lack of B, production is drastically reduced.

### **Boron deficiency.**

Boron deficiencies are common and can effectively be corrected by foliar sprays, soil applications or fertigation. Soil applications have a longer residual effect than foliar sprays.

Symptom of a boron deficiency manifested firstly in the fruit. The fruit is smaller, skins are thin and very hard with gum pockets in the juice vesicles around the centre.

Leaf symptoms of a boron deficiency resemble that of mild cold damage. The veins especially on the underside of the leaf are cracked and corky.

### **Excess boron.**

Of all the micro-nutrients, B is the one that reaches toxic levels the easiest. Even where B deficiency prevails, uneven spreading of the boron source on the soil can cause an excessive concentration in the soil and leaves. When the boron supply increases that quickly the tree will drop its leaves. The root that were overdosed and the branch directly above it, will suffer alone or the most. The dropped leaves will be scorched but the some will remain green with no symptoms.

Symptoms of a moderate but continuous excess of boron (Like when the soil or irrigation water

contains high levels of B) start at the tip of older leaves. The tip turns yellow, then necrotic with mottles between the veins.

The effects of excess boron, especially if it is a temporary condition, can be alleviated by the application of Ca. Lime or gypsum will then be the appropriate source.

### 13.2 Sources of boron.

Of the six micro-nutrients required by plants, only B and molybdenum can successfully be corrected by foliar sprays and soil applications. Various sources of boron are available and the majority can be used in both application methods (Table 24).

**Table 24. Sources of boron**

Source	% B
Water soluble sodium borate	16 – 21
Boric acid	17
Borax	11
Calcium borate	5 - 14

Some sodium borates (Like Solubor<sup>R</sup> and Spraybor<sup>TM</sup>) are formulated for foliar sprays, but like boric acid can also be applied to the soil in a solution by means of an adapted herbicide spray.

Borax is used for soil applications. It contains 11% boron and only 50g per tree or 20kg per ha, must be applied. This small mass must be distributed evenly beneath the canopy. This and the potential toxic effect when the borate is not probably distributed, makes soil applications much less convenient.

Calcium borate contains 14%, total and 1% water soluble B. It is much more convenient and safer to use. Applications of 150g per mature tree on sandy soils (10 -15% clay) and 250g on clayey soils (20 – 25% clay) are safe and much easier to distribute. This application is much more efficient on sandy than clayey soils.

Soil applications of borates last longer with a residual effect of up to five years. Foliar sprays have a residual effect of about 18 months. The soil applications are however, more risky. Even though the correct mass is applied, poor distribution can be risky

Soluble sodium borates (like Solubor<sup>R</sup>) are special formulations for foliar applications. Most borates are not compatible with oil or oil bases formulations, arsenate or lime sulphur.

Initially a warning against applications of borates on the blossom was sound. However, borates are sprayed on mango trees to improve fruit set by supporting the growth of the pollen tube. Most citrus cultivars blossom so profoundly that borates can be applied on the blossom, if required. A reduction in the number of flowers, except perhaps on navels and Deltas can only be beneficent.

Borates will form an insoluble salt manganese borate, if combined at high rates in excess of 150g Solubor<sup>R</sup> or 30g B per 100 litres water. Zinc sulphate will also form a precipitate with borates which renders the Zn ineffective. Manganese sulphate, zinc nitrate and soluble boron are compatible at rates of 80mg Zn, 500mg Mn and 300mg B per litre.

Boric acid is also soluble in water and the same precautions as for sodium borates apply.

### 13.3 Fertilisation with boron

#### Soil applications

Soil applications of borates are very effective on citrus. Either the powders or solutions can be applied by hand or mechanically. Ensure that the borate is properly distributed.

#### Fertigation with microjets.

Fertigation with microjets is generally basically the same as hand or mechanical application and the same principles applies. However if the water is distributed poorly, so will the borate and poor distribution might cause toxicities.

### **Fertigation with drippers**

Any water soluble product can be applied at low concentrations. Also beware of possible accumulation on the perimeter of the wetted zone.

#### **13.4 Foliar sprays.**

Again any soluble borate can be applied as a foliar spray. The effective concentration is mentioned above (30g B per 100 litre water or 300mg B per litre). Adapt the dosage of other products to equal this.

Again, do not mix borates with oil or oil based compounds.

## **14. MOLYBDENUM**

### **14.1 Roll in citrus production.**

Molybdenum (Mo) is the nutrient element that is required in the lowest dosage. Nevertheless, without Mo, no plant production is possible.

Molybdenum is absorbed as the molybdate ( $\text{MoO}_4^-$ ) and is an essential component of at least two important enzymes namely, nitrogenase and nitroreductase. These enzymes are very involved in the assimilation of nitrogen.

### **Molybdenum deficiencies**

Although molybdenum deficiencies can develop on any soil, it is more associated with acid soils which also contain allophane and iron oxides. These minerals form insoluble compounds with Mo if the pH(water) is less than 6,0. Liming these acid soils will release the fixed Mo in adequate concentrations for absorption by the plants.

Soils containing between 0,15 and 5,00 mg Mo per kg (in an oxalate extract at a pHwater of < 6,30) will be able to satisfy the requirement of citrus.

Organic soils, even when acidic, will supply enough Mo.

### **Excess molybdate**

No molybdenum excesses have been reported in citrus production.

Disorders due to excess Mo can develop in animals if the feed contains more than 5mg Mo/kg. Excess Mo limits the metabolism of Cu and  $\text{SO}_4$ .

#### **14.2 Sources of molybdenum.**

Sodium and ammonium molybdate are the common sources and are applied at very low rates.

#### **14.3 Fertilisation with molybdate.**

### **Soil applications.**

An absolute deficiency seldom occurs in the soil. The deficiency is usually induced and without correcting these conditions, soil applications are worthless. Liming is a good approach to also correct the Mo supply from acid soils.

Due to the small application rates Mo is supplemented by adding Mo to any other treatment to the soil.

#### **Fertigation with microjets.**

If the factors like low pH, that induce the Mo deficiency are not corrected, then applications through the microjets will not be effective. It is convenient but not practical.

#### **Fertigation with drippers**

Molybdate can be successfully applied through drippers but again very small rates are required. .

### **14.4 Foliar sprays**

Foliar applications are successful and convenient. The ammonium or sodium molybdate is applied at rates of 15 to 50g per 100 litre water.

## **15. OTHER ELEMENTS**

Humans and animals require more micronutrients for optimal development than plants. Animals require also iodine (I), chromium (Cr), nickel (Ni), selenium (Se), strontium (Sr), vanadium (V) and cobalt (Co). The influence of many of these elements on plant production has been investigated.

It was found that Co and Se improved yield in a variety of crops.

Foliar sprays with potassium iodide at 20mg I per litre water increased the sugar content of apples and grapes.

Strontium can supplement Ca. Applications of Sr will lift the Ca deficiency due to magnesium excess.

Vanadium and gallium stimulate root development but are required at concentrations of 1 part per billion.

Silicon (Si) is known to protect the plant physically against adverse environmental conditions. Silicon is absorbed by the roots and leaves and precipitates just below the epidermis where it provides protection against the penetration of mycelium. Insect find silicon treated plants not tasty. Si is also precipitated in roots, stems, trunks and leaves and supports the plant during periods of cols, heat and drought.

## **16. INTERACTIONS BETWEEN ELEMENTS**

In citriculture the most known interactions are those between N and P and also K and Mg.

In general when the level of N increases, the level of P will decrease and visa versa although the opposite is much less obvious.

When the concentration of potassium in the leaves is increased by means of soil application or foliar sprays, the concentration of Mg will decrease significantly. The opposite interaction is also strong especially if the water contains a fair amount of Mg. Therefore it is very important not to increase K without watching the level of Mg. The increasing K status can reduce the Mg status to such an extent that fruit size will also suffer. It is also very common that the Mg status do decrease when K is applied, especially by means of foliar sprays (Table 25).

**Table 25. The influence of foliar applied potassium nitrate on the magnesium status of the leaves.**

	N%	P%	K%	Ca%	Mg%	S%
Before KNO <sub>3</sub> was applied	2,45	0,15	<b>0,65</b>	5,08	<b>0,32</b>	0,37
After KNO <sub>3</sub> was applied	2,50	0,16	<b>1,22</b>	4,74	<b>0,21</b>	0,36

The other important interaction is between NH<sub>4</sub><sup>+</sup> and K, especially in nutrient solutions. The absorption of K will be severely reduced when the concentration of NH<sub>4</sub><sup>+</sup> is slightly too high. On the other hand NO<sub>3</sub><sup>-</sup> will enhance the concentration of K in the plants. NH<sub>4</sub><sup>+</sup> also suppresses the absorption of NO<sub>3</sub><sup>-</sup>.

Citrus leaves deficient in K will accumulate up to 2,5 times more ammonium than leaves receiving ample K. This gives rise to the increase production of arginine, proline en putresine resulting in stress and a decreased number of flowers and fruit set.

If the P status in the soil or in the plant is too high it will suppress the absorption of Cu and Zn and can induce deficiencies (Martin & Van Gundy, 1963). When the concentration of P in the fertigation solution of sweet peppers is not decreased at the end of the season, Zn deficiency develops.

Zn and Fe will also influence each other negatively when one is in excess present. The high concentration of Fe reported in some leaf analyses will not interfere with Zn because that Fe is insoluble. It is the active iron that interferes with the metabolism of Zn.

Other possible interactions are given in Table 26.

**Table 26. Mutual interactions of the nutrient elements.**

Absorption of .....will	reduce the absorption of .... (Suppression/antagonism)	increase the absorption of... (Stimulates/synergism)
NH <sub>4</sub> <sup>+</sup>	Mg, Ca, K, NO <sub>3</sub> en Mo	Mn, H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> , SO <sub>4</sub> <sup>2-</sup> en Cl <sup>-</sup>
NO <sub>3</sub> <sup>-</sup>	Fe and Zn	K, Ca, Mg and Mo
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> of HPO <sub>4</sub> <sup>2-</sup>	Cu and Zn	Mo
K <sup>+</sup>	Ca and Mg	Mn and Fe
Ca <sup>++</sup>	NH <sub>4</sub> <sup>+</sup> -N	Mn and B
Mg <sup>++</sup>	Ca, K en S	?
Fe <sup>++</sup>	Cu and Zn	?
Zn <sup>++</sup>	Cu	?
Cu <sup>++</sup>	Zn and Mo	?
Mn <sup>++</sup>	Zn and Mo	?
MoO <sub>4</sub> <sup>2-</sup>	Fe	N

Plaaskem (011-397 4640) published the "Mulder's Chart" that lists a number of unusual interactions between the elements as well as the influence of some other factors on the supply of nutrients to the plant. Some interesting ones are as follows.

- A low pH in the soil will reduce the absorption or supply P, K, Ca, S, Mg, Zn, Cu and Mo.
- Cold and wet soils will reduce the absorption or supply of NO<sub>3</sub>-N, P, K, Ca, Mg, Fe, Zn and B.
- High clay content in the soil will reduce the absorption or supply of P, K, Ca, Mg, S, Fe, Zn and Mn.
- Poor aeration or poor drainage will reduce the absorption or supply of NO<sub>3</sub>-N, K en Fe.

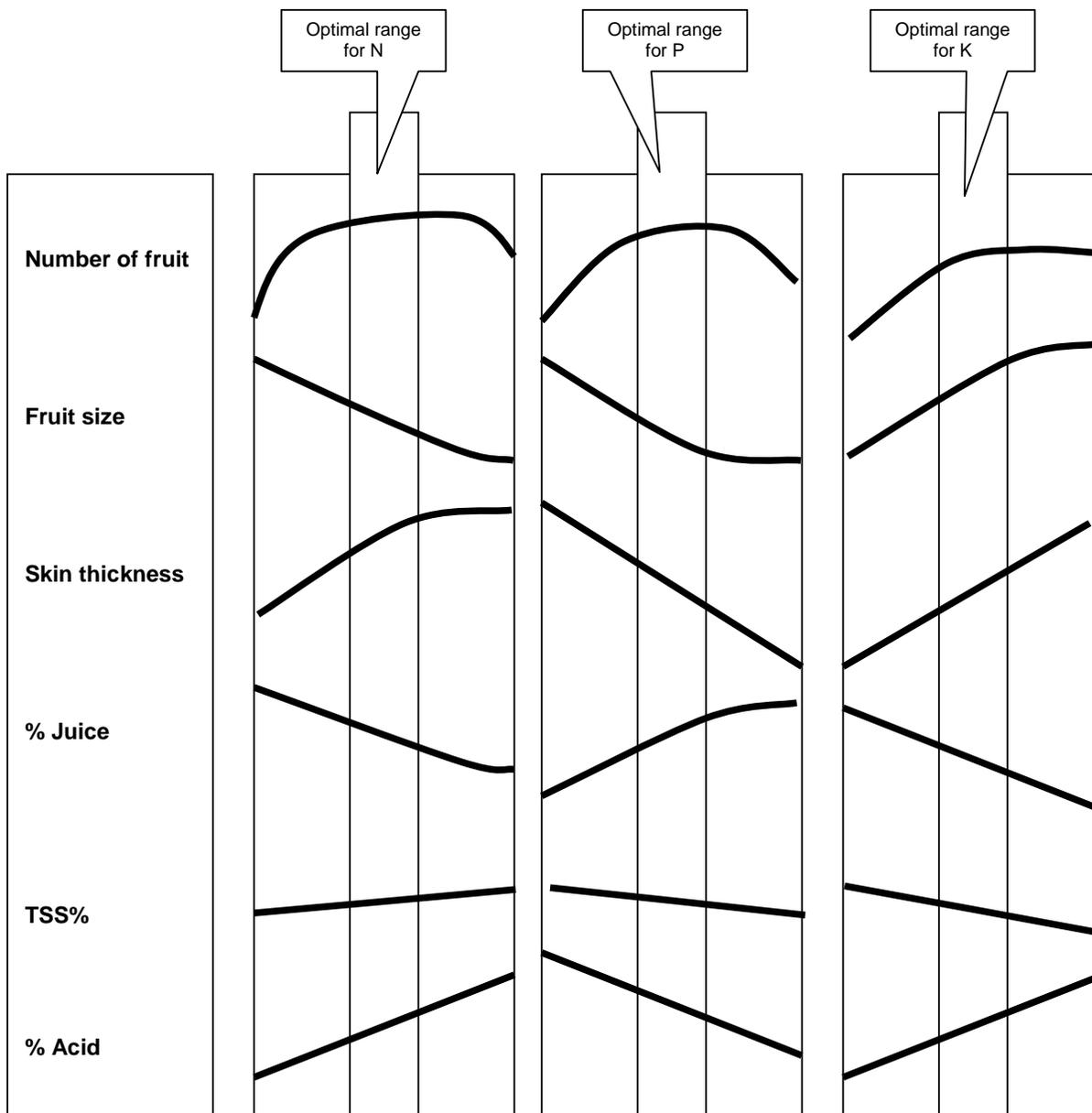
## 17. NUTRITION AND DISEASES.

It is well recognised that nutritionally balanced plants are less susceptible to pests and insect damage. Another well accepted theory is that potassium strengthens the resistance to diseases. This subject did not receive much attention on citrus but the following were established on other crops.

- When plants are subjected to water logged conditions for more than two hours, they become more susceptible to pathogens.
- Avocados planted in red loamy Hutton soils containing > 2000 mg Ca/kg soil are less susceptible to *Phytophthora* than plants in Hutton soils with < 2000 mg Ca/kg.
- The incidence of *Fusarium oxysporum* can be reduced if the pH and Ca status of the soil is increased.
- Nitrates reduce the incidence of *F. oxysporum* in comparison to ammonium nitrogen.
- Ammonium nitrogen reduces the growth of *Verticillium sp.*
- Cu and to some extent also Zn reduce the presence of fungi in general. The problem applying this is that roots are also sensitive to excess Cu.
- The activity of *Pythium coloratum* is suppressed at a soil pH(water) of 6,9 compared to 5,1.
- Neutral to alkaline pH values suppress the activity of pathogens and stimulate that of saprophytes.

## 18. NUTRITION AND FRUIT QUALITY.

The effect of nutrition on fruit quality is well demonstrated when the nutritional status of any of the macro elements (N, P, K, Ca, Mg en S) is increased from a deficient to an optimal level (Figure 6). The change in the quality of the fruit within the optimal range of the elements is however small. When the nutrient concentrations move from optimal to excess the change in quality is again noticeable. Therefore it is very important to get the concentration of all nutrients within the optimal range. Then at least one production factor is under control and will not contribute to poor quality. Figure 6 indicates the relationship between the nutritional status for N, P and K and certain fruit quality parameters. The changes within the optimal range are small and seldom controllable.



**Figure 6. The relationship between the concentrations of the nutrient element and fruit quality.**

Climate plays an over riding roll in the outcome of fruit quality. Even when the nutritional status of all nutrients is optimal, climate can impact negatively on fruit quality. An example is skin thickness which is increased by the warm winter temperatures notwithstanding the optimal status for N, P and K and all the other elements. The hotter the winters the thicker the skins. The opposite is also true and climate can over ride the poor nutritional status to improve fruit quality. In Malelane area low potassium levels are over ride by humidity and heat to give acceptable sized fruit.

A water stress during February /March will increase TSS. The stress can be due to hot climate or purposely induced. This can however not always be done successfully in the summer rainfall areas.

### **Fruit size.**

The prevailing conditions during the development of a fruit will determine the size and quality of that fruit. When a fruit let formed on a rough lemon (RL) rootstock is grafted on a Carrizo citrange rootstock, the mature fruit will express the characteristics of that of fruit produced on the CC and not the RL.

The potential size of a fruit is determined by the number of cells in the ovary but the eventual size by regulating factors like light, temperature, nutrition, irrigation etc. It is therefore very important to keep conditions optimal during bud break, blossom and fruit set. That is one reason why it is risky to used nitrogen stress to reduce the number of fruit in the hope to increase fruit size. Nitrogen is essential for cell division to get the maximum number of cells in the ovary.

Therefore the only time and way the grower can influence the number of cells in the ovary is to keep conditions optimal during bud break, blossom and fruit set. Thereafter he/she can only grow what number of cells was formed. Starting with many cells, required to grow them to 50% of their capacity to get a large fruit. But starting with a few cells in the ovary, every one must be grown to 100% of its capacity to get an acceptable size fruit.

The success of a foliar spray with potassium nitrate depends on the K status of the trees. A K status between 1,00 and 1,25% (optimal) will more likely increase the number of cells in the ovary because the other processes already received enough K. However, when the K status is low (<0,70%) additional K will also be required for other processes than cell division for example for development of leaf buds and more flowers. A foliar spray will therefore also increase the number of fruit which will dilute the effect on fruit size.

In Isreal, 18ppm 2,4-D is added to the 4% potassium nitrate to increase fruit size (Haifa Chemicals).

Another important aspect of nutrition and fruit size is the N:K ratios in the leaves. This was studied in depth by Du Plessis and others. To produce large Valencia fruit the N:K ration must be 1,6 to 2,2 provided the K-status is at least 0,80% (Du Plessis & Koen, 1988 and Du Plessis, 1992). It is usually much easier to change the N-status to reach the required ration, than to increase the K-status. However, do not attempt to reach the optimal ratio if the K-status is too low. As soon as the K-status improves the N-level in the leaves can also be increased. Ensure that the N-status was determined correctly and that the "hidden nitrogen deficiency syndrome" (See chapter 2) did not mask the true N level. In areas where the climate assists in better fruit size the N:K ratios can be increased to 3,4 to 4,5. For instance in areas like Malelane-Komatipoort where the influence of low K on fruit size is over ride by the climate (probably humidity and heat) good sized fruit is produced at K levels as low as 0,60%. Du Plessis also determined that a  $K_{\text{leaf}}:Mg_{\text{leaf}} < 1,00$  results in too small fruit. The optimal ratio is  $\pm 2,85$ .

Selections of clementines like SRA are known to bear too small fruit. However, the nitrogen level cannot be reduced to give larger fruit. This can better be done by pruning, fruit thinning and hormone sprays on trees that are in an optimal nutritional condition.

### **Creasing.**

Although calcium plays an important roll a deficient supply of other elements like S, Mo, Zn, B, Mn, P and K are also involved in this physiological disorder.

Calcium is absorbed passively and at a rate of  $\pm 10\%$  that of potassium which renders the calcium supply more prone to be too low. Another factor that suppresses the absorption of Ca is the biochemistry. When K is absorbed in the presence of nitrate ( $\text{NO}_3$ ) the ratio is 1:1 but when Ca is absorbed the Ca:  $\text{NO}_3$  is 1:0,8. This ratio will increase the pH on the root surface. Ca is immobile in the plant and unlike K cannot be stored in the plant for use when supplies are low. Therefore, it is very important to apply Ca at the correct physiological time when the absorption is critical. For the same reason, foliar sprays with Ca will not be effective. Foliar sprays with Ca only have value

when they are applied at exactly the period when the supply of Ca is too low. Continuous supply to the leaves and fruit via the roots is still the most successful way.

The incidence of creasing is determined very early in the life of the fruit. Additional Ca must therefore be applied during August to November to reduce creasing. With microjets and even drippers, gypsum can be applied. With drippers the gypsum must be applied in a small basin below each dripper. Calcium nitrate can be used as a source of N, which will also supply ample Ca during the critical period.

As already mentioned, other nutritional elements are also involved in creasing. When the N and/or K status is low, the skins of fruit will be thinner and smoother which make creasing more visible. The same applies when the P status is too high.

Foliar applied zinc and molybdenum can reduce the incidence of creasing. These sprays have to be applied during the cell division stage, which is from prior to blossom up to petal drop.

Foliar sprays with urea phosphate (UP), MKP and even MAP are claimed to reduce creasing but the results are inconsistent. Sprays should also be done during pre-blossom to petal drop.

Gilfillan (1979) studied the effect of UP on creasing and concluded that it is only successful when combined with gibberilic acid. In some trials the gibberilic acid on its own gave better results.

### Alternating bearing

An alternating bearing pattern is seldom due to nutritional imbalances or deficiencies. However with certain mandarins a deficient magnesium status can trigger the alternating pattern. ‘

Alternating bearing has an effect on the nutritional status of the trees. During an “on year” (high yield) the concentrations of N, P and K in the leaves are lower and visa versa during “off years” (Table 27).

**Table 27. The effect of fruit load on the nutritional status of the trees with a marginal status.**

Season	Yield	%N	%P	%K
2000	High	2,12	0,10	0,50
2001	Low	2,43	0,12	0,74
2002	High	1,79	0,09	0,40
2003	Low	2,04	0,11	0,74

Trees with an optimal or near optimal nutritional status resist such huge variations in the concentrations of these three elements better (Table 28).

**Table 28. The effect of fruit load on the nutritional status of the trees with a high status.**

Season	Yield	%N	%P	%K
2001	High	2,31	0,13	1,35
2002	Low	2,43	0,13	1,44
2003	High	2,32	0,12	1,37
2004	Low	2,39	0,14	1,42

On the other hand, the larger the variation in yield of Deltas the larger will be the variation in the nutritional status of the trees (Table 29).

**Table 29. The effect of an alternating fruit load on the nutritional status of the trees.**

Season	Yield	%N	%P	%K
2001	27 ton/ha	2,91	0,18	1,38
2002	49 ton/ha	2,10	0,13	0,79
2003	30 ton/ha	3,00	0,17	1,25
2004	52 ton/ha	2,05	0,11	0,66

The alternating fruit bearing pattern should be taken inconsideration when the fertilisation program is formulated. When an “on year” is expected the applications of N and sometimes K must be increased unless the grower will thin the number of fruit. When an “off year” is expected the N application can be reduced (depending on the leaf level) unless actions like girdling or gibberillic acid sprays will be done.

Remember when Deltas are harvested late, the next set will be reduced by  $\pm 5\%$  for every week later than the “normal” time.

### Internal fruit quality

Changes within the optimal concentration range of the nutrient elements will have little effect on the internal quality of the fruit. Significant changes will occur when a deficiency or excess are corrected.

It is therefore important to measure the nutritional status of the trees through leaf analyses and do the required adjustments in the fertilisation program in order to get the concentration of all 14 nutrient elements in the optimal range.

Climate, rootstock, cultivar, soil type and fruit load usually over ride the effects of the nutritional status during adverse conditions but compliment it when conditions are favourable.

The result of the effects of N, P and K is cumulative and together an excess of N and K plus a deficient status of P will have a bigger impact on fruit quality than the effect of single elements. The cumulative effects can be expressed in terms of N+K:P, N:P and K:P. Preliminary optimal ranges for navels are presented in Table 30.

**Table 30. The relationship between the concentration of N, P and K in the leaves and the acid content of the fruit.**

Ratio	Fruit with a low acid content	Fruit with a high acid content
N:P	<19	>21
K:P	<6,50	>7,25
N+K:P	<25	>29

Preliminary ranges for the N, P and K concentrations in the leaves of grapefruit, satsumas and navels known to produce good quality fruit are given in Table 31.

**Table 31. Ratios of N, P and K in the leaves that usually result in good quality fruit.**

	N:P	N+K:P
Grapefruit	13 tot 18	18 tot 22
Satsumas	11 tot 15	16 tot 20
Navels	16 tot 24	24 tot 28

The value of these ratios is to help in determining the possibility that the nutritional status contributes to the poor quality of the fruit. If the quality of grapefruit is poor and the N:P ratio is 20 then the nutritional status contributes to the problem. The opposite is not true that if the ratio is 20 the quality of the fruit will be poor. Too many other factors contribute to quality

The nutritional status of the plants and climate also has a cumulative effect on fruit quality. A cool climate and a deficient P status will give thicker skins than the two factors alone. However, this can also result in a positive effect where the one offsets the negative effect of the other. In a cool climate the effect of too high nitrogen levels will be neutralised by low temperatures prior to harvesting. The effect of a low K status is “neutralised” by higher heat units and humidity in the Malelane area.

Nevertheless a number of practises will help to improve fruit quality. Some foliar applications are used to manipulate the trees. These chemicals accidentally also contain nutrient elements but the reason for the applications is not to apply nutrients but to manipulate.

For instance, foliar sprays with 1% MAP 6 weeks after petal drop will reduce the acid content of the fruit by manipulating the physiological process involved in acid formation. This treatment replaces the application of calcium arsenate. The decrease in the concentration of acids can perhaps also be achieved with extra P through the drippers. Fruit thinning and hence increase in size was achieved by applying a 4% MAP (Lavon & Bar-Akiva 1976).

Foliar application of 1,25% MKP 6, 4 and 2 weeks prior to harvest can apparently increase the sugar content of fruit with as much as 1% (from 9,0 to 10,0%). Perhaps this can also be achieved with extra P through drippers.

A controlled water stress lasting 6 weeks during January to March will increase the dissolved solids (sugars and acids) in the fruit. Early cultivars need to be stressed in January/February and late cultivars in February/March. With controlled water stress the water tension at the roots should not exceed -60 to -70 kPa. If the trees are too much stressed, the stomata will close and photosynthesis will stop and the whole purpose of the exercise is negated. The stress must also not be too weak. An indicator of the level of stress is the curling of the leaves. If the leaves curl by 11:00 the stress must be lifted by irrigation. If by 11:00 no curling is experienced, no irrigation is required for that day.

With Marisol the acid content of the fruit depends on the fruit load. If the load is high, the acids will be low.

#### **Skin thickness and texture.**

Again, the nutritional status of the trees will only influence the thickness and texture of the skin if the concentrations are too high or too low. A too low P and too high N and K status will result in thick and coarse skins. As mentioned earlier, these effects are cumulative. Trees with a nitrogen deficiency will set less fruit and when the K status is high, the few fruit will be large with thick and coarse skins.

Poor quality fruit is not related to the nitrogen status during fruit set, but during autumn. The nitrogen levels of orchards are measured during late summer and autumn and the optimal level is what it should be at that time to ensure good quality fruit. The nitrogen content has a lesser effect on fruit colour of late than early cultivars. Remember to pick the leaf sample from behind a fruit.

A number of special treatments can be applied to get smoother skins. However the results are quite variable. Some of these treatments are listed below.

- A foliar spray with 5%MKP to Star Ruby grapefruit increased the juice content and skin thickness. The acid content dropped and the P and K content of the leaves increased (Lavon et al 1995).
- Urea phosphate (UP) is a physical mixture of urea (50%) and MAP and is applied to improve the skin qualities. UP contains 27% N and 12,7% P and is applied as 1 to 1,5% solutions. Foliar sprays with various P compounds 6 weeks after full bloom gave smoother skins with Nouvelle, Thoro Temple, Shamouti and Valencia Late. Applications rates were 1% MKP, 3% MKP, 5% MKP and 2% UP with little difference between P compounds (Mudau et al. 2005).
- Shamouti is prone to coarse skins but with special treatment this can be improved (Refer to the program in Chapter 22). The number of fruit set on Shamouti, certain satsumas and even young Star Ruby grapefruit must be high to improve skin qualities. Water stress, urea sprays and other methods must be used to set enough fruit.

- When lemons are cultivated for their oil content in the peel, gibberillic acid sprays will enlarge the oil cells and hence the oil production.

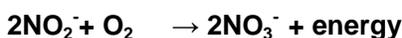
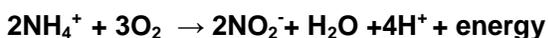
## 19. ACIDIFICATION OF SOIL.

Acidification of the soil is enhanced by the application and subsequent oxidation of ammonium nitrogen. Other factors like the buffer capacity of the soil, quality of irrigation water and environmental factors determines the rate and magnitude of the acidification.

Acidification can also be done purposefully to reduce the pH of alkaline soils.

### Acidification due to fertilisation.

In the soil the nitrifying bacteria will oxidise ammonium nitrogen to nitrate. The source of the ammonium (fertilisers or organic matter) has little influence on this process. The process depends on temperature and moisture and is usually completed within 14 to 21 days. During the nitrification process acid is formed.



The  $4\text{H}^+$  in the equation above is the acid and responsible for acidification of the soil. Ammonium nitrogen moves fairly easily into the subsoil where it is nitrified. Lime is also applied to the topsoil and the neutralising starts at the top. The subsoil is therefore more prone to be acidic than the top soil. Therefore it is important to start liming when the pH(water) in the topsoil approaches 6,00.

Low pH conditions will have at least three detrimental effects on the citrus tree.

- The direct effect of the concentration of the  $\text{H}^+$  on root activity.
- The direct effect of the elevated concentrations of aluminium and heavy metals.
- The indirect effect on the availability of the nutrient elements.

### The direct effect of the concentration of the $\text{H}^+$ ion.

Acidification of the root zone is one factor that will reduce production of citrus trees unnoticed. Smith (1957) found in Florida that the production of citrus fruit can be increased from 20kg per tree at pH 4,00 to 110kg per tree at pH 7,00 (Table 32).

**Table 32. The effect of various pH levels on citrus production.**

pH	Yield kg/tree	Surface area of the canopy $\text{m}^2$	Mass roots in kg per tree
4,00	20	18,3	5,20
5,00	50	26,6	7,50
6,00	100	30,9	7,80
7,00	110	33,8	7,75

The source of the acid was not important.

### The direct effect of the concentrations of aluminium.

When the pH(water) of the soil is reduced beyond 5,3, more aluminium dissolves in the soil solution. Aluminium is toxic to plants and root growth is the first to suffer. In an experiment with rough lemon seedlings increased concentration of aluminium in the nutrient solution, reduced plant growth in totality (Table 33, Coetzee, unpublished data).

**Table 33. The effects of increasing concentrations of aluminium in the nutrient solution on growth of citrus seedlings.**

Al in mg per litre	Plant length in mm	Leaf mass in gram	Stem mass in gram	Root mass in gram
0	401	7,84	4,31	13,68
10	361	7,45	3,56	11,30
25	320	6,15	3,74	11,06
50	257	4,86	2,46	5,98
100	164	2,87	1,11	2,40

Root growth was restricted more than shoot growth. The mass of top growth was reduced by 67,24% but root mass decreased by 82,46%. No leaf symptoms, only loss in growth was visible and the plants retain a healthy appearance. Note, no aluminium toxicity symptom appears on the leaf.

Due to the faster rate of acidification of the subsoil, sampling this volume will be required from time to time. It is more important for orchards with a root system exceeding 30cm because the standard depth of sampling is 0 to 30cm. In orchards with an effective rooting depth of less than 30 cm, the reason might be too acid subsoil.

#### **The indirect effect of soil pH(water) on the availability of the nutrient elements.**

Apart from the detrimental effect of too acid soil on the roots, the availability of the nutrients is also reduced by an unfavourable pH (Table 34). The influence on the efficiency of the nutrient elements is due to solubility of the element but also to the concentration of other elements and microbial activity.

**Table 34. The effect of soil pH (water) on the efficiency of N, P and K fertilisers.**

pH(water) of the soil	Efficiency (%) of N sources	Efficiency (%) of P sources	Efficiency (%) of K sources
4,50	35-30	20-25	30-35
5,00	50-55	30-35	50-55
5,50	70-75	45-50	70-75
6,00	85-90	75-80	100
7,00	100	100	100

\* Efficiency is expressed as a % of the efficiency at pH(water) 7,00 taken as 100%.

The efficiency of nitrogen amongst other factors governed by the microbial activity in the soil. Mineralization, nitrification and nitrogen fixing are less at a low (acid) pH. When ammonium nitrogen accumulates in the soil, the absorption of K and  $\text{NO}_3$  is reduced.

The highest concentration of available P, namely  $\text{HPO}_4^{2-}$  and  $\text{H}_2\text{PO}_4^-$  is at a pH between 6 and 7. Above pH 7,0 insoluble more P as tri-calcium phosphate reduces the concentration of available P. At a pH less than 6,0 P is precipitated as aluminium phosphate.

The absorption of K is related to the size of the root surface. At a low pH root growth is reduced and less K will be absorbed.

#### **Results of a too acid environment.**

Various "symptoms" of a too acid root zone have been observed.

- The development of feeder roots is directly related to the pH of the soil. This is more noticeable when the pH of the root zone is increased to 7,0. The higher the pH (up to 7,00) the higher the mass of roots.
- An investigation into the cause of poor yields in one part of a citrus orchard revealed that

the only significant difference was the pH of the soil (Table 35).

**Table 35. The effect of soil pH on the performance of citrus trees.**

Depth	Good section	Poor section
0 tot 150mm	7,08	6,82
150 tot 300mm	6,02	5,33

- The production of satsumas was increased by >30% when the pH(KCl) of the soil was increased from 4,0 to 5,5.
- The relative production of Valencias was only 51% on sites where no lime was applied compared to sites that were limed to keep the pH(water) at 7,00 (Anderson, 1984).
- In a growth medium consisting of composted bark, citrus seedlings showed signs of withering even after irrigation on an overcast and rainy day. The pH(1:1,5) of the medium was 4,1.
- In acid soils the concentration of both aluminium and H<sup>+</sup> increase and these elements damage and/or reduce the root tips. The number of root tips is well correlated with production.
- When the pH(1:1,5 water extract) is less than 5,50 long roots with little or no branching are formed. The new root buds do not develop and resemble bud mite damage on leaf buds.
- The length of the taproot of pecan nut trees increased by >60% when the pH(water) was increased from 5,0 to 6,5. The production of feeder roots increase 6 fold.

#### **Purposeful acidification of the soil.**

Alkaline soils can be acidified on purpose and various options are available. Apart from acidification by ammonium salts, the soils can also be acidified by sulphuric-, nitric- or phosphoric acid. The acidification is immediate. Another option is the application of elementary sulphur (S), also known as flowers of sulphur. This is a microbial reaction and it takes about 3 months to convert all S. The sulphur bacteria will oxidise the S to SO<sub>2</sub> and with water it forms sulphurous acid (H<sub>2</sub>SO<sub>3</sub>). This is a more manageable process than acidification with acids.

Aluminium sulphate or iron sulphate will also acidify the soil. When these two salts are added to an alkaline soil, the aluminium and iron will precipitate and creates an electrical imbalance. To balance this H<sup>+</sup> is formed which will acidify the environment. Please note that the acidification is not due to the sulphate but to the ammonium, aluminium or iron in these compounds. The SO<sub>4</sub><sup>2-</sup> in these salt, like in gypsum (calcium sulphate) or potassium sulphate contribute little to the acidification. To acidify H<sup>+</sup> ions must be produced.

Reactions that acidify the soil can be summarized as follows.

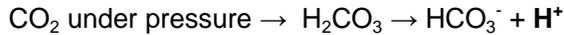
- $(\text{NH}_4)_2\text{SO}_4 \rightarrow 2\text{NO}_2^- + 8\text{H}^+$  a biological reaction.
- $\text{S} \rightarrow \text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3 \rightarrow 2\text{H}^+ + \text{SO}_3^{2-}$  a chemical reaction.
- $\text{S} + \textit{Thiobaccillus} \text{ sp} \rightarrow \text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$  a biological reaction.
- $\text{Al}_2(\text{SO}_4)_3 + \text{H}_2\text{O} \rightarrow 2\text{Al}(\text{OH})_3 + \text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$  a chemical reaction.
- $\text{FeSO}_4 + \text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_3 + \text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$  a chemical reaction.

The reaction of gypsum or potassium sulphate, when applied to the soil creates no H<sup>+</sup>.

- $\text{CaSO}_4 \rightarrow \text{Ca}^{++} + \text{SO}_4^{--}$

The acid requirement of soils can be determined in the laboratory on the same bases as the lime requirement. Soils from the Sundays River Valley requires 275ml sulphuric acid or 160g S per m<sup>2</sup> and 15cm deep to reduce the pH to 6,50.

Where drip irrigation is used, acidification of the nutrient solution and the root zone can be done by acids or carbon dioxide gas ( $\text{CO}_2$ ). In water there are three different species of  $\text{CO}_2$  present namely  $\text{CO}_3^{2-}$ ,  $\text{HCO}_3^-$  and  $\text{H}_2\text{CO}_3$ . When  $\text{CO}_2$  is pressurised carbonic acid is formed and the pH will decrease. As soon as the pressure is lifted the pH will increase again. Therefore this method is only suitable with drippers. With microjets the pH of the nutrient solution will start to increase before it hits the soil.



The pH of soda water is for the same reason  $\pm 4,20$  but as soon as the container is opened the pressure is released and the pH starts to increase.

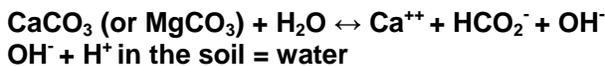
When alkaline soils are acidified a lot of salts will dissolve and the EC of the soil will increase. The EC will rise according to the rate of acidification and might be so quickly that the roots and leaves can be scorched. These salts must be removed as quickly as possible by leaching. However this is not a simple operation and must be handled cautiously.

In calcareous soils (rich in free lime) the buffer capacity will prevent the pH from increasing slowly. The pH will remain high until all the free lime has been neutralised and dissolved before it decline. The development of the acidification therefore cannot be monitored by pH. There is no relation between the free lime and pH nor between the volume of acid required to acidify and pH.

## 20. LIMING AND LIMING MATERIALS

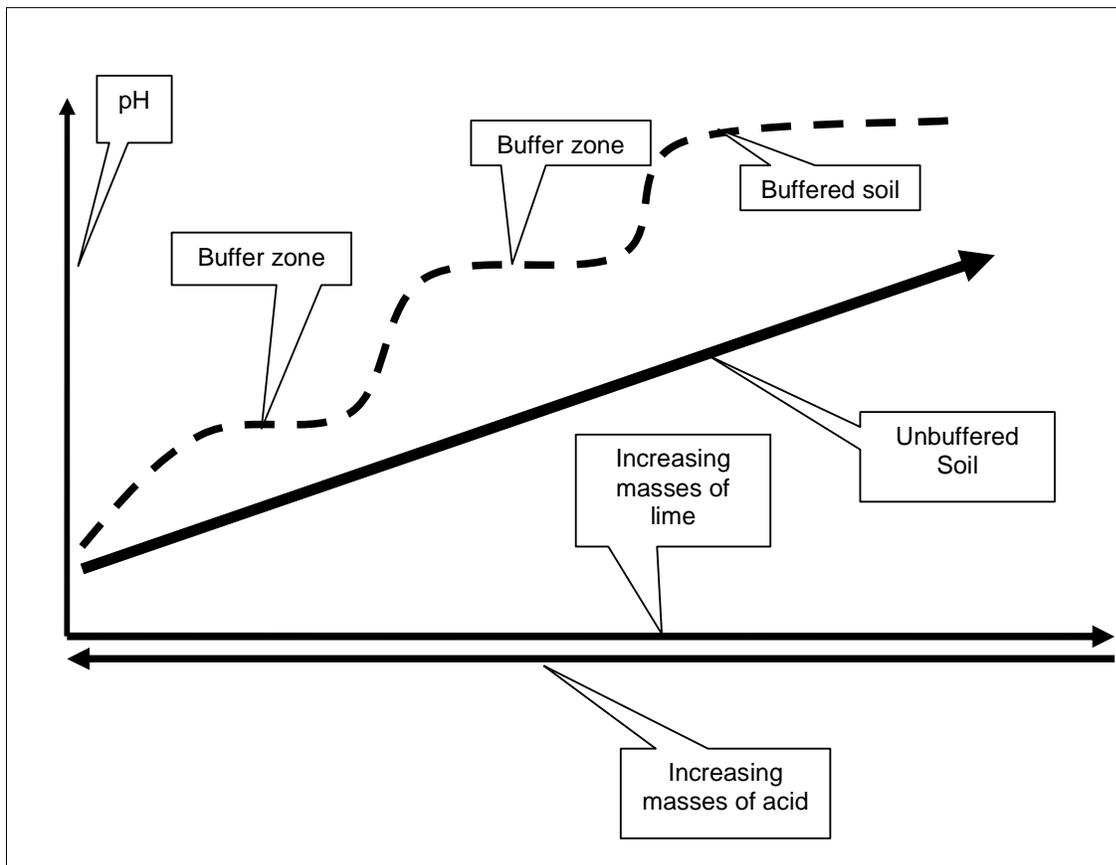
Natural soil forming processes, cultivation and fertilisation are some of the factors that cause the pH of the soil to decrease. Low pH conditions are not conducive to plant production and need to be corrected.

The low pH conditions can be corrected by applying liming materials to neutralise the acids in the soil. Chemicals used must produce  $\text{OH}^-$  ions to neutralise the  $\text{H}^+$ -ions in the soil. Liming materials like dolomitic and calcitic lime supply these ions when dissolved in water. The  $\text{OH}^-$  then reacts with the  $\text{H}^+$  in the soil as follows;



Calcium carbonate is only slightly soluble in water and the reaction develops slowly. Therefore the pH will never exceeds 8,50.

Liming (increasing the pH) or acidification (reduction of the pH) develops according to the same buffer systems in the soil. In sandy soils the buffer capacity is low and the reaction curve is a straight line. Clayey soils like Black Turf have very strong buffer capacities. The more lime applied the higher the pH (Figure 7). A stepwise change in the pH is experienced when buffered soils are limed (Figure 7). This means that at a certain stage the pH will hardly change (horizontal parts of the curve) when additional lime is applied. As soon as the buffer capacity at this point is exhausted, the pH will increase sharply until the next buffer zone is reached. This is the result of "stored"  $\text{H}^+$ -ions released to neutralise the  $\text{OH}^-$  ions from the lime. This resistance of the soil against changes in the pH is called the buffer capacity. Natural soils may have many stages of buffering (dissociation constants) where the pH remains the same whether lime or acid is applied.



**Figure 7. The different responds cures of buffered and un-buffered soils on liming and acidification.**

Liming (increasing the pH) follows the curve from left to right. Acidification will follow the same curve for a particular soil from right to left as more and more acid is applied.

For the maximum effect, liming materials should be mixed with the soil. Therefore it is important to apply lime (where required) prior to planting and mix it properly with the soil in the root zone. After planting, lime cannot be incorporated properly with the soil. Such damage to the roots is unwanted.

In existing orchards the lime is applied to the surface where it will dissolve slowly and eventually reaches the acidified soil. Therefore is it very important to start applying when the pH(water) of the top 30cm approaches 6,00

Lime applied to the surface result in a sharp increase of the pH of the very top layer of soil. This will affect the solubility of some elements, especially the micro-nutrients. The manganese status of citrus, for example dropped from 122 mg Mn/kg before liming (2001) to 39 mg Mn/kg after liming (2002). Nevertheless, the effect is controllable with foliar sprays and less devastating than an acid environment around the roots.

Increasing the pH of acid soils will also improve the availability of elements like N, P, K, Ca, Mg and Mo (Also refer to Table 34) and increase the resistance to root diseases. That on its own is worth more than the few sporadic negative effects of liming.

### **Liming materials.**

All materials that have the potential to deliver  $\text{OH}^-$  ion are potential liming materials. This includes hydroxides, carbonates and bicarbonates of potassium, calcium, magnesium and sodium. The

traditional liming materials are magnesium- and calcium carbonates better known as dolomitic and calcitic lime. The oxides and hydroxides of Ca and Mg are also applied on a limited scale. Calcium silicate is used on sugar cane (Table 36).

**Table 36. Liming materials available in Southern Africa.**

Material	Neutralising capacity*
Dolomitic lime	109
Calcitic lime	93
Hydrated lime	136
Slaked lime	179
Calcium silicate	40 - 60

\*Pure calcium carbonate is taken as 100

Dolomitic lime contains at least 15% magnesium carbonate and a good quality lime will have a total carbonate content >70%. Due to the magnesium content dolomitic lime can only be applied to soils which also require additional Mg. Good quality dolomitic lime contains between 40 and 50% magnesium carbonate.

Calcitic lime contains at the most 15% magnesium carbonate with a total carbonate content of at least 70%. Calcitic lime can be applied to any depending on the magnesium requirement, but is usually applied to soils containing high levels of magnesium.

Hydrated lime is calcium hydroxide and like slaked lime (calcium oxide) caustic. These two materials react faster with the soil and will also penetrate the soil profile much quicker. Nevertheless the solubility is still very low.

Calcium silicate is applied to cane fields where it can be mixed with the soil.

Although the effect of gypsum on the pH of the soil is hardly noticeable, the combination of soluble Ca (gypsum) and lime can be used to displace the aluminium in the subsoil. The applied  $\text{Ca}^{++}$  will also counter act the negative effects of  $\text{Al}^{+++}$  and  $\text{H}^+$ .

The conventional liming materials are fairly insoluble (Table 37) and require time to reach the subsoil.

**Table 37. Solubility in water of the main sources of liming material and gypsum.**

Source	Solubility in gram per litre at 25°C
Calcium carbonate (calcitic lime)	0,0153
Magnesium carbonate (dolomitic lime)	0,106
Calcium sulphate (gypsum)	2,41
Calcium silicate	
Calcium oxide (Slaked lime)	1,30
Calcium hydroxide (Hydrated lime)	1,85
Magnesium oxide	0,006
Magnesium hydroxide	0.009

Theoretically will 100mm rain or irrigation water dissolve 2400kg gypsum, 15kg calcium carbonate and 106kg magnesium carbonate per ha. The residual effect of dolomitic and calcitic limes are much higher (as indicated by soil analyses) than that of gypsum, due to their poor solubility.

The solubility of liming materials is also a result of a number of factors.

- Fineness

The finer the insoluble material, the larger the exposed surface area that can be eroded. The surface area of one cubic cm is  $6\text{cm}^2$ . If that cube is cut into two, the volume will still be one  $\text{cm}^3$  but the surface area will now be  $8\text{cm}^2$ . If these two blocks are halved, the volume will still be  $1\text{cm}^3$  but the surface area is now be  $10\text{cm}^2$ . When lime is ground to pass a 0,05mm (50 micron) sieve one  $\text{cm}^3$  will have a surface area of  $1200\text{cm}^2$ .

To register a lime for application in agriculture, the requirements are that 90% will have to pass a 1000 micron (1mm) and 50% a 250 micron sieve.

- Hardness

The reactivity of lime depends on the surfaces exposed to the neutralising reaction. The rate at which the lime particles will break or reduced in size will determine the efficacy of the material to neutralise acids. The softer the lime particles, the better.

- Neutralising capacity.

The neutralising capacity is determined by the mass of acid that can be removed by the  $\text{OH}^-$  generated by a unit of the lime. The higher the neutralising capacity the less lime needs to be transported to do the job. The neutralising capacity is expressed as a percentage of the capacity of pure calcium carbonate and is noted as calcium carbonate equivalent (CCE). In other words the mass of acid that can be neutralised by the lime compared to the mass of acid that will be neutralised by 100g of pure calcium carbonate.

The CCE of liming materials can be determined by more than one method. Usually the values are indicated as CCE(HCl) or CCE(Resin) when determined by the hydrochloric or resin methods.

The CCE(HCl) is done by dissolving a known mass of the lime in a known mass of acid. The mass of acid that was not neutralised is then determined. This is then expressed in relation to the mass of acid neutralised by pure calcium carbonate. For example if Lime A has a CCE(HCl) of 79 and Lime B a CCE(HCl) = 87, lime A will only neutralise a mass of 79g acid compared to the 100g neutralised by pure calcium carbonate. Lime B is slightly better 100g of the lime will neutralise 87g of the acid neutralised by 100g pure calcium carbonate.

**Table 38. The Pro's and cons of the two methods used to evaluate liming materials.**

Met ode	Pro's	Cons
CCE(HCl)	Determines the total neutralising capacity in a strong acid environment.	Fineness and softness that play important rolls in the soil are not considered.
CCE(Resin)	Die evaluation incorporates the fineness and softness of the liming material.	Evaluates only that part of the neutralising capacity that reacts in a moderate acid environment.

A CCE-resin of  $>60$  is perceived as good and  $< 50$  as poor.

- Chemical composition

Calcitic and dolomitic lime neutralise acid through the formation of  $\text{OH}^-$ -ions. They also apply calcium and magnesium to the soil. Calcium silicate will also neutralise the acid but applies Ca and silicon. The value of the "extras" needs to be considered.

At existing orchards where the liming materials cannot be mixed with the soil, fineness ad softness will be the important properties of liming materials.

## 21. ORGANIC MATERIAL

### Introduction

Although plants can grow and produce optimally in the complete absence of organic material, it seems that a certain level of organic material in the soil can benefit productions. The benefits are not easily quantified and their value must be regarded as relative. The value of organic material is more readily quantifiable in soils with a coarse texture (sandy soils) than in soils with a fine texture (clayey).

Unfortunately the accumulation of organic matter in citrus orchards also threatens the production of quality citrus fruit. Before the hazards can be qualified and managed, accumulation of organic material in citrus orchards cannot be promoted.

Organic material is applied for five major reasons.

- To increase the organic fraction of the soil.
- To reduce leaching of nutrient elements, mainly N from sandy soils.
- To establish a heterogeneous population of microbes.
- To mobilise accumulated and fixed plant nutrients from the soil.
- To improve the general wellbeing of the soil in terms of the physical, chemical and biological aspects.

It is important to distinguish at this stage between organic farming, application of organic nitrogen and integrated fertilisation. Fertilisation with organic nitrogen has at goal to minimise the losses of nitrogen from the soil and to supply the N in smaller dosages over a longer period. It acts as a slow release N source with no aim to increase the organic fraction. Organic farming only allows organic fertilisers and aim to build the organic fraction of the soil. Integrated fertilisations consolidate the pros of organic and inorganic fertilisation to reach a sustainable profit.

Unfortunately these practises have not yet been tested and cannot be recommended for citrus production without hesitation. The old problems with accumulated organic nitrogen and fruit quality have not been resolved.

We cannot ignore the fact that there are many citrus orchards that produce well above the industry average without a single application of organic material. It is also true that the soil of many orchards is today in a better condition than before cultivation commences.

Cultivation destroys the organic material in and structure of the soil, but that cannot be the only parameter for the wellbeing of the soil. An acid soil receiving organic material will still be less productive unless it is limed. Sandy soils have no real structure that can be destroyed and liming of an acids soil will render it more productive than applying organic material.

The organic material is usually sourced from nearby. The inherent problems of the area can only be overcome by adding what is required from elsewhere. For instance, if the soil and water contains high concentrations of magnesium, this imbalance will only prolong in the orchard by applying local material.

Accumulating organic matter in the soil is not the salvation of profitable agriculture in South Africa. The solution lies in integrated fertilisation that will incorporate what is required at the lowest cost to sustain profitable production.

It is therefore necessary to be objective and evaluate the reasons for the organic drive. At this stage little information is available to conclude for or against the application of organic material to citrus orchards. Nevertheless, by looking at the pros and cons will already be a step in the right direction. It is further important to evaluate the organic, inorganic and integrated approaches scientifically without all the emotions.

### **Accumulation of organic material in the soil.**

The quantity of humus that will accumulate under conventional orchard practises is very low. It is estimated that less than 1% of the material applied will eventually converted to humus or humus-like compounds. It is however unknown how much humus is required to make a significant impact on the stability of soil structure or the water holding capacity. Such a change could easier be done in sandy than clayey soils. Unfortunately will humus be oxidised much quicker is sandy than clayey soils.

An increase of only 0,2% in the carbon content of dry land maize, is reckon to have an impact on production. To increase the carbon content by 0,2% an application of 4000kg organic carbon or 7 tonnes ( $\pm 10-15 \text{ m}^3$ ) is required per ha 15cm deep. According to information on other crops, an initial application of  $10 \text{ m}^3$  per ha is required which can then be decreased in subsequent years and maintained at  $4-5 \text{ m}^3$  per ha per annum. The big question is whether enough organic material will be available at affordable prices.

The quality of organic material varies a lot. Care must be taken not to add too much salt like sodium, chloride and boron with the material. Nitrogen is required during the decay of organic material. If the material contains too little N, the microbes will source for that in the environment. The plant cannot compete with the microbes for N and may suffer a temporary nitrogen deficiency. Therefore the material, compost excluded, should contain more than 1,8% N.

Compost has a higher intrinsic value than the raw organic material. It is calculated that  $10 \text{ m}^3$  organic material has the same value than  $1 \text{ m}^3$  compost. Furthermore  $3 \text{ m}^3$  raw materials are required to prepare  $1 \text{ m}^3$  compost.

Please note that compost is not rotten organic material. To prepare fungal compost for citrus, the following is required.

- 25% manure or green material.
- 30% hay and
- 45% wood.

Hay is material from a plant that has completed its life cycle to seed. Dried green grass is not hay. During the process about three times more biomass is retained by fungi compared to a composting process rich in bacteria.

Other important requirements for good compost are aeration, temperature and moisture. The magnitude of control of these three factors will determine the quality of the compost.

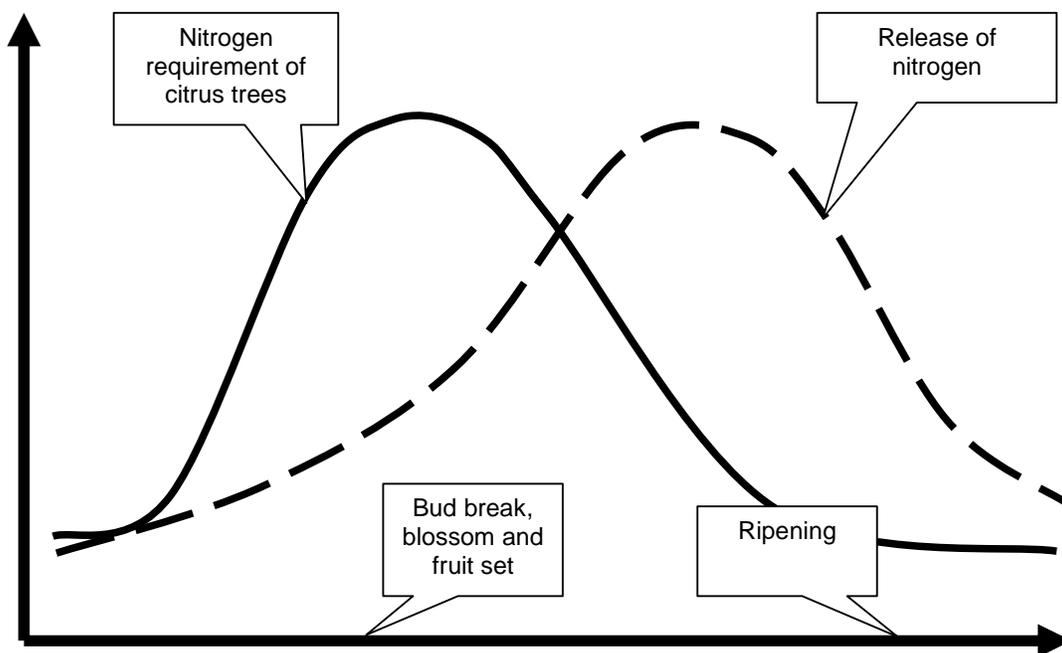
### **Reduction of losses of nitrogen and other elements through leaching.**

Leaching of nitrate is limited by organic material because the N is fixed in organic compounds which are less subjected to leaching. These organic compounds are not available to the trees. Once mineralised by the microbes to ammonium and nitrate, the nitrogen become available but is then also subjected to leaching.

In commercial citrus production, it is important that the nitrogen status of the trees follow a certain pattern (See Figure 3). The mineralization of organic matter is a biological process and effected by the temperature and moisture content of the soil. The grower has no control over this process and it will progress as the temperature rises during spring.

This release curve does not necessarily follow the demand curve. In fact it does almost never follow the demand curve of citrus (Figure 8). If the microbes require nitrogen during the period of high demand by the trees (flowering and fruit set), it will have catastrophic consequences. The trees cannot compete with the microbes for N.

On the other hand, if nitrogen is released from the organic component during late summer and autumn when the trees require no additional N, the effect on fruit quality can ruin the crop. This release of nitrogen is at a high during the alternating hot/cool and dry/wet summer months. A release of N in late summer and autumn in the hot area will delay colour break.



**Figure 8. The relationship between the nitrogen requirement of citrus trees and the natural pattern of nitrogen release from the organic matter in the soil.**

Additional nitrogen released during January to May will also stimulate vegetative growth resulting in poor quality, especially grapefruit that may turn puffy.

The mass of nitrogen released is directly related to the mass organic nitrogen in the soil. The higher the concentration of organic nitrogen in the soil, the more will be released during mineralization.

Repeated application of organic material will result in a gradual accumulation of organic nitrogen in the soil. This accumulation happens unnoticed until the release rate will be high enough to delay fruit colour. It is almost impossible to reverse the accumulation and could take years to deplete the reserves, especially in fine textured soils.

The magnitude of the accumulated N is much higher than expected. Even in a sand where no organic material other than leaves and weeds, were applied, the total nitrogen amounts to >300mg N per kg soil. If only 1% of this total is mineralised during January to May, the equivalent of >100g LAN is supplied per tree at the wrong time (Table 39).

**Table 39. The total N content of three soils that received no organic material and the expected mass released when 1% of the total is mineralised in grams per tree under three irrigation systems.**

Clay content %	Total N in the soil mg/kg	Root volume 200 litre soil with OHS	Root volume 5500 litre soil with single line drippers	Root volume 10000 litre soil with microjets
5	306	0,61	17	31
17	1022	2,04	56	102
28	1374	2,75	76	137

This also illustrate why nitrogen needs to be apply continuously when the OHS is used. The amount of N released from the limited volume of soil utilised with the OHS is too small to satisfy the N requirement and need to be supplemented. When microjets are used, enough N is supplied naturally by the soil and no additional N must be applied.

If the organic matter in soil no 3 accumulates to 5% the expected release can exceeds 2500mg N/kg soil under microjets. This is equal to 890g N per tree during the wrong time.

When organic material contains less than 0,50% N (like saw dust) the microbes will source nitrogen from the environment to digest the material and a nitrogen deficiency will develop. It will take about 6 months before this fixed N will be released again. If the organic material contains 1.8 to 2.0% N, no additional N will be required but it will start to release small amounts immediately. The mass of N that will be released from organic material can be estimated as follows.

- If the total N concentration is 1,80 to 2,00%  $\pm 65\%$  will be released during the ensuing season. Therefore total N  $\times 0,65$  = available N. If we assume that the material contains 1.95% N then the available fraction =  $1,95 \times 0,65 = 1,27\%$  or 1,27kg per 100kg organic material.
- If the material contains less than 1,00% N then an external source is required. During microbial degradation 1,00-2,00 = -1,00% or 1,00kg N per 100kg material will be required. However compost with a N content of 1,0% will not have the same requirement than uncomposted material.
- When the total nitrogen content exceeds 2,0% the available N can be estimated by  $N = \text{Total N} - 2,00 + 2,00 \times 0,65$ . Assuming the material contains 3,43% total N, then the available N =  $3,43 - 2,00 + 2,00 \times 0,65 = 1,43 + 2 \times 0,65 = 2,73\%$  or 2,73kg N per 100kg material.

Of the remaining N about 12% will be released during the second and 5% during the third season (Fisher, 1992). These percentages will vary according to many factors and the estimations serve merely as a guideline until the local conditions can refine the calculations.

Organic materials can be use successfully on young non-bearing trees. With young trees it is not required to manipulate the N status and a continuous supply of available N at low concentrations, will suite the demand better. This is especially applicable to sandy soils. An even better approach will be to incorporate the organic material into the soil before planting. Chicken manure and other similar products serve only as a source of slow release N and other nutrient elements and not as a mulch or to improve the organic carbon content. Kraal manure contains more roughage and will also serves as a mulch.

Various trials have been conducted to establish the effect of organic and half organic fertilisers on citrus production. The results are usually variable with little if any benefits. During 1983 reports on such trials at Zebediela were published (Table 40, Bester. 1983).

**Table 40. Yield and fruit size as the result of organic and inorganic fertilisation. Recalculated from Bester, 1983**

Treatment	Yield as % of the inorganic treatment	Fruit diameter in mm
Mixtures of guano	91	98
Chicken manure	92	95
Inorganic + organic	99	103
Inorganic fertilisers	100	100

#### **Establishing a heterogeneous microbial population.**

The main advantage of accumulating organic material in the soil is to establish a natural heterogeneous population of microbes in the soil. In turn the heterogeneous population will restrict the development of a dominating and pathogenic population. The accumulation of phytotoxins will also be limited, because such a variety of microbes can deal with almost any compound.

In citriculture a fungal reach population will also help to keep the soil loose, aggregated and aerated. Fungi need a complex source of energy like wood (Lignin) and it is important to supply energy to maintain the microbes. Without the application of energy sources, the microbes will deplete the existing organic material.

It is important to distinguish between organic material, chicken and kraal manure and compost. Organic material is plant and animal waste products and has little value in establishing a fungal population. Kraal and chicken manure are sources of organic nitrogen and some other elements and are not mediums to establish a fungal population. Compost is not rotten material but a specific mix of organic materials treated under a specific set of conditions to form compost. Important components of the composting process are the mix of organic materials, the inoculum and the conditions during the composting process which will determine the value of the compost.

The value of compost is not in the mineral component but in the variety of microbes and organic compounds formed that will be applied to the soil. Therefore the compost must not be spread out but must be piled below the canopy. This will prevent drying out and give the microbes and organic compounds time to enter the root zone. One or more heaps in the shade where the microjets will irrigate are preferred. If mulches are used to keep the compost moist, it can be spread out but the layer must not be too thin.

The initial inoculum can be prepared by gathering rotten plant material from the natural bush. This is then mixed with the organic material and composted. Afterwards, the coarse particles from a compost heap can be used as an inoculum for the next batch.

A few successes with the establishment of a heterogeneous microbial population had been reported. The incidence of "Young tree decline" or "blight" had been reduced by adding humus to the soil (Pinckard, 1979). Applications of 100lb humus per tree stopped dying back and 46% more fruit was produced when compared to untreated trees.

#### **Mobilising accumulated nutrients in the soil.**

Natural microbial populations from soils rich in humus or organic material contain microbes that can dissolve the P from the unavailable pool and left it available to the plants.

Others can fix nitrogen from the atmosphere while another mix can release potassium from unavailable sources.

Due to the activities of these microbes a variety of chemicals are released in the root zone. This includes compounds which will stimulate root growth similar to hormones.

Another relative advantage of organic material in the soil is the concentration and variety of natural chelates like that of iron, manganese, zinc and copper increase. Chelates are metal-organic complexes that will not be fixed by the conditions in the soil, which render the metals available to the plant over a longer period.

It is also mentioned that the microbes will fix sodium and chloride and "desalt" the environment.

#### **Improvement of the wellbeing of the soil.**

The exact meaning of this term or soil health is not quite clear. Does it refer to the activity or variety of microbes or the concentration of humus in the soil?

Organic material will also detoxify the soil by chelating heavy metals to limit their suppressing effect.

Organic material and especially stabile humus will improve the structure, water holding capacity (WHC) and cation exchange capacity (CEC) of the soil. Although this sounds wonderful, these improvements can actually be detrimental. The mass of humus required to obtain these advantages are still unknown but seems to be somewhat impractical.

Fertilisation with organic material will not really improve the WHC and CEC of the soil. These soil properties will only be improved by humus like compounds. To make humus requires many-many

years of stable conditions.

When the aeration of a soil is improved it will also improve the potential of the soil. Whether the improvement is due to the addition of organic material or cultivation is irrelevant. Citrus seedlings grow better in a growth medium with an air filled porosity (AFP) of 9% (Coetzee, 1989). Unfortunately, the incidence of *Phytophthora* infestation is also higher at AFP's less than 12%. In soils the preferred AFP will therefore be  $\pm 15\%$  or more.

### Sources of organic material

Kraal manure, chicken litter, guano and various mixes of these are used on a commercial scale. Other sources include by-products from the sugar cane industry, compost and pig manure. The average mineral content of these materials vary depending on the processes incurred and means of storage (Table 41).

**Table 41. Average values of a few quality parameters for organic material.**

Source	N%	P%	K%	Ca%	As%
Chicken manure	3,00 tot 4,00	1,25 tot 1,75	0,80 tot 1,00	5,75 tot 6,25	5 tot 12
Kraal manure	1,75 tot 2,00	0,20 tot 0,50	1,75 tot 2,00	2,00 tot 3,00	15 tot 40
Guano	10 tot 14	3,00 tot 4,00	1,75 tot 2,00	4,50 tot 6,00	10 tot 20
Compost	0,80 tot 1,50	0,10 tot 0,50	0,75 tot 1,25	2,00 tot 10,00	15 tot 50

It is always advisable to submit a sample for analyses when organic material of an unknown supplier is ordered for the first time. The quality of organic materials is determined by the concentration of nitrogen, chloride, sodium, boron and organic material. The concentration of organic material can quickly and cheaply estimate in the test for the ash content. The total minus the ash = the organic component. The concentrations of P and K as well as other nutrient materials, can be considered as a bonus, but the N and ash content are the important issues. Moisture is also important when transport is involved. To register an organic material, the National Department Agriculture requires an ash content of less than 20% at a moisture content of 40%.

The mass of organic material to be applied per tree or per ha will be determined by the availability, price and the concentrations of N, Cl, Na and B in the material. The recommendation in Florida (USA) is to apply 4 ton per acre to grapefruit and 5 ton per acre to oranges and they also recommend that the material be mixed with the soil. If it is not mixed, about 18% of the nitrogen is lost by volatilisation (Fisher, 1992). Mixing is not a sound practise and should not be done at existing orchards.

Sodium, chloride and boron are the factors limiting the mass to be applied per tree. Table 42 relates the maximum mass that can be applied, of any organic material to their content of N, Cl, Na and B. The maximum is determined by the most limiting element.

**Table 42. The maximum application rate (kg/ha) of kraal manure as dictated by the concentrations of sodium, chloride and boron.**

	400	600	800	1000	1200	1400	1600	1800	2000
% Na	3,97	2,64	1,98	1,59	1,32	1,13	0,99	0,88	0,79
% Cl	6,06	4,04	3,03	2,42	2,02	1,73	1,52	1,35	1,21
B mg/kg	565	377	283	226	189	162	142	126	113

For example if an organic material contains 1,44% Na, 1,53 % Cl and 270mg B/kg the maximum that can be applied is 800kg per ha due to the restriction by the B content.

### Compost

Compost is not rotten or aged plant material. The value of compost is more than the value of the initial ingredients provided it is properly prepared. Apart from the organic material and nutrient

elements that are applied by means of compost, a heterogeneous population of microbes is also applied. The value of compost is based on the properties of this population and the microbes are the component that will add value to the soil. The properties of this microbial population will depend on the material used and the prevailing conditions during composting.

True composting of organic material has a number of basic requirements.

- Energy sources

Any plant material and animal refuse can be used as energy sources. The energy required during composting must include sources of simple compounds like sugars but also more complex molecules like wood. Green material, chicken litter and kraal manure serves as sources of simple energy sources to start the composting process. Wood and hay serve as sources of complexed compounds for the fungi.

- Inoculum.

Most green material and manures contain enough microbes to start the composting process. However, mature wood and dry material might not contain enough and without an inoculum the composting process will take longer. A number of inoculums are available and the wider the variety of microbes in the heap the better. A good quality compost can also serve as an inoculum for the next batch. About 1kg good quality compost per m<sup>3</sup> raw material is required as an inoculum. Compost prepared with material from the area, in the area has the most suitable spectrum of microbes for that area.

Compost or mould from the natural bush in the area can also be used as an inoculum.

- Nutrient element.

The demand for mineral nutrients during composting is usually satisfied by the contents of the plant and animal debris. However, sometimes materials like wood, contains too little nitrogen and an external source will be required. This can be done by means of N rich materials including fertilisers. Calcium is an important element helping to stabilise the compost. Calcium in the form of lime (if the pH needs adjustment) or as gypsum can be added.

- Oxygen

Compost can be prepared under aerobic or anaerobic conditions, but aerobic compost is preferred because the conditions in the soil will be aerobic. Of the total volume 50% must constitute air. Therefore do not compress the material. If proper aeration with the coarse material by itself is not possible, artificial aeration can be installed. The volume of air that is required daily is 25 to 30m<sup>3</sup> per m<sup>3</sup> material.

The size of the particles used in the compost heap must therefore not be too small. Large pieces of up to 100mm must also be included. When the compost heap turns anaerobic the pH will drop due to the formation of organic acids like lactic acid.

The dimensions of the compost heap will also facilitate aeration. The maximum width is 4m and height is 3m.

Aeration will of course also benefit when the heap is turned.

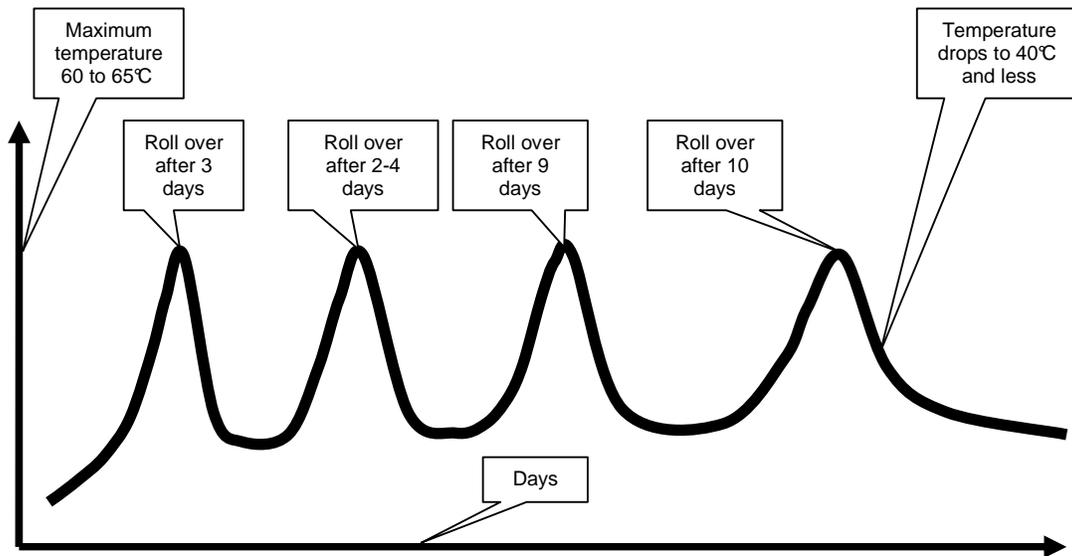
- Water

The optimal moisture content in a compost heap is 50-60% on a volume basis. During the rainy season it might be required to protect the heap from too much water. Perforated plastic, shade net or paper can be used. The heap will dry from the outside but the lower moisture content should not penetrate more than 10-15 cm. When the heap is turned, the drier material will be rewetted again. When compost is at the right moisture content, it will feel like a wet sponge, moist but no free water is visible even if it is squeezed lightly.

- Heat.

Heat is generated by the microbes during the composting process. The heat accumulates in the heap and can lead to spontaneous combustion. Therefore when the heap reaches a temperature

of 60 to 65°C it must be turned. After turning the temperature of the heap will increase again. If the temperature does not increase again after the heap was turned, the composting process is completed provided it was aerated and watered properly. The temperature graph of the heap will describe the composting process (Figure 9). The composting process can therefore be completed within 30 to 40 days.



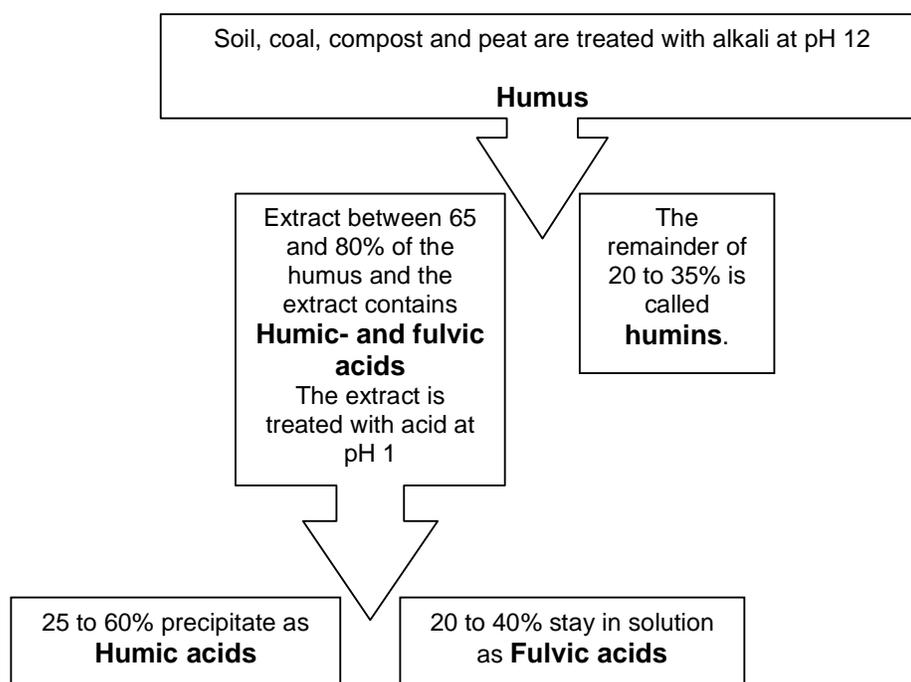
**Figure 9. The temperature curve of a well constructed compost heap under optimal conditions.**

### Humus

The organic fraction in the soil consists of plant, animal and microbial waste in various degrees of decomposition. Another part of the organic material is present in a fairly stable state and is called humus. Humus is an amorphous (has not crystal structure) material with no resemblance to the material it originates from. The first research on humus was reported in 1786. Humus accumulated in the soil and is flocculated on the clay with the interaction of Ca. The flocculated humus is stable and cannot be digested by microbes. Through a process of condensation the humus is transformed over many years into macro molecules.

To study humus it has to be separated from the soil. This was done by dissolving the humus in caustic soda (sodium hydroxide). Only a part of the humus is extracted in this manner. The remainder is called humins. The extract is then treated in several ways to fractionate the different components of humus.

The same process is used today to extract humus from materials like coal (leonardite), peat and compost. The process is illustrated in Figure 10.



**Figure 10. Schematic presentation of the extraction process to obtain humic and fulvic acids.**

Humus is therefore equal to humins + humic acid + fulvic acids. The properties of humic and fulvic acids are summarised in Table 43.

**Table 43. Properties of humic and fulvic acids\*.**

Property	Humic acids	Fulvic acids
Name of salts e.g. Ca, K, Mg, NH <sub>4</sub>	Humate; Ca-humate, K-humate etc	Fulvate; Ca-fulvate, K-fulvate, etc
Solubility in water	Not at pH's < 7,0	Yes
Solubility in acids	Not soluble	Yes
C:O:H:N	61:31:4:4	46:48:4:2
Calculation from %C	%C x 1,64 = % Humate	%C x 2,17 = % Fulvate
Structure	No structure, amorphous	No structure, amorphous
Molecular mass	10 000 to 150 000	1 000 to 15 000
CEC in me/100g	250 to 500	450 to 1000
Active groups in me/g		
Total acids	±5,70	±10,80
-COOH-groups	±2,80	± 7,20
-OH-groups	±5,90	± 6,40
Phenol OH-groups	±2,90	± 3,60
Alcoholic OH-groups	±3,00	± 2,80
C=O-groups	±3,00	-
-COH <sub>3</sub> -groups	±0,50	± 0,20

\* The origin of the humus will determine the composition.

The building blocks of humins, humates and fulvates are the same. It can be illustrated by taking an A4-page as the humins. By tearing it into two, the parts will represent humates. If the two halves are torn again into four parts, these will be equal to the fulvates. The molecular mass of humins is in the order of 1 000 000 and represents a condensate of humic and fulvic acids that took many years to stabilise but minutes to destroy. Humates will therefore be reduced by the microbes to fulvates. Fulvates are more active than humates as can be judged by the higher CEC (Table 43).

Even under conditions of optimal inorganic nutrition, applications of humus showed constantly improvements in biomass produced (Chen & Aviad, 1985). Root stimulation is normally more obvious than that of the top growth. Both root length and number of secondary roots increase. The reaction to increased applications of humic acids follow the normal responds curve and will also reach a plateau where additional humic acids will reduce yield. Fulvic acids contains more compound with low molecular weights as humic acids which is most probably why plants respond better to fulvic acids than humic acids. These molecules reduce the surface tension of the water around the roots (Vakhmistrov, 1987), increase the permeability of the membranes (Chen & Aviad, 1985) and show hormonal activities.

## 22. SOIL APPLICATIONS

Soil applications are the most natural way to supply nutrients to the trees. These applications are done to supply the required nutrients, to create conditions for optimal root growth and root activity, to manipulate the trees and to suppress imbalances and other negative reactions.

As already have been mentioned in the chapters on nutritional elements, growing plants require 17 elements for optimal production. These elements are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), sulphur (S), chloride (Cl), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B) and molybdenum (Mo). Three of these (C, H en O) are not considered in any conventional fertilisation program. They are utilised as gasses (CO<sub>2</sub>, O<sub>2</sub>) and water (H<sub>2</sub>O) by the plants.

Fortunately it is seldom required to apply all 14 nutrient elements in one program except in hydroponics or other drip systems where the hydroponic principles are applicable. Soils and irrigation water also contribute to the total requirement of the trees although not always in the required concentrations and ratios. Unfortunately, some elements are also over supplied.

The citrus tree has to provide in his requirements in this climate of over and short supply. Sometimes the requirement is unnatural and the requirements need to be adapted to suit the market. The best example for this is the natural tendency for most trees to bear a lot but small fruit. To suit the market the tree must now set less but larger fruit.

Fertilisation is therefore meant to supply those elements that are in short supply, to reach a certain predetermined goal. The purpose of the fertilisation program is therefore to improve or maintain the status of all the nutritional elements in the optimal range in the most economical way. Excessive supplies are limited which will help to preserve the soil for future production.

This leads to a requirement of methods to determine the nutritional status of an orchard and methods to satisfy the needs. These include analyses of leaves, soil, water and fruit as well as other information on crop and quality.

When the type and mass of nutrients required are determined, the most effective fertiliser and method to apply the fertiliser must be used. We endeavour to reach the situation where the biggest advantage is reached with the smallest input.

Factors that determine the success of a soil application are the following.

- The mass of the nutrient,
- The chemical compound of the nutrient element
- The pH, salt content, concentration clay in the soil.
- Application time or times.
- The method of application.

The better a nutrient is absorbed and utilised by the plant the less needs to be applied to reach the optimal concentration in the leaf. The method of application is therefore important and determines to a large extent the success of a fertilisation program.

### **The concentration of the nutrient in the fertiliser.**

When the concentration of the nutrient in the fertiliser is low, large masses/volumes must be applied in order to get the required mass of the nutrient into the plant. This will increase the transport, handling, application and storage cost. On the other hand if the fertilisers are concentrated, small masses/volumes need to be applied, which make spreading difficult. Otherwise, the concentration of the nutrient in the fertiliser is of little importance.

### **The chemical formulation of the nutrient element.**

The conditions prevailing on the farm and in the orchard will determine which chemical compound will be the best. In general the most acceptable chemical formula is the one that is

- Directly available to the plant,
- Can easily be transformed to an available form
- Contains no elements that will harm the soil or tree and
- One that will also supply a second element that is required.

For an acid soil the right nitrogen formulation will be the one with the lowest, but for an alkaline soil the one with the highest acidification potential. When P needs to be applied in a narrow strip (banding) then a water soluble phosphate that contains no N and K is the best. In this case single or double supers will be selected. MAP, MKP or rock phosphate will not do.

A wide variety of fertilisers are available. These include the so called straights (contains only one of N or P or K), compound fertilisers (a chemical composition with a set ratio between N, P and/or K) and mixtures (more than one of N, P and K). Straights contain only one of N, P or K but may also contain Ca, Mg and S.

Fertiliser mixes contain 2 or more of N, P and/or K in a variable ratio. These are merely physical mixtures of the straights. The elements Ca, Mg and S can also be included. Fertiliser mixtures are identified by the ratio between N, P and K as well as the total concentration of these three elements in the fertiliser.

For instance a 4:1:1 (30) contains 4 parts N, 1 part P and 1 part K and the three together constitute 30% of the contents of the bag. The other 70% consists of O, H, S, Mg, Ca and inactive filler material like clay.

This means that the 4:1:1(30) mix contains;

$$\frac{4}{4+1+1} \times 30 = 20\% \text{ nitrogen};$$

$$\frac{1}{4+1+1} \times 30 = 5\% \text{ phosphorus and}$$

$$\frac{1}{4+1+1} \times 30 = 5\% \text{ potassium.}$$

The ratios of N, P and K can be changed, within limits, at will and a wide range of mixtures is possible.

Compound fertilisers or chemical mixtures have a definite and fixed ratio between the elements. The total concentration of the nutrients is only limited by the purity of the compound. Potassium nitrate is a chemical mixture containing 39% K and 13% N. If it is pure potassium nitrate the total N+K = 52%

The simpler the formulation of a fertiliser, the easier the application rate can be adjusted to satisfy the requirement of an orchard. In fact by storing three fertilisers, a source of N, one for P and one for K, the requirement for all orchards in terms of N, P and K can be met very effectively. Once mixtures are incorporated into the program many more types of fertilisers are required to meet the demand. One or even two mixtures will very seldom satisfy the demand of all orchards. Using mixtures one has to over supply P or K more often than not, to apply the required N.

The root system of citrus is sensitive for high concentrations of salts. To satisfy the requirements of all the elements will need fairly heavy applications. Therefore the applications should be split into a few applications otherwise temporary salinity cold damage the roots, leaves and even shoots. For instance 1850g 3:1:5 (38) or 500g urea is needed to satisfy the N-requirement. The mix cannot be applied in one single application and the only advantage of fertiliser mixes is defeated.

#### **pH and salt content of the soil.**

The pH and concentration of salts in the soil will determine the most appropriate chemical compound. When the concentration salt is high, fertilisers with a low salt index will be preferred. Chlorides usually have higher salt indexes than the nitrates and nitrate do not apply unwanted elements. Cost will also be a decisive factor.

The pH need to be considered when the nitrogen sources are selected. Ammonium nitrogen ( $\text{NH}_4^+$ ) will acidify but is also subjected to volatilisation in alkaline soils. When ammonium is applied to alkaline soils ammonia gas ( $\text{NH}_3$ ) is formed. This gas will escape into the atmosphere and the magnitude of losses is determined by the prevailing conditions when applied. Volatilisation is highest when the ammonium is applied to the surface (Table 44, du Preez and Burger, according to Van Biljon, 2004).

**Table 44. Losses of ammonium nitrogen (as % of the mass applied) from various sources under different conditions.**

<b>Product</b>	<b>Spread on the surface</b>	<b>Mixed with the topsoil</b>	<b>Banding below the surface</b>
Urea	34	27	16
LAN*	14	7	3
DAP**	30	23	13

\* Limestone ammonium nitrate \*\*Di-ammonium phosphate

#### **Time of application**

The time of application of a fertiliser is determined by the phenology of the tree, the physiology of the element and the transformations of the element in the soil.

- According to the phenology of the tree/crop, certain nutrient elements will be required at higher concentrations at certain stages. The applications must provide for these special requirements.
- The physiology determines whether an element can be accumulated in the tree to be relocated at another time. Potassium, nitrogen, phosphorus and magnesium are mobile in the tree and can be accumulated for future use. Calcium and to some extent S are immobile and need to be supplied when required.
- Certain fertilisers contain the nutrient element in a form that needs to be transformed before it will be available. The transformation will require certain conditions and time. The N in urea and organic material need to be transformed before the plants can utilise it. Moisture, temperature and pH will determine the rate of conversion.

#### **Application of fertilisers.**

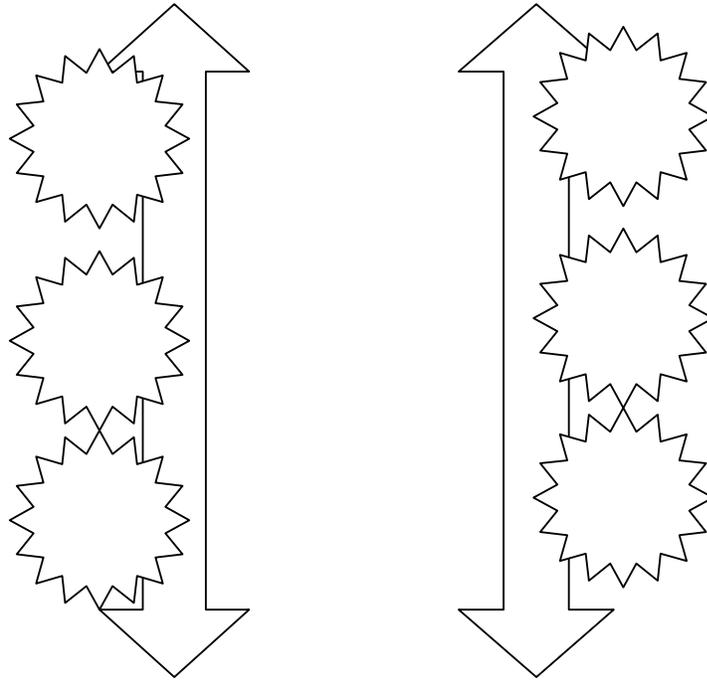
The clay content and to some extent the pH and cation balance will determine whether fertilisation must be done in one or more applications. The less clay a soil contains, the smaller the maximum mass of water soluble fertilisers that can be applied without increasing the total salt content too much. Table 45 provides guidelines to the splitting of N, P and K fertilisers applied by hand, mechanically or fertigation with microjets. The splitting is based on the clay content of the soil.

**Table 45. Split applications of the fertilisers (as % of the total requirement) on sandy to clayey soils.**

% Clay	Element	July	Aug	Sept	Oct	Nov	Dec
<5	N	40 (0)*	30 (40)	20 (30)	10 (20)	0 (10)	
	P		100 (0)*	0 (100)*			
	K				33	33	33
	Gypsum		100 (0)*	0 (100)*			
	MgO				100		
	Lime					100**	
5 tot 10	N	40 (0)*	40 (40)	0 (40)	20 (0)	0 (20)	
	P		100 (0)*	0 (100)*			
	K				33	33	33
	Gypsum		100 (0)*	0 (100)*			
	MgO				100		
	Lime					100**	
11 tot 20	N	50 (0)*	25 (50)	25 (25)	0 (25)		
	P		100 (0)*	0 (100)*			
	K				50	50	
	Gypsum		100 (0)*	0 (100)*			
	MgO				100		
	Lime					100**	
21 tot 30	N	50 (0)*	50 (50)	0 (50)			
	P		100 (0)*	0 (100)*			
	K				100		
	Gypsum		100 (0)*	0 (100)*			
	MgO				100		
	Lime					100**	
>30	N	100 (0)*	0 (100)				
	P		100 (0)*	0 (100)*			
	K				100		
	Gypsum		100 (0)*	0 (100)*			
	MgO				100		
	Lime					100*	

(50)\* Cold areas

\*\* Any time after the last N-application up to April.



**Figure 11. The most effective placing of fertilisers by hand or mechanical spreader when microjets are used.**

When fertilisers are applied by hand or mechanically, the most effective placing is 50cm outside to 50cm inside the drip line of the trees (Figure 11). The next best is from the stem to 50cm beyond the drip line. It is however important that this area must be kept clean from weeds and also be irrigated.

The roots between the rows are not very active. Only 7% of the available P in the areas between the rows (orchard roads) is utilised by the trees (Citrus Industry Vol 3 p139).

### **Special treatments.**

Shamouti is prone to bear small crops of fruit with coarse and thick skins. To limit this, a special treatment was developed for Shamouti (Warrington, Karino Koöp, personal communication). The program is as follows.

Just after harvest (May);

- Irrigate with just 10 to 15 mm water.
- Apply 50% of the N requirement
- Apply a foliar spray of 1000g low biuret urea plus 150ml zinc nitrate (5,5% Zn) per 100 litre water.

May to end June;

- No irrigation until July.

July;

- Irrigate to wet the total root zone. This usually requires at least 1,5 times the normal application.
- Apply the second 50% of the N
- Apply a foliar spray of 1000g low biuret urea plus 150ml zinc nitrate (5,5% Zn) per 100 litre water.
- Irrigate at the normal rate for this time of the season.

August onwards;

- Irrigate at the normal rate for this time of the season.
- Apply the other nutrients as recommended.
- Apply 2x2000g MKP per 100 litre water at 100% petal drop.

Satsuma is also treated differently to overcome the problem with puffy fruit. Fertilisation after harvest is possible due to the early harvesting. The program below improve fruit set and lower the incidence of puffy fruit.

After harvest;

- Irrigate the trees properly and ensure that the total root zone is wet.
- Apply 50% of the nitrogen requirement and a light irrigation to wash it into the root zone.
- Apply a foliar spray of 1000g low biuret urea per 100 litre water plus Zn and B if recommended.
- No further irrigation unless the trees show signs of water stress.

Julie onwards;

- Irrigate the trees properly and ensure that the total root zone is wet. This could require 1,5 times the normal application.
- Apply the second 50% of the N
- Apply a foliar spray of 1000g low biuret urea per 100 litre water plus Zn and B if recommended.
- Irrigate at the normal rate for this time of the season.
- Apply the other nutrients as recommended.

### 23. FERTIGATION WITH MICROJETS

In general, fertigation with microjets is approached the same as hand or mechanical applications. The splitting of the nitrogen sources is exactly the same and based on the clay content of the soil. With fertigation an extra one or at the most two applications of N on sandy soils can be justified to improve efficiency. The volume of soil treated with water and fertilisers when hand applications or fertigation with microjets are done is almost the same. The splitting of N- and P fertilisers, gypsum, magnesium oxide and lime are the same as presented in Table 45. Please note that gypsum, magnesium oxide and lime cannot be fertigated.

P as super phosphate still needs to be banded.

Fertigating potassium is the only difference between hand applications and fertigation with microjets. When potassium chloride or sulphate is applied in small quantities during the entire irrigation cycle, the absorption of K is improved, even under suboptimal soil conditions. This method proved to be successful in the Sundays River Valley. Potassium chloride was fertigated at 100g per tree over the total length of the irrigation cycle for 20 successive irrigations. Notwithstanding the adverse conditions in the soil (pH<sub>water</sub> = 7,20, %K = 2,5), the leaf status was improved from 0,56 to 1,44 over 6 years (Table 46).

**Table 46. The effect of continuous applications of low concentrations potassium on the K status of leaves from a Valencia orchard.**

	K% in leaves
1996	0,56
1997	0,74
1998	0,91
1999	1,24
2000	1,29
2001	1,44

Therefore only nitrogen, potassium, sulphur, iron and boron can effectively be fertigated when microjets are used.

Apply the fertilisers during the last quarter of the irrigation cycle and follow that with only enough water to clean the piping.

The effective distribution of the water is a prerequisite for successful fertigation with microjets. If the distribution of water is poor, the distribution of the fertilisers will also be poor.

## 24. FERTIGATION WITH DRIPPERS.

A completely different approach is required when fertigation is applied through drippers. This approach also offers numerous other possibilities. The volume of soil treated has a dominant effect on the application of this technique. If double line drippers are used, the wetted zones overlap and a continuous wet strip is fertigated. Depending on the dimensions of the wetted strip, especially in clayey soil this method will not differ much from fertigation with microjets. The difference lies in pH control and the application of P and Mg.

When the wetted zones from individual drippers do not overlap, the application of fertilisers need to be split even further. With the OHS fertilisers need to be applied with every irrigation between July and March even if more than one irrigation might be required per day.

Fertigation with drippers can have many advantages and in the Sundays River Valley the following have been high-lighted;

Absorption of K by the trees can be improved and less expensive foliar sprays are required.

The control of iron deficiencies is cheaper

P applications are more effective.

Nematode and *Phytophthora* control are more effective and cheaper.

Systemic insecticides can be better utilised.

Ca applications can be done more effectively.

Old trees respond quicker to treatments.

Canopy and root system reacts faster to treatments.

However, some practical problems arise namely;

Preparation of nutrient mixtures.

Different cultivars planted in the same orchard cannot be treated differently.

The specific requirements of every orchard make logistics a nightmare.

Water soluble fertilisers are more expensive.

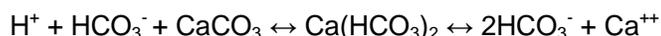
The primary advantage of hydroponics is that manipulations can be done easier and more effective to satisfy the requirements of the trees. However with hydroponics the buffer against errors is so much smaller.

A few other comments can be helpful in the operation of fertigation with drippers.

- Gypsum, but not lime, can be applied in small basins below each dripper to supply Ca and S. Lime cannot be applied like this. Lime will precipitate all P, Zn, Cu, Fe and Mn from the nutrient solution.
- When mixing chemicals, the acids must be added firstly, then the liquids, then neutral salts and lastly the alkaline materials. Thereafter the pH must be corrected.
- Physiological drought (high osmotic potential due to high concentrations of chlorides) can be offset by nitrates. A ratio of 1:2 me  $\text{NO}_3^-:\text{Cl}^-$  reduces the effect of Cl and a ratio of 1:1 can remove the effect completely. The limitation however is the nitrogen requirement of the trees which cannot be exceeded.
- Acidification of the irrigation water can also be done by  $\text{CO}_2$ . When the partial pressure of  $\text{CO}_2$  is increased, more carbonic acid is formed and the pH decreases. When the pressure is lifted, the reaction will shift back and the acid is converted into bicarbonates and the pH rises. This can only be done in a closed system. When the water is emitted at the dripper, the pressure is lifted and the pH will rise. However the reaction time to complete the shifts is long enough to acidify the soil and root environment. That is why this method of acidification can only successfully be applied with drippers.



- In calcareous soils (soils rich in lime) the  $\text{H}^+ + \text{HCO}_3^-$  will react with the carbonates of calcium to form the soluble bicarbonates that can be leached.



With the introduction of hydroponics to commercial citrus orchards, many attempts to synchronise the phenology and nutrition were proposed. Various presentations are available and one is given in Table 47 but please note that it is only applicable in hydroponics where the root volume is restricted to less than 200 litre per tree. With early cultivars like satsuma, the concentrations of the nutrients, especially nitrogen during Phase 4 should be changed to that of Phase 5 by the end of January.

**Table 47. Phenological phases in the development of citrus fruit and the concentrations of N, P and K to be applied.**

Phase	Period	Phenology	Days	ppm N	ppm P	ppm K
1	End of harvest until bud break	Cell differentiation and accumulation of carbohydrates.	40-45	25	5	20
2	Bud break to first open flowers	Bud break, flowering and fruit set	40-45	45	7	50
3	Blossom to fruit drop in November.	Fruit set and cell growth	90	30	3	15
4	Fruit drop to end January/February	Fruit growth	70-100	90	3	45
5	Till end of harvest	Ripening and harvest	60-90	0	10	70

The application of nitrogen can also be split according to visual stages of the tree (Tables 48 and 49).

**Table 48. Distribution of nitrogen according to visible parameters of the physiological stages of early cultivars.**

Stage	Duration in week	% N required
Eight weeks prior to end of harvest	9 to 13	0
End of harvest to 6 weeks prior to bud break	5 to 9	5
6 weeks prior to bud break to full bloom	6 to 8	30
Bloom to fruit drop	6 to 8	20
Fruit drop to 8 weeks prior to harvest	15 to 25	45

**Table 49. Distribution of nitrogen according to visible parameters of the physiological stages of late cultivars.**

Stage	Duration in weeks	% N Required
Six weeks prior to bud break	6 to 8	35
Full bloom to fruit drop	6 to 8	20
Fruit drop to end March	22 to 24	35
Beginning of April to 6 weeks prior to bud break	12 to 18	10

Assuming that the trees require  $\pm 7500\text{m}^3$  water per ha the following volumes can be calculated (Table 50).

**Table 50. Guideline for the distribution of water over a 12 month period.**

Month	% of total	Month	% of total
July	4,7	January	11,7
August	6,0	February	11,0
September	7,8	March	9,1
October	9,7	April	7,3
November	11,0	May	5,7
December	11,7	June	4,7

These will vary according to the prevailing climate but it gives guideline for planning the water capacity of the system.

When the water requirement is divided according to the physiological phases, the following serves as guidelines (Table 51).

**Table 51. The distribution of water according to the different physiological phases of early cultivars.**

Stage	Length in weeks	% water required
Eight weeks prior to end of harvest	9 to 13	15
End of harvest to 6 weeks prior to bud break	5 to 9	7
6 weeks prior to bud break to full bloom	6 to 8	15
Bloom to fruit drop	6 to 8	18
Fruit drop to 8 weeks prior to harvest	15 to 25	45

For late cultivars the distribution is slightly different (Table 52).

**Table 52. The distribution of water according to the different physiological phases of late cultivars.**

Stage	Length in weeks	% water required
Six weeks prior to bud break	6 tot 8	15
Full bloom to fruit drop	6 tot 8	18
Fruit drop to end March	22 tot 24	45
Beginning of April to 6 weeks prior to bud break	12 tot 18	22

During a heat stress, the regulation of stomata functions can be better done through the combination of K and Ca. Reducing the concentration of Ca and keep that of K constant will decrease the osmotic pressure which, will help to reduce the stress. During hot weather more water is transpired and therefore more nutrients are absorbed, but the requirement is not more. Therefore by reducing the concentration, especially that of Ca, will alleviate the stress and trees will be able to absorb the water better.

The opposite is also true. During cold and wet weather, the concentration of the nutrients, especially Ca must be increased so that the same mass of nutrients is still absorbed per day. During August to November the Ca concentration should be increased. When the evapotranspiration doubles, the concentration of the nutrients can be halved, and the visa versa in order to keep the total mass of nutrient supplied per day the same.

Under normal conditions, changing the concentrations of the individual elements should be done with the least change to the EC of the solution. This can be done by using K and Mg as "buffer" ions. Because these two are mobile in the plant, they can be stored. During periods of high demand for N and Ca, the concentrations of K and Mg can be reduced to keep the EC constant. Otherwise, change the EC stepwise over an extended period.

When only  $\text{NH}_4^+\text{-N}$  is supplied, more anions are absorbed in order to keep electrical neutrality (Table 53).

**Table 53. Difference in the number of molecules of K, Ca, Mg absorbed when all the nitrogen is supplied as nitrate or ammonium.**

	<b>Cations</b>	<b>Anions</b>		<b>Cations</b>	<b>Anions</b>
N as ammonium	8 NH <sub>4</sub> <sup>+</sup>	9 H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	N as nitrate		8 NO <sub>3</sub> <sup>-</sup>
	4 K <sup>+</sup>	3 SO <sub>4</sub> <sup>2-</sup>		8 K <sup>+</sup>	5 H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>
	1 Ca <sup>++</sup>	1 Cl <sup>-</sup>		2 Ca <sup>++</sup>	1 SO <sub>4</sub> <sup>2-</sup>
	1 Mg <sup>++</sup>			2 Mg <sup>++</sup>	1 Cl <sup>-</sup>
Number of charges	16	16	Number of charges	16	16

Other considerations when fertigation is done by drippers are as follows.

- Nett photosynthesis is maximum at concentrations of 3,50mg Fe and 1,85mg Mn per litre.
- In respect of changing the pH around the root, the responds to the absorption of phosphate (H<sub>2</sub>PO<sub>4</sub><sup>-</sup> en HPO<sub>4</sub><sup>2-</sup>) and sulphate (SO<sub>4</sub><sup>2-</sup>) is like that of nitrate. The difference is that much less P than N is required, about 10 times less and the change in pH is small.
- Increase the concentrations of P and K during fruit growth (phases 2 to 4) and keep the N constant.
- Root growth stops at temperatures <12°C, water stress > 50kPa and an air content <9%
- Gypsum but not lime, may be placed in small basins below each dripper to supply Ca. Lime will precipitate elements like P, Zn, Cu, Mn and Fe.
- The water soluble MAP is prepared using super phosphoric acid and contains 26% P. The combination of NH<sub>4</sub><sup>+</sup> and H<sub>2</sub>PO<sub>4</sub><sup>-</sup> stimulates root growth.
- CMS (Concentrated molasses stillage) can be used in fertigation programmes. It contains organic material and about 1% N, 1%P and 5%K.
- Volatilisation of NH<sub>4</sub><sup>+</sup>-N will occur when ammonium containing fertilisers are dissolved in alkaline water.

When fertigation is done without the micro-nutrient elements the roots grow mainly between the dripper. When the micro-nutrients are included, the roots will also grow below the drippers. Various formulations of micro-nutrient mixes are available. These mixes will not be able to satisfy all requirements, especially not that of boron. The concentration of boron in the irrigation water should be considered when preparing the micro-nutrient mix. Too much boron is phytotoxic. Concentrations of more than 0,25 mg B per litre is potentially dangerous. The formulation of Hoagland (1950) is still the benchmark for solutions of micro-nutrients (Table 54). Concentrations of half the Hoagland solution, is generally recommended for permanent crops

**Table 54. The concentration of micro nutrient elements in Hoagland's solution.**

<b>Element</b>	<b>Half strength mg/litre</b>	<b>Full strength mg/litre</b>
Cu	0,015	0,025
Fe	2,500	5,000
Mn	0,250	0,500
Zn	0,025	0,050
B	0,250	0,500
Mo	0.005	0,010

**Table 55. Solubility of some fertilisers suitable for fertigation.**

<b>Product</b>	<b>Formula</b>	<b>Solubility in gram per litre</b>
Ammonium nitrate (34% N)	NH <sub>4</sub> NO <sub>3</sub>	180
Ammonium sulphate (21% N)	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	705

Calcium nitrate (% Ca 12% N)	$\text{Ca}(\text{NO}_3)_2$	1210
Urea (46% N)	$\text{NH}_2\text{CONH}_2$	1000
Mono-ammonium phosphate (12% N 26% P)	$\text{NH}_4\text{H}_2\text{PO}_4$	227
Potassium chloride (50% K)	KCl	345
Potassium nitrate (13% N 38% K)	$\text{KNO}_3$	130
Potassium sulphate (45% K 23% S)	$\text{K}_2\text{SO}_4$	120
Mono potassium phosphate (24% P 28%K)	$\text{KH}_2\text{PO}_4$	330

Applying the following when preparing the nutrient solutions will make the operation less risky.

- Fill the container to 70-75% capacity before the chemicals are added.
- Firstly, add the acids, then the liquids followed by the neutral salts and then the alkaline ones.
- Ensure that the chemical was properly dissolved before the next one is added. Remember that some chemicals like phosphoric acid has a density of >1,50 and will go straight down to the bottom when added.
- Stir the solutions using an up-down-action and not just swirling in circles.
- Add the acids while the solution is constantly being mixed.
- Add the neutral salt slowly and ensure that it dissolves at the rate of application.
- Never mix an acid with active chlorine.
- Never mix concentrated fertilisers.
- Do not mix calcium salts and sulphates in concentrations exceeding single strength (Single strength is the concentration that should reach the trees).
- When uncertain about compatibilities, do the "bottle test".

Bottle test.

Consider the bottle as a replica of the mixing tank. Use a 5 litre clear plastic bottle. Fill it to 75% capacity. Add the chemicals one at a time in the same ratio of mass/volume to water and ensure that the first one is completely dissolved before the next one is added. Leave the mix for 24 hours and observe any precipitation at the bottom. If no sediment is present and the solution is clear, then the two chemicals are compatible in that ratio and dilution.

Factors that determines the efficiency of a fertigation system.

- Quality of the irrigation system
- Volume soil treated.
- Distribution of phosphate.
- Splitting of applications based on clay content and volume of soil treated.
- Distance of the point of introducing the fertilisers to the orchard. The mass fertilisers remaining in the piping is important.
- Mixture of cultivars served by the same water and fertiliser pumps.

## 25. FOLIAR SPRAYS

Plants can obtain all their non-gaseous requirements via the root system. However, most plant organs including woody parts can also absorb nutrients from solutions (Wittwer, 1963). Although the leaves can only absorb small masses of nutrients, foliar sprays can be used successfully to supplement nutrition. The efficacy of foliar sprays is much higher than that of soil applications (Eichert et al, 1999) especially regarding the micro-nutrient elements like copper and zinc.

Foliar sprays can be regarded as an aid and are applied for two main reasons namely.

- When the supply of nutrients via the root system is not sufficient, foliar sprays are applied to supplement the nutrient supply. The supply might be too low due to a sick root system (*Phytophthora* or nematodes), conditions in the soil fixing the available forms of the

nutrients (high pH, free lime, clay or a too low pH) or due to limited mobility of the element in the plant (greening and Zn).

- When it is required to manipulate the physiology of the trees for a specific reason, foliar sprays are an effective method. For instance sprays with urea for fruit set and MAP to reduce the acid levels in the fruit.

Although foliar sprays can substitute soil applications too many applications are required rendering foliar sprays for this reason impractical. Usually so many foliar applications will be detrimental due to the additional effects like biuret, even at low concentrations. To apply 250g N per tree, about 5 sprays with 1000g urea at a 100% efficiency are required. Foliar sprays can therefore only be considered for remedial actions and specific interventions.

However, foliar sprays can be used to substitute part of the soil applications. It is especially useful during January/February to supplement nitrogen when a quick response and short residual effect is required. The effect of a foliar spray can also be easier manipulated by reducing the concentration in the spray solution to apply less nitrogen with more peace of mind at such late stages.

Live cells carry a negative charge in relation to the environment. Cations will therefore move towards the inside of the tree until the charge gradient reaches equilibrium. Cations ( $K^+$ ,  $Ca^{++}$  and  $Mg^{++}$ ) are actively and anions passively attached to the surface of the leaves. From here on the rate of absorption will depend on the specific element and other factors. Some of the stress factors that can harm the physiology of the tree and hence yield can be lifted by foliar sprays at the right time. The most sensitive stage for detrimental factors to reduce yields is during budding, blossom and fruit set.

In commercial citriculture, foliar sprays should be able to increase production under the following conditions.

- When the incidence of fixing a nutrient element by the soil is high.
- When it is required to lift stress quickly, especially during the forming phases of the fruit. The reaction time of foliar sprays is seconds and in most cases the potential absorption is 80% completed within 15 minutes.
- When the root system is sick and ineffective.
- When weeds will reduce the absorption of nutrients by the trees.
- When the supply of an element at a critical stage is too low.
- To manipulate the physiology of the tree.

The basic requirements for successful foliar sprays are;

- Mass of the nutrient applied
- Formulation.
- Contact.

### **Mass required to be absorbed.**

One of the most important issues of foliar sprays is the mass of the nutrient applied per tree or ha. Evaluating any spray material should start by calculation the potential of the formulation to be successful. A mature citrus tree carries on average 4750g dried leaf material (Embelton in The Citrus Industry Vol 2).

Therefore if the concentration of potassium in the leaves need to be increased by 0,25% a mass of  $0,25 \times 4750g = 12g$  K per tree need to be absorbed. At 416 trees per ha 4992g K per ha is required. The absorption of K is never 100%. Under orchard conditions absorption efficiency of potassium is only  $\pm 25\%$ . Therefore 20kg K or 53kg potassium nitrate need to be apply per ha. On average 1500-2000 litre are sprayed per ha. At a rate of 4000g potassium nitrate per 100 litre water, 60kg potassium nitrate or 22,5kg K will be applied. This spray can therefore be successful. When the concentration of the potassium nitrate is reduced to 1000g per 100 litres, only 15g K is applied and this spray will not be able to increase the K status of the trees sufficiently.

A foliar spray with 4% potassium nitrate can increase the K content of the leaves by more than 100% but at an efficiency of 30 to 40%. Additives can increase the efficiency (Table 18).

To raise the Zn status of the leaves by 20mg Zn per kg requires therefore the absorption of  $20 \times 4,75 = 95\text{mg Zn}$  per tree or  $20 \times 4,75 \times 416 = 39\,520\text{mg Zn}$  per ha. At an efficiency rate of 25% a mass of 380mg Zn per tree 158g Zn per ha must be applied. At 1500 litre per ha and 150ml zinc nitrate (5,5% Zn) per 100 litre water, 124g zinc per ha will be applied. This spray will therefore hardly be successful.

The mass of the nutrient that can be retained depends on the volume of water that can be retained on the surface of the leaves as well as the concentration of the nutrient in the spray solution. The volume, in turn depends on the size of the droplets.

In order to retain 2000 litre water on the leaves, the correct droplet size must be selected. The smaller the size of the droplets, the less water can be retained and the more sprays are required to total the 2000 litres (Table 56).

**Table 56. The number of sprays required to put 2000 litres water per ha on the leaves of mature trees as influenced by droplet size.**

Droplet size in micron (or in mm)	Number of sprays
60 (0,06)	3639
500 (0,50)	6
1000 (1,00)	1

The ideal droplet size for nutritional foliar sprays is 500 to 1000 micron or 0,50 to 1,00 mm. For pest control droplets with an average size of 300 to 500 micron are preferred.

The optimal droplet size for bait applications is 4 to 6mm average diameter.

The size of the droplets is a function of the pressure applied during spray, the orifice of the nozzles and the whiler plates used (Table 57).

**Table 57. The relation between orifice, whiler plate number and pressure and the size of the droplets**

Orifice	Whiler plate no	At 5 Bar	At 7 Bar	At 10 Bar	At 15 Bar
D2 1 mm	25	90	78	70	65
D5 2 mm	25	145	133	125	120
D8 3,2 mm	25	183	174	165	160
D2	56	250	238	225	215
D5	56	390	365	340	320
D8	56	472	435	400	370

Droplets with a diameter of 10 to 40 micron will float for hundreds of metres but those with a diameter of 250 micron less than 2 to 3m.

A droplet with a diameter of 800 microns has eight times the volume of one with a diameter of 400 microns and 64 times the volume of that of 200 micron diameter. That is one reason why smaller drops will dry out quicker. The volume per surface area of small drops is so much less. For example one millilitre can be divided into 1 900 drops with a diameter of 1000 micron or in 1 900 000 drops with a diameter of 100 micron.

#### **Formulation.**

Amongst the inorganic carriers of cations like K, Ca and Mg is nitrate the most effective for foliar sprays. A study with pumpkin showed that twice as much K is absorbed by the leaves from  $\text{KNO}_3$  as from  $\text{K}_2\text{SO}_4$  (Table 58, Chamel 1969).

**Table 58. Comparative absorption by the leaves of potassium applied as the nitrate, phosphate and sulphate.**

Source	K in the leaves as % of what was applied.	% of absorbed K transported to the rest of the trees.
Potassium nitrate	43,3	20,1
Mono potassium phosphate	33,7	15,1
Potassium sulphate	19,4	13,2

This was confirmed with Valencias when potassium nitrate and sulphate sprays were compared (Table 59, Coetzee, unpublished data).

**Table 59. The increase in the concentration of potassium in the leaves (% increase in brackets) two hour and 7 months after applications on trees with an optimal (A) and suboptimal (B) potassium status.**

Source	%K in the leaves prior to spraying	%K in the leaves 2 hours after spraying	%K in the leaves 7 months after spraying
Orchard A-KNO <sub>3</sub>	1,22	2,31 (89%)	1,55 (27%)
Orchard A-K <sub>2</sub> SO <sub>4</sub>	1,19	1,58 (33%)	1,26 (6%)
Orchard B-KNO <sub>3</sub>	0,65	1,86 (286%)	0,72 (11%)
Orchard B-K <sub>2</sub> SO <sub>4</sub>	0,68	0,92 (35%)	0,66 (-3%)

The improved absorption from potassium nitrate can partly be attributed to the presence of the nitrate ion, lower salt index and the manipulation of certain physiological processes.

The importance of concentration does not relate to that of the product in its undiluted state, but that of the spray solution after the recommended dilution. The required concentration of the nutrient element is the effective concentration. The dilution rate of a product should therefore be aimed to reach the highest possible concentration without damaging the leaves.

The effective concentrations of the various nutrient elements can be benchmarked against the concentrations of chemicals known for their success to increase the concentration in the leaf satisfactory (Table 60). This is applicable for citrus and many other crops.

**Table 60. The effective concentrations of a number of nutrient elements applied successfully as foliar sprays.**

Product	Concentration of active ingredient in the product	Dosage g of ml per 100 litre water	Effective concentration of the water soluble part in the spray mix in mg per litre.
Zinc nitrate	5,5%	150ml	82mg Zn
Zn-EDTA	10%	100g	100mg Zn
Solubor <sup>R</sup>	20%	150g	300mg B
Manganese sulphate	23%	200g	460mg Mn
Copper sulphate	25%	20g	50mg Cu
Potassium nitrate	38% K	4000g	15200mg K
Urea	46% N	1000g	4600mg N
MAP	26% P 12% N	2000g	5200mg P
MKP	28% K 23% P	2000g	5600mg K 4600mg P
Magnesium nitrate	10% Mg 11% N	1250g	1250mg Mg

Any new product can be evaluated according to these guidelines. For a product to have a potential to be effective it should have a concentration of at least 80% after the recommended dilution of the benchmark chemical.

Additives can improve absorption, but if the effective concentration is more than 80% less than the benchmark chemical, then sufficient proof of such claim, must be available.

Additives that can improve the penetration of nutrients into the leaf like acidification (best at pH5,0 to 6,0) and reduction of the surface tension (wettters), will also improve absorption. When wettters are added, the water tends to form a thin layer in stead of droplets on the surface. Much less water is retained and the film dries out much faster. Therefore the mass of the chemical and the contact period is reduced. Urea and fulvates, as mentioned above, are additives that can increase the absorption of potassium from 30 to 33% (urea) and 30 to 40% (fulvates) (Chamel, 1969 and Table 18).

In a recent study the efficiency of the inorganic salts and organic compounds of manganese, magnesium and zinc was compared. The sulphates of manganese and magnesium as well as zinc chloride proved to be the best (Boaretto et al, 1999 and Thalheimer et al, 2002.). Unfortunately the nitrates of these salts were not included.

#### **Contact time.**

Nutrients can only be absorbed when in solution. Therefore the spray solution must be kept on the leaves as long as possible before it dries out. About 80% of the potential absorptions happen during the period just after spraying. If this period is too short, the efficiency will be reduced. . When the spray solution dries out and left a residue on the leaves, the "laws of cuticular penetration" will determine how much of the residue will penetrate the cuticle (Schönherr, 1999). This "law" is based on the relative humidity (RH) required to redissolve salts. According to this, calcium and magnesium chloride will require a RH of 33%, potassium carbonate 44%, and calcium and magnesium nitrate requires a RH of 56% to dissolve. Salts like di-potassium phosphate, mono-potassium phosphate, potassium nitrate and chelates from acetate, lactate and propionate require a RH close to 100% and will not easily dissolve. This theory does not consider condensation and the formation of free water to dissolve the residues.

The duration of the contact period is a function of RH, temperature and droplet size (Table 61).

**Table 61. The effect of relative humidity (RH), temperature and droplet size on time (in seconds) required to dry the drops.**

RH %	Temperature °C	Droplet size in microns	Drying time in seconds
70	20	100	20
70	20	50	5
40	20	100	9

In practise a contact period of 15 to 20 minutes is possible and should be the aim. That is one reason why foliar sprays during the night are more effective than during the day. During the night the temperature is lower and RH is higher. This is especially important for applications of magnesium, potassium and also urea. Therefore apply the sprays during the night, early morning or late afternoon when temperatures are lower and RH higher.

Foliar sprays are usually more effective than soil applications but are still quite ineffective. In Table 18 the efficiency of potassium nitrate sprays are reported to be only 30 to 40%. That is, only 30 to 40% of the mass applied will be absorbed. When the conditions for absorption from foliar sprays are kept optimal for extended periods, efficiency rates of 90 to 95% can be obtained during contact times of 30 minutes to 20 days (Table 62). This information stress the importance to spray when conditions for absorption is most favourable.

**Table 62. The contact time require for an absorption rate of 90 to 95% of the common nutrients used in foliar sprays.**

Source	Concentration in g of ml per 100 litre water	Contact time in hours
Urea (46% N)	1000g	½ to 2
Magnesium nitrate (10% Mg)	1250ml	2 to 5
Potassium nitrate (38 % K)	4000g	10 to 24
Calcium nitrate (17% Ca)	1000g	24 to 48
Zinc nitrate (5,5 % Zn)	150ml	24 to 48
MAP (26% P)	1500g	120 to 240

### **Mechanisms of foliar absorption of nutrients.**

Currently three theories endeavour to explain the mechanisms of absorption of nutrients and other chemicals by the leaves. These three mechanisms need not exclude each other and are possibly together responsible for the absorption of water, nutrients and chemicals. The three mechanisms are the following;

- **Inter fibril pores**

The outermost layer of cells of the leaf is called the cuticle and consists of cutin, which is water repelling. Water and other chemical compounds are secreted through the cuticle and it is also possible that water and nutrients can enter the leaf through this mechanism.

The next layer of cells consists of cellulose, pectin, hemicelluloses and wax. The structure is formed by interconnecting fibrils which leaves openings (pores) for water movement. The number of inter fibril pores is enormous. Numbers like  $10^8$  per  $\text{mm}^2$  (100 000 000) are mentioned. In the guard cells of the stomata, the concentration of these pores is higher which partly explains the better absorption by the underside of the leaf compared to the upper side.

The inter fibril pores are very small, about 1,0 nano metre in diameter. To put this small openings into perspective, compare the pore size with the diameter of the urea molecule, which is even smaller at 0,44 nm. Table 63 contains more information about molecular masses of other chemicals known to be absorbed by the leaves of various plants, including citrus. Please note that the masses and not the diameters are supplied to illustrate size.

**Table 63. The molecular mass of some compounds known to be absorbed by the leaves.**

Compound	Molecular mass	Molecular diameter in nm
Water	18	
Potassium	39	0,60
Calcium	40	0.86
Urea	60	0,44
Glucose	180	
Fructose	180	
Glyphosate	169	
Dimiton-S-metiel	230	
H-EDTA	292	
Phosetyl-aluminium	354	

Below the epidermal cells is the plasmalemma consisting of lipo-proteins, which offers no barrier to water and nutrients passing through the inter fibril pores.

- **Stomata**

Citrus leaves contain about 800 per stomata per  $\text{mm}^2$  on the underside and 40 per  $\text{mm}^2$  on the upperside. The average diameter is 8 micron but these openings are filled with gas which cannot easily being displaced by water. Nevertheless enough proof exists to support the stomata as an entry point of water and nutrients through the leaf. The fact that potassium is better absorbed

during the night when the stomata are closed, indicates that this is not the only mechanism of absorption.

- **Modification of the waxy layer.**

Usually the waxy layer will repel water but some chemicals have the ability to change this to a point where water and nutrients can penetrate. Such modifications are possible by adding urea and fulvates to the spray solutions. The modification lasts only for a few minutes after the application. The increased absorption of potassium reported in Table 18 was possible by adding urea and fulvates (Table 18 and Chamel, 1969) .

### **Compatibility.**

When compatibility is discussed, three aspects are involved

- **Chemical compatibility.**

Chemicals that will react with each other to cause scorching of the fruit or leaves, or rendering either one or both less effective, should not be mixed. Examples of scorching due to mixing are copper oxychloride and zinc or magnesium nitrates. The last two are usually in an acidic medium which will dissolve more copper from the copper oxychloride suspension and increase the concentration of soluble copper to phytotoxic levels. Potassium nitrate has an alkaline reaction and with zinc nitrate will precipitate the zinc leaving the solution ineffective as far as Zn is concerned. Under certain conditions (pH and concentration) mixtures of magnesium and phosphate will form insoluble magnesium phosphate.

Oil and sulphur containing chemicals must never be mixed.

Dursban and boron are not compatible.

- **Application times and volumes.**

Application of bait requires big droplets and a low volume that are not compatible with the requirements of foliar feeding.

The application time of certain sprays is very important. If the times are not compatible the two chemicals cannot be mixed.

- **Reduced efficiency.**

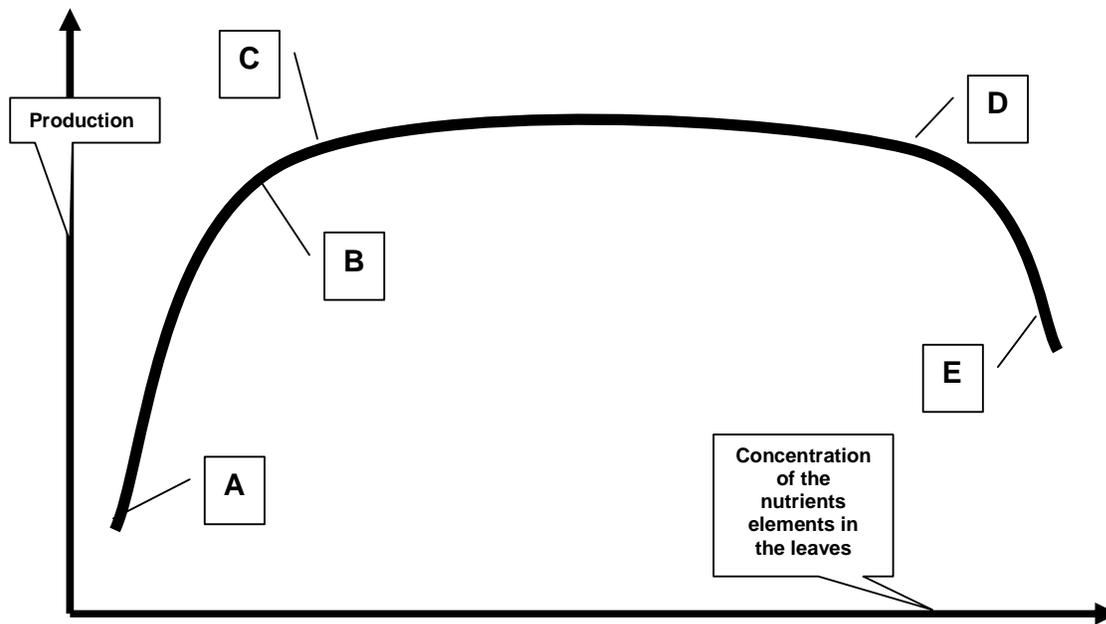
In general the efficiency of an element will be reduced by the addition of a second one to the spray solution. Usually the decrease in efficiency is sometimes so small that mixing justifies the savings in spraying cost. However, some elements will reduce the efficiency of another, without any chemical reaction, to such a degree that they are not compatible. A well known example is potassium and magnesium. When potassium is sprayed the uptake of Mg from the soil is suppressed and visa versa. Therefore these two should not be mixed.

Also refer to Table 79.

## **26. SOIL, LEAF, WATER AND FRUIT ANALYSES.**

### **Leaf analyses.**

Leaf analyses are an indicator of the nutritional status of the trees. During the research into this method a relationship was established between the concentration of the nutrient elements in the leaves and production. This relationship was developed for almost every nutrient element. For some like chloride and sodium only the maximum tolerable concentration was determined. The production-leaf-concentration-curves are illustrated in Figure 12.



**Figure 12. Generalised production curve as affected by the concentration of the nutrient elements in the leaves.**

When the concentration of a nutrient increases from a very low status, the response in production is dramatic as shown by portion AB. The part BC represents the best result in terms of production and nutrient status. CD represents the concentration range where a higher or lower concentration of the nutrient will have little effect on production. A decrease in production is experienced when the concentration of the nutrient is increased more than the maximum from D to E.

It is however impractical and hardly possible to keep the concentration of the nutrient within the narrow range of BC and in practice the concentration range between C and D is regarded as the optimal range. Any variation within this range will therefore be regarded as optimal and will not influence production.

These optimal ranges are not dependent on external conditions like soil type, climate etc but these factors will differ between plant species and even selections within a species (Table 64).

**Table 64. Optimal concentration of the nutrient elements in the leaves (fruiting terminals) of a few citrus cultivars.**

Element	Cultivar/selection	Deficient	Optimal	Excess
N%	Valencias Hot areas	<1,90	2,30-2,60	>2,80
	Other areas	<1,90	2,10-2,30	>2,50
	Young trees	<2,10	2,40-2,60	>2,80
	Deltas and Midnights	<2,10	2,40-2,60	>2,80
	Mid season type oranges	<1,90	2,10-2,30	>2,50
	Mid season type mandarins	<1,90	2,30-2,50	>2,75
	Clementines	<1,90	2,20-2,40	>2,60
	Minneola tangelo	<2,20	2,60-2,75	>3,00
	Satsumas Owari and others	<1,90	2,10-2,30	>2,50
	Miho Wase	<1,90	2,20-2,40	>2,50
P%	Navels	<1,90	2,40-2,60	>2,80
	Lemons	<1,90	2,30-2,60	>2,80
	Pommello	<1,90	2,30-2,60	>2,80
	Grapefruit	<1,70	1,80-2,20	>2,40
	Satsumas	<0,14	0.16-0,18	>0,22

	Grapefruit	<0,12	0,14-0,16	>0,18
	All others	<0,10	0,12-0,15	>0,17
K%	Valencias	<0,60	0,90-1,50	>1,80
	Deltas and Midknights	<0,60	0,90-1,50	>1,80
	Mid season type oranges	<0,60	0,90-1,50	>1,80
	Clementines	<0,60	0,90-1,60	>1,80
	Minneola tangelo	<0,60	0,90-1,25	>1,50
	Satsuma	<0,60	0,90-1,25	>1,50
	Navels	<0,50	0,70-1,10	>1,50
	Lemons	<0,60	0,80-1,20	>1,50
	Pommello	<0,60	0,80-1,00	>1,25
	Grapefruit	<0,60	0,80-1,00	>1,25
Ca%	All cultivars and selections	<2,50	3,50-6,00	>7,00
Mg%	All cultivars and selections	<0,25	0,35-0,50	>0,75
S%	All cultivars and selections	<0,15	0,20-0,30	>0,50
Cl%	All cultivars and selections			>0,65
Na mg/kg	All cultivars and selections			>4000
Cu mg/kg	All cultivars and selections	<3	5-20	>40
Fe mg/kg	All cultivars and selections	<40		
Mn mg/kg	All cultivars and selections	<25	40-150	>300
Zn mg/kg	All cultivars and selections	<15	25-100	>200
B mg/kg	All cultivars and selections	<40	75-200	>300
Mo mg/kg	All cultivars and selections	<0,05		

Leaf analysis is not a simple process. Different techniques can give different values for the same element on the same sample.

Nitrogen is present in two forms in leaves. The majority is present as amine nitrogen ( $\text{NH}_2^+$ ) as in proteins and a small portion is present as nitrate nitrogen. The method originally used to establish the optimal values evaluates only the amine nitrogen because the nitrate represents less than 5% of the total nitrogen content of a leaf. It is not that important with citrus but with annual crops where the nitrates may represent as much as 25% of the total N, it is important to choose the correct method. The nitrogen status of citrus leaves is determined in Israel by the nitrate content (Bar-Akiva, 1974).

When the phosphorus status of most citrus orchards is compared year on year, a wave-like pattern is noticed. The general trend is downwards unless an application is done. For instance, successive leaf analyses data indicate levels of 0,15, 0,12, 0,13, 0,10 and 0,11% P with the next reading probably at 0,08% unless P is supplied.

Leaf analyses gave a good estimate of the phosphorus status of the trees. There is however no relationship between the concentration of P in the leaves and the concentration in the soil.

The results of a leaf analysis on the magnesium status can only be properly evaluated if the trees show no signs of a visual or hidden magnesium deficiency.

The concentration of Ca in the leaf has no relation with the physiological disorders related to a calcium deficiency. The leaf analyses give a summary of the calcium status over a 7 to 9 month period with no indication of a period of Ca stress. The physiological disorders are the result of a very short period of Ca deficiency.

The concentration of iron in the leaf has only any value in the deficient range of <35 mg/kg. Above this value the trees can experience a Fe deficiency or not, but the analyses cannot indicate that. The iron content reported is the total and not the concentration actively participating in the

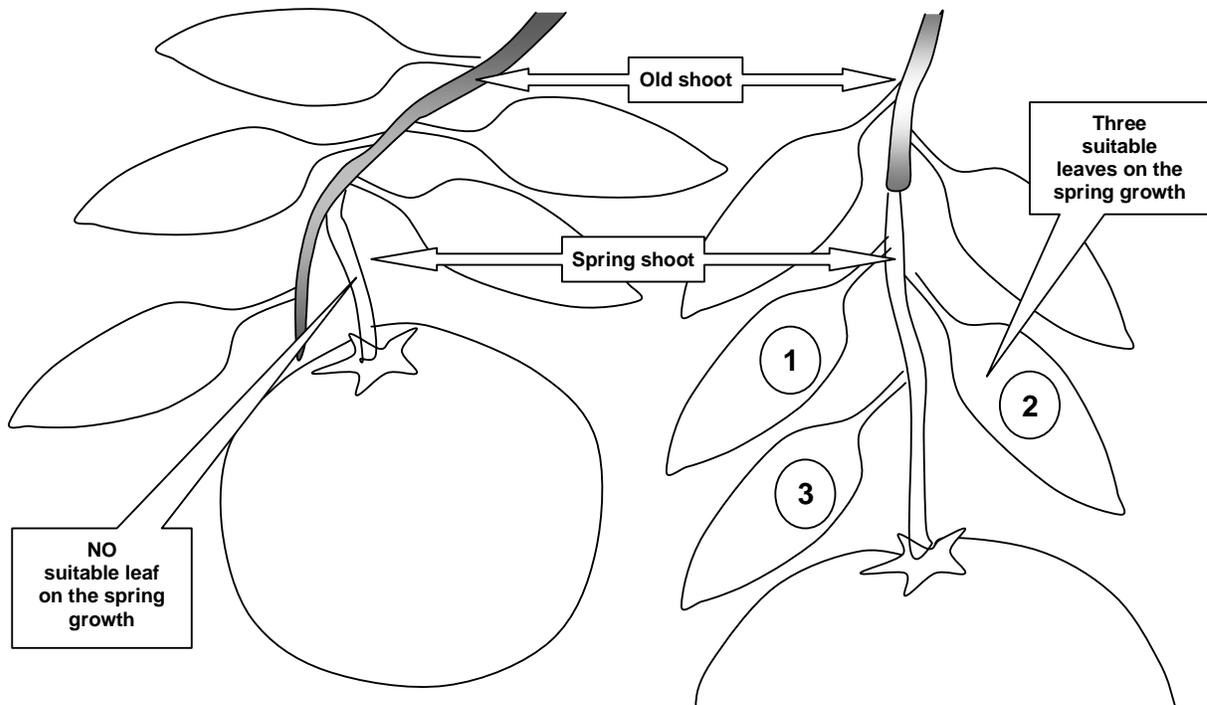
physiology. Leaves with a visual iron deficiency due to a high pH in the soil, contain high concentrations of total iron but too little is active in the physiology.

Rootstocks influence the composition of the leaves but the same optimal range is required, irrespective of the rootstock. The supplies and conditions required to reach the optimal range will however differ between rootstocks.

### **Leaf sampling at bearing trees.**

No analysis how sophisticated can change the quality of the sample. Therefore ensure that the right leaves are picked. Based on the results of this sample many cost will be incurred on fertilisers, while the yield and quality may also be at stake. Sample each year the same set of trees (index trees) and stick to the same procedure and time. Like any other sample, the leaf sample must represent the orchard in its totality. Also attend to the following specific requirements.

- Split the orchards in sampling units. A sampling unit is a group of trees of the same cultivar, rootstock, irrigation, age and planted on the same soil type.
- A sampling unit must preferably not exceed 5ha.
- Select two or four rows that are representative of the orchard and mark these rows. These rows are the index rows and all sampling (leaf, soil and fruit) can be done at these rows. Rows are preferred above diagonal paths due to ease of sampling and repetitiveness of the sampling procedure, year after year. By doing that one can concentrate on the changes brought about by the fertilisation program and not the variations in the orchard.
- Use every year the same index rows.
- Enter the orchard between two index rows and pick a leaf from the right and left hand (shady and sunny) sides between hip and head height.
- Pick between 50 and 75 leaves per sample.
- Pick leaves from fruit bearing terminals which had been grown from the same twig as the fruit during spring (Figure 13).
- The leaves must be 5 to 9 months old.
- Pick the samples during February and May each year the same time (second half of March) Leaf samples taken during June and even July are still useful but left little time to organise the orders and applications of fertilisers starting in July.
- Put the leaves in a clean plastic bag, squeeze out all the air and knot tight. If the leaves have free water on, firstly blot it dry with a paper towel.
- Mark the sample with a label stuck to the outside of the bag or tie it with a string. Use a water resistant pen. Do not put the label with the leaves inside the bag. The label should contain at least your name and that of the orchard.
- Keep the samples cool but do not freeze until it can be send to the laboratory. Ship as soon as possible to the laboratory. Samples that have been treated properly (contain no free water and was kept cool) will last for up to one month



**Figure 13. Illustration of the leaves from fruit bearing terminal, suitable for sampling.**

#### **Taking leaf samples from non-bearing trees.**

If the soil were sampled, prepared and fertilised properly before planting, it is not necessary to take leaf samples from non-bearing trees. However it is never too early to monitor the nutritional status.

Leaf samples can also be taken from nursery trees.

When sampling non-bearing trees, the same procedure regarding index trees, packaging and forwarding is applicable. Take 50 to 75 leaves per sample, one per plant, of leaf numbers 5 to 7 from the tip (Figure 14).

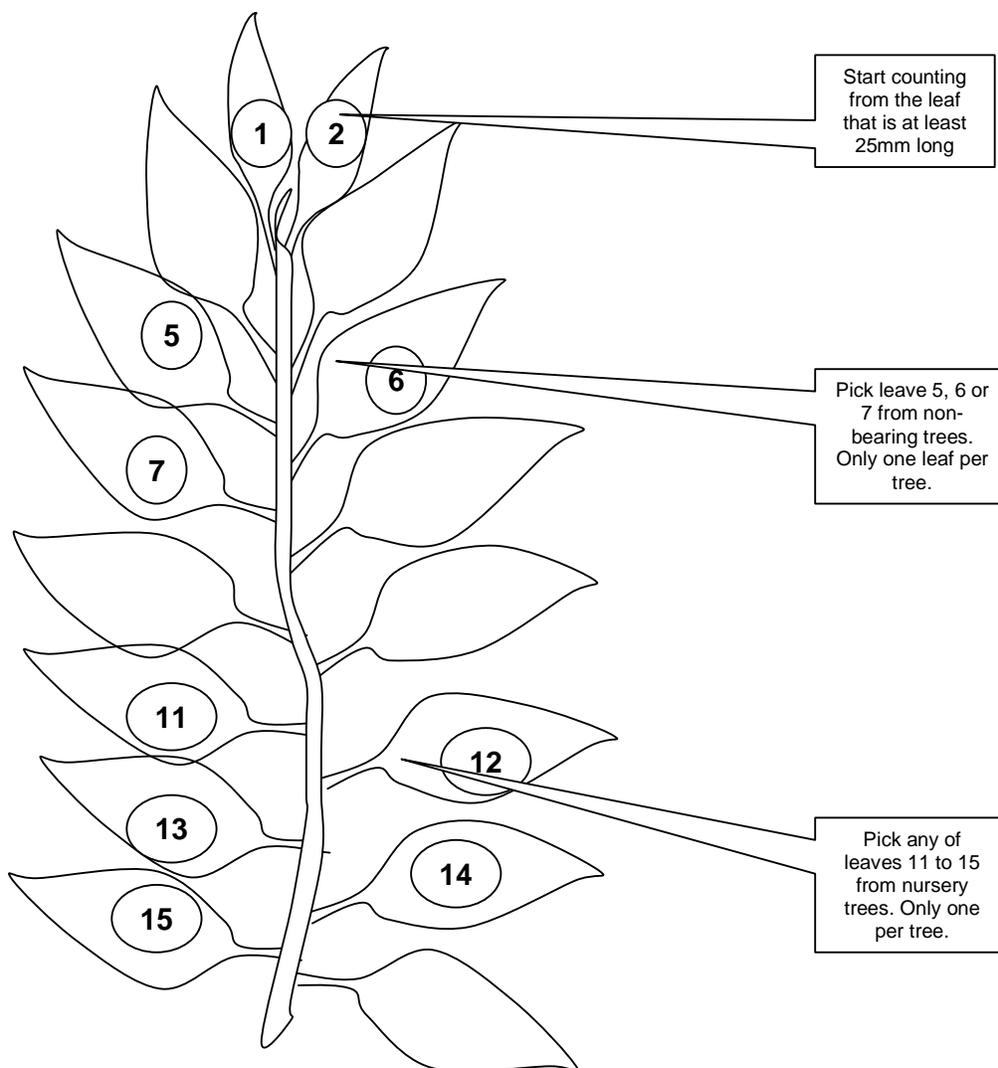
When sampling nursery stock pick leaf numbers 11 to 15. Pick 50 to 75 leaves per sample, one leaf per plant (Figure 14).

The optimal ranges of the nutrient elements for non-bearing and nursery stock are supplied in Table 65 (Coetzee, 1989).

**Table 65. Optimal range of the concentration of the nutrient elements for leaf samples from nursery and non-bearing trees.**

Element	Minimum to maximum
N %	3,00 to 4,50
P %	0,25 to 0,35
K %	2,25 to 3,00

Ca %	1,50 to 3,00
Mg %	0,25 to 0,50
S %	0,25 to 0,50
Cu mg/kg	8 to 20
Fe mg/kg	>30 if the pH < 7,0
Mn mg/kg	30 to 200
Zn mg/kg	20 to 100
B mg/kg	25 to 100



**Figure 14. Illustration of the type of leaf to be sampled from non-bearing and nursery trees.**

The electrical conductivity (EC) of an extract of leaves from nursery trees will also give an indication of the total amount of salt absorbed. This measurement is handy when dealing with fluctuating EC in the nutrient solution. One gram dried leaf material is extracted with 25ml demineralised water for one hour. The optimal EC of the extract is 150 to 200  $\text{mSm}^{-1}$ .

## Soil analysis

Soil analyses supply useful information to decide what measure to take to correct deficiencies, imbalances and excesses in the nutritional status of the trees. With a soil analysis it is attempted to remove from the soil in a few seconds corresponding masses of the nutrients that a plant will remove in 8 to 10 months. Each method applied, therefore went through a series of evaluating steps before it can be accepted as a suitable method for soil analyses.

These methods determine only the plant available portion of the nutrient in the soil, including a part of the reserves that will be utilised over the next few months. The portion measured therefore includes the water soluble and the readily available portion of the nutrients.

These are important principles and the reason for more than one method for the same element that will give different values for the same soil. The variety of methods was developed in an endeavour to simulate the plant. That is also a reason why different methods are used for different crops and in different areas.

Seven different methods are in use in South Africa to test for available P, 2 for K and 3 for pH of the soil. Therefore it is also important to mention the method used on the analytical report. For example, the three methods for pH will give three different answers for the same soil. On average  $\text{pH}(\text{KCl}) + 0,50 = \text{pH}(\text{CaCl}_2) + 0,50 = \text{pH}(\text{water})$  or  $\text{pH}(\text{KCl}) + 1,00 = \text{pH}(\text{water})$ . The description in brackets indicates the chemical used to suspend the soil namely KCl (potassium chloride) or  $\text{CaCl}_2$  (calcium chloride) or water at a specific ratio with the soil. A pH reading of a soil of 5,00 means nothing until the designation is attached. If it was a reading from a KCl suspension the pH of that soil is almost optimal. However if it was done in a water suspension, the soil is too acid.

The relation between these three methods mentioned above, is based on averages but is seldom applicable in practise. Factors like the salt content of the soil have an influence on the reading. Therefore it is not advisable to jump between methods.

Due to the non-existence of a relation between the P content of the soil and that of the water, and that we strive to maintain a  $\text{pH}(\text{water})$  between 6,5 and 7,5 the Bray 1 method for P is preferred. This does not implicate that any of the other methods are inferior.

The base cations in the soil (K, Ca, Mg and Na) are extracted by 1N ammonium acetate (pH 7). These results are then be used to determine the following.

- Can K be supplied by means of soil applications or foliar sprays?
- Does the soil contain enough Ca to supply the trees and maintain the structure of the soil?
- Existence and magnitude of any imbalances.
- Can Mg be supplied by means of soil applications or foliar sprays?
- What is the magnitude of the salinity hazard?

For the reasons mentioned, the results are also expressed as ratios. A typical report is illustrated in Table 66.

**Table 66. An example of a report on the base cations. Optimal ranges are given in brackets below.**

K mg/kg	Ca mg/kg	Mg mg/kg	Na mg/kg	K%	Ca%	Mg%	Na%	Mg:K	Ca+Mg+Na :K
235	763	198	32	9,7	61	27	2,2	2,73	6,33
*	*	*	*	5-7,5	70-75	20-25	<3	<5	<18

\* The clay content of a soil determines the optimal concentration of K, Ca, Mg and Na and therefore cannot be listed. The higher the clay content the higher the optimal concentration.

These ratios are less important in soils containing less than 10% clay. The ratios are of importance because they have effects on the absorption of the cations and the structure of the soil. These ratios are not applicable to citrus cultivated with hydroponic systems. In nutrient solutions the concentration of K is about five times that of Ca and in the soil exactly the opposite.

The potassium-, calcium-, magnesium- and sodium saturation of the soils are expressed as the percentage that the cations contribute to the total.

The saturation of each of the cations can be calculated as follows.

- $\%K = \frac{K \div 390 \times 100}{Ca \div 200 + Mg \div 120 + K \div 390 + Na \div 230}$   
 $= \frac{235 \div 390 \times 100}{763 \div 200 + 198 \div 120 + 235 \div 390 + 32 \div 230}$   
 $= \frac{0,6026 \times 100}{3,8150 + 1,6500 + 0,6026 + 0,1391}$   
 $= \frac{60,26}{6,2067}$   
 $= 9,71$
- $\%Ca = \frac{Ca \div 200 \times 100}{Ca \div 200 + Mg \div 120 + K \div 390 + Na \div 230}$   
 $= \frac{763 \div 200 \times 100}{763 \div 200 + 198 \div 120 + 235 \div 390 + 32 \div 230}$   
 $= \frac{3,8150 \times 100}{3,8150 + 1,6500 + 0,6026 + 0,1391}$   
 $= \frac{381,50}{6,2067}$   
 $= 61,47$
- $\%Mg = \frac{Mg \div 120 \times 100}{Ca \div 200 + Mg \div 120 + K \div 390 + Na \div 230}$   
 $= \frac{198 \div 120 \times 100}{763 \div 200 + 198 \div 120 + 235 \div 390 + 32 \div 230}$   
 $= \frac{1,6500 \times 100}{3,8150 + 1,6500 + 0,6026 + 0,1391}$   
 $= \frac{165}{6,2067}$   
 $= 26,58$
- $\%Na = \frac{Na \div 230 \times 100}{Ca \div 200 + Mg \div 120 + K \div 390 + Na \div 230}$   
 $= \frac{32 \div 230 \times 100}{763 \div 200 + 198 \div 120 + 235 \div 390 + 32 \div 230}$   
 $= \frac{0,1391 \times 100}{3,8150 + 1,6500 + 0,6026 + 0,1391}$   
 $= \frac{13,91}{6,2067}$   
 $= 2,24$

To put these values in perspective, potassium (K) will be used in an example. The K% in the example above is 9,71% indicating that the soil contains enough available K. In Table 67 another dimension of K is emphasized when the concentration K in the soil is related to the volume of soil per tree (spacing) and the mass K removed by the crop. To calculate the volume of soil the following assumptions were made; Volume = inter-row-spacing less 2,5m for roads, times the between-tree-spacing times the assumed rooting depth of 40cm. To convert from kg to litres, the density of the soil is taken as 1,25. Now it can be calculated that 150kg fruit will remove only 33mg K per kg soil at spacing of 7x4m is (Table 67). The 235mg K/kg soil in the example above will be enough for about 7 crops of 150kg fruit per tree.

**Table 67. The mg K removed by yields of 50, 100, 150 and 200kg fruit per tree, at various tree spacing from the soil**

Spacing m x m	Mass soil kg	50kg fruit per tree	100kg fruit per tree	150kg fruit per tree	200kg fruit per tree
7x6	13 500	8	15	22	30
7x5	11 250	9	18	27	36
<b>7x4</b>	9 000	11	22	<b>33</b>	44
6x6	10 500	10	19	29	38
6x4	8 750	11	23	33	46

If the potassium status of the trees in this example is not optimal, it will be useless to apply more K to the soil. The soil already contains enough K but the trees cannot utilise it. Other methods to improve the K status must be considered. Foliar sprays or fertigation with low concentrations continuously are two options. Another consideration is that potassium fertilisation has nothing to do with the current situation. A poor root system or poor irrigation could be the cause of the low potassium status. When deciding on an action to correct a problem as much as possible relevant information must be considered.

In the Sundays River Valley a relation of about 70% was found between the calcium saturation in the soil (Ca as % of the total of the four cations) and the Ca% in the leaves. When the calcium saturation was less than 70%, the concentration of Ca in the leaves was less than 3,50%.

### Soil sampling and fertilisation advise.

The soil samples are taken from the same index rows as the leaf samples. Kindly note the following specific requirements.

Soil sampling at microjets.

- Use a spade or soil auger to collect a sub-sample and sample the top 30cm. Remove the leaves and other debris but no soil.
- Take the sub-sample where the fertilisers and water are applied, usually below the drip line of the tree.
- Take 15 to 20 sub-samples from the trees in the index rows. Put the sub-samples in a plastic bucket, mix properly and retain  $\pm 500\text{g}$  for sending to the laboratory.
- Mark the samples with your name and that of the orchard plus all relevant information on a label and stick or tie it to the outside of the container.

Soil sampling at drippers (Figure 15).

- Remove the top 5cm of soil plus debris. .
- Take the sub-sample from 5 to 30cm deep.
- Take the sample between the dripper and the perimeter of the wetted zone. If the wetted zones of two adjacent drippers overlap, take the sub-sample between the two drippers.
- Collect 15 to 20 sub-samples at the index trees. Put the sub-samples in a plastic bucket, mix properly and retain  $\pm 500\text{g}$  for sending to the laboratory.
- Mark the samples with your name and that of the orchard plus all relevant information on a label and stick or tie it to the outside of the container.

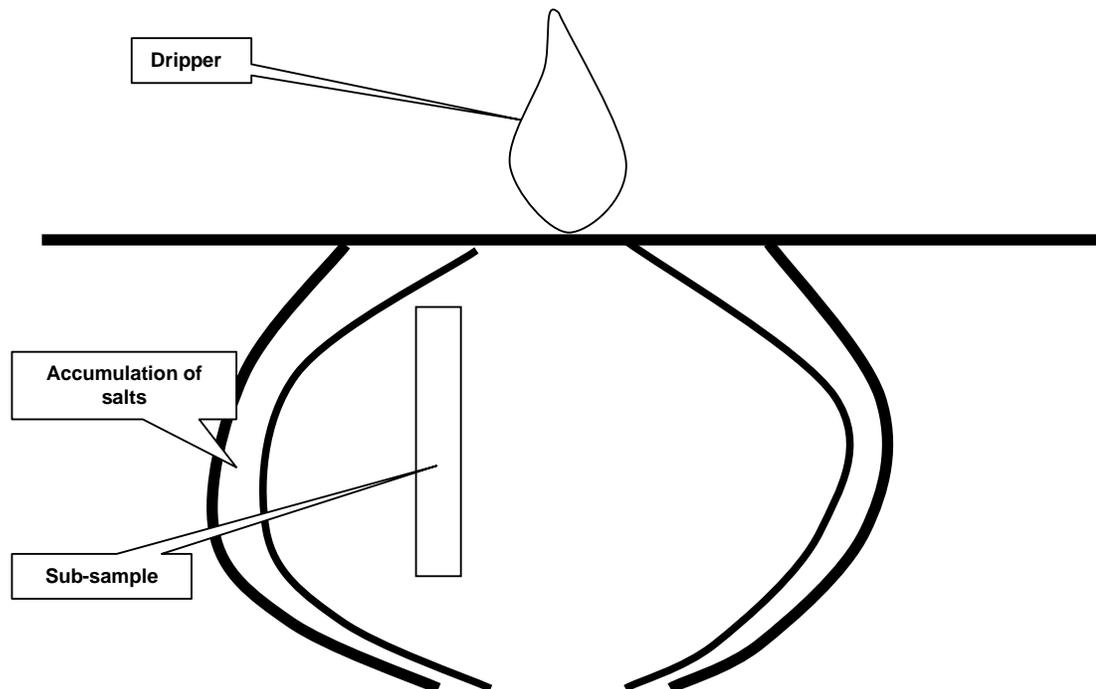


Figure 15. The sampling position in relation to the dripper, surface and perimeter of the wetted zone.

### Analyses of growth mediums.

One extraction method in the evaluation of growth mediums is the 1:1,5 (v/v, medium to water) for which the ranges of optimal values are given in Table 68 (Coetzee, 1989). The optimal

concentrations of the nutrient elements also depend on the water holding capacity (WHC) and the moisture content of the sample.

**Table 68. Optimal concentration range of the nutrient elements in a 1:1,5 water extract, at three different water holding capacities (WHC).**

Element	WHV 10-20% In mmol/l	WHV 21-40% In mmol/l	WHV 41-60% In mmol/l	WHV 10-20% In mg/l	WHV 21-40% In mg/l	WHV 41-60% In mg/l
HPO <sub>4</sub> <sup>=</sup>	0,10-0,30	0,25-0,45	0,40-0,60	10-29	24-44	39-58
NO <sub>3</sub> <sup>-</sup> +NH <sub>4</sub> <sup>+</sup>	0,90-2,00	1,75-3,90	3,50-5,75	32-70	61-137	122-200
SO <sub>4</sub> <sup>=</sup>	0,21-0,50	0,40-0,85	0,65-1,25	20-48	38-82	62-120
Cl <sup>-</sup>	<0,50	<1,00	<1,50	<18	<35	<53
K <sup>+</sup>	0,35-0,75	0,65-1,40	1,25-2,00	14-29	25-55	49-78
Ca <sup>++</sup>	0,35-0,75	0,65-1,40	1,20-1,75	14-30	26-56	48-70
Mg <sup>++</sup>	0,15-0,35	0,30-0,60	0,55-0,80	4-8	7-14	13-19
Na <sup>+</sup>	<0,50	<0,75	<1,00	<11	<17	<23
	In micromol/l	In micromol/l	In micromol/l	In mg/l	In mg/l	In mg/l
Cu <sup>++</sup>	0,10-0,20	0,16-0,47	0,40-0,65	0,006-0,013	0,010-0,030	0,025-0,041
Fe <sup>++</sup>	6-12	10-25	20-36	0,35-0,67	0,56-1,40	1,12-2,01
Mn <sup>++</sup>	2,50-5,00	4-10	9-15	0,14-0,27	0,22-0,55	0,49-0,82
Zn <sup>++</sup>	0,50-1,10	0,90-2,00	1,75-3,00	0,033-0,072	0,06-0,131	0,115-0,200
BO <sub>3</sub> <sup>---</sup>	23-46	37-56	46-69	0,25-0,50	0,40-0,60	0,50-0,75
EC mS/m	30-60	50-85	75-100	30-60	50-85	75-100

### Water analyses.

Natural water does not consist of water alone but also salts and is also a source of nutrients. Natural waters always contain some calcium, magnesium and sulphur and it is usually the magnesium content that interferes with the fertilisation program.

Unfortunately water contains also sodium (Na), chloride (Cl) and bicarbonate (HCO<sub>3</sub>) and when present in high concentrations, could cause problems with osmotic pressure (sodium, Cl and all salts) or availability (HCO<sub>3</sub>) of micro nutrient elements. The HCO<sub>3</sub> is responsible for the pH of the water but there is not a strong relation between these two measurements.

When drip irrigation and fertigation is used, nitric and phosphoric acid can be used to remove the HCO<sub>3</sub> and lower the pH at the same time.

The total soluble salt content of the water is also measured in terms of the electrical conductivity (EC). The higher the concentration of dissolved salts, the higher the EC. The international standard (SI) unit for EC is milli-Siemen per metre (mSm<sup>-1</sup>). A water source with an EC of 150mSm<sup>-1</sup> has a osmotic potential (OP) of 50kPa which is equal to the maximum tension a tree can handle without using energy to absorbed water. When the EC exceeds 150 mSm<sup>-1</sup> sugars is used to increase the OP in the roots in order to obtain water. The use of sugars to obtain the required water in stead of producing leaves and fruit has a negative impact on production.

Polluted water also contains nitrates (NO<sub>3</sub>), sulphates (SO<sub>4</sub>) and even phosphates (PO<sub>4</sub>). The presence of nitrates is quite common and can render water unsuitable for irrigation of citrus. This is a growing problem caused by liberal use of fertilisers but also from human and animal sewerage.

The increasing concentration of nitrates in irrigation water holds a real treat to citrus production. When irrigation water contains too much nitrates the water can not be used during the second half of the production cycle. The amount of nitrogen applied by means of the irrigation water will be comparable to an application of nitrogen at the wrong time. Table 69 illustrates the mass of N

applied by various irrigation regimes at various concentrations of nitrate. During the first part of the production cycle the nitrates in the water should form part of the nitrogen requirement.

**Table 69. The relationship between the concentration of nitrogen in the water (mg/litre) and the mass nitrogen applied (kg per ha) with at 200 to 1000mm irrigation.**

mg N per litre water	Irrigation at 200mm	Irrigation at 400mm	Irrigation at 600mm	Irrigation at 800mm	Irrigation at 1000mm
10	20	40	60	80	100
15	30	60	90	120	150
20	40	80	120	160	200
25	50	100	150	200	250
30	60	120	180	240	300

Therefore, an irrigation of 800mm per annum with water containing more than 20mg N per litre, will not be suitable for citrus, because too much nitrogen ( $>160 \div 2 = 80\text{kg}$ ) will be applied during the second half of the production cycle.

Fortunately a biological process is available that will reduce the nitrates to  $\text{N}_2$ , a gas which is not available to the trees

Water containing more than 100mg Cl and 50mg Na per litre should not be used for foliar sprays, especially when potassium nitrate is sprayed.

The pH and buffer capacity of water is important when used for foliar sprays. The absorption of nutrients is in general best at a pH between 5,00 and 6,00. If zinc nitrate is added to water with a pH above 6,50 the zinc will be precipitated and the efficiency of the spray reduced. The volume of acid required to lower the pH of the water is determined by the buffer capacity which in turn is dependent on the bicarbonate content of the water. Sometimes the volume of acid required is so much that the increase in the total salt contents of the water will scorch the leaves. In such cases, sulphuric acid will be a better acidifier than any of the weaker acids.

The leaching requirement (LR) is the extra water required to keep the concentration of salts in the root zone constant. The LR is expressed as a percentage of the application. A LR of 10% therefore means that 110% of "normal" precipitation is required to keep the salt content constant. The LR is therefore based on the salt content (EC) of the water (Table 70).

**Table 70. The relationship between the EC of the water and the leaching requirement (LR) for 100 and 90% production.**

EC of the water in $\text{mSm}^{-1}$	LR for 100% production	LR for 90% production
50	7	5
75	10	7
100	14	10
125	18	12
150	22	15
175	26	18

These values are calculated from the following formula;

LR for 100% production =  $\text{EC of the water} \div 850 - \text{EC of the water}$ .

LR for 90% production =  $\text{EC of the water} \div 1165 - \text{EC of the water}$  (according to Rhoades, 1978).

### Taking water samples.

The basic requirements for sampling any commodity are also applicable to water sampling. However, kindly note the following specific requirements for water samples.

- When water from a bore hole needs to be sampled, let the pump run to get rid of all the water that was standing in the pipes for some period. Only sample water that comes directly from the bore hole.
- Do not sample water next to the wall or side of a dam. Take the sample from the middle or at least 2 m from the side and 30-50cm below the surface.
- Rinse the cleaned sample container at least three times with the water that needs to be sampled. Ensure that the lid is also properly cleaned.
- When the water sample is also destined for microbial analyses, rinse the container three times with hot water (60-70°C) and then again three times with the water to be sampled.
- Use the 500ml soft drink polycarbonate bottles (Coke or Fanta) with a screw cap that is freely available.
- Mark the samples with a label stuck to or tie it to the bottle. Do not write on the bottle. Use a waterproof marker and write your name and the reference number of the water source on the label. Also write the analyses required (irrigation or human consumption) on the label.
- Send the sample to the laboratory as soon as possible. Samples that need to be analysed for their microbial content, especially *E. Coli*, must reach the laboratory within 24 hours.

### Fruit analyses.

Fruit analyses to determine the nutritional status of the trees have been investigated more than once. This technique is not practical due to the large volumes to be handled (50 fruit against 50 leaves per sample). Fruit is generally also less sensitive to changes in nutritional status than leaves.

Fruit analyses are however useful to determine their quality and shelf life. Analyses of fruit can also be used to determine the masses of nutrients removed from the orchard (See Table 2).

Although the composition of fruit from various cultivars differs, the variation between analyses from the same cultivar and year-on-year is of the same order. Table 71 contains the chemical composition of fruit from 10 different cultivars sampled over a period of three years. This serves only as a guideline to calculate removal figures and the efficiency of fertiliser applications.

**Table 71. Average range of the nutrient element content of 10 different citrus cultivars obtained over a three year period.**

Element	Concentration in dried material	Concentration in fresh material
N	1,00 – 1,75%	150 – 265mg/kg
P	0,10 – 0,15%	15 – 25mg/kg
K	1,70 – 3,00%	255 – 450mg/kg
Ca	0,50 – 0,75%	75 - 115mg/kg
Mg	0,10 – 0,20%	15 – 30mg/kg
S	0,15 – 0,25%	25 – 40mg/kg
Cu	5 -10 mg/kg	0,75 – 1,50mg/kg
Fe	10 - 20 mg/kg	1,50 – 3,00mg/kg
Mn	10 - 20 mg/kg	1,50 – 3,00mg/kg
Zn	7 – 15 mg/kg	1,05 – 2,25mg/kg
B	10 - 15 mg/kg	1,50 – 2,25mg/kg

Research to relate the mineral composition of fruit and fruit quality has started only recently. For example, the nitrogen content in the peel of good quality grapefruit is less than 1,50% in December, 1,30% in January/February and 1,10% in March (ITSG, report at a study group meeting) For good quality Valencias the peel should contain less than 0,90% nitrogen at maturity. Higher concentrations will result in thicker skins.

Silicon is also present in the skins of citrus fruit but its role is still uncertain. Silicon provides a physical barrier against fungal, insect damage and sunburn in crops other than citrus.

## 27. SOIL PREPARATION AND FERTILISATION OF NON-BEARING TREES.

Once the suitability of a site for citrus plantings is confirmed, soil preparation can commence.

The purpose of soil preparation before planting is to optimise the chemical and physical properties of the soil in order to have a homogeneous layer of 50 to 60cm depth for optimal root development. This will enable the trees to reach maturity quicker and improve the productive life of the trees. A sound root system will be able to sustain a healthy canopy with more resistance against adverse conditions of heat and cold. A deeper root system, especially during the initial stages will also be less susceptible to adverse climatic conditions.

The preparation can therefore only follow the laboratory and site analyses. Site analyses of profile pits will determine the type of preparation required.

Two of the most important characteristics of the soil are the effective depth and the clay content. The concentration (texture) and type of clay in the soil cannot be changed. The effective depth can be manipulated using ridges or deep ploughing. The concentration of silt and fine sand are also important because these fine particles have a negative effect on the potential of a soil. The concentrations of clay, clay+silt and clay+silt+fine sand are used to evaluate the suitability of soils for citrus production (Table 72).

**Table 72. The suitability of soils for citrus based on the clay, clay+silt and clay+silt +fine sand of the soil.**

	<b>Clay %</b>	<b>Clay+silt %</b>	<b>Clay+silt+fine sand %</b>
Optimal	5-20	5-30	< 40
Marginal	< 5	< 5	< 10
Marginal	21-30	31-40	40-50
Unsuitable	> 30	>40	>50

A low content of fine particles (clay, silt and fine sand) has a detrimental effect on citrus trees during the initial settling period. This can be overcome by applying water and nutrients more frequently at lower rates.

### Evaluating the profile properties of a soil.

The purpose of this evaluation is;

- To determine the potential depth of the soil. A layer of soil with no limitations to draining of 100cm can be regarded as optimal. This will allow a rooting depth of at least 50cm. During the evaluation the presence of any limiting factors must be noted. If the potential rooting depth is less than 30cm, ridging can be considered. Limitations include the concentration of clay, poor draining, rocks etc.
- To determine the type of successive layers. If the clay content between two successive layer of soil differs more than 1,5 fold, the two horizons must be mixed. For instance if the A-horizon contains 20% clay and the B<sub>1</sub>-horizon 11% clay ( $20 \div 1,5 = 13,3$ ). The difference is therefore >1,5 fold. Likewise if the A-horizon contains 20% clay and the B<sub>1</sub>-horison 35% clay ( $20 \times 1,5 = 30$ ) and 35 are > 30. Under these conditions the two layers must be mixed. If the clay content of two successive layers differs less than 1,5 fold, the layers need only to be loosened.
- To take soil samples for chemical and clay content analyses. The chemical analyses should include at least pH, resistance, P, K, Ca, Mg and Na.

### Soil sampling before planting.

These samples are collected from the profile pits. Prepare two profile pits per ha, one on the upper and the second on the lower side of the slope. If the properties of the two profile pits are the same, the samples from the two pits can be mixed together.

Mark the horizons by drawing a horizontal line on the visible transition between the two layers, based on the structure, colour and clay content. Note the depth and thickness of the layers. For instance A = 0 to 25cm, B<sub>1</sub> = 25 to 60cm.

Take small sub-samples from each horizon at all four sides of the profile pit. Put the four sub-samples from a layer in a plastic bucket but keep samples from different horizons separate. Do not sample the transitional areas. If the properties of profile pit 1 are the same as profile pit 2, the sub-samples from each layer can be mixed together.

Mix the sub-samples from the layers in the plastic bucket properly and take  $\pm 500$ g as a sample to be sent to the laboratory. Mark the sample container properly indicating the site and horizon. For example Orchard F 0 – 25cm, Orchard F 25 - 60cm.

Pre-plant soil analyses will indicate the mass of lime, gypsum and/or phosphorus to be mixed into the profile before the trees can be planted. Table 73 supplies some guidelines on the optimal values for soils destined to be planted with citrus.

**Table 73. Optimal ranges of some nutrient elements of citrus soils.**

Component	New orchards	Existing orchards
Phosphorus Bray 1 mg/kg	25-35	>50
Potassium saturation %	4,0-5,0	5,0-7,5
Calcium saturation %	70-75	70-75
Magnesium saturation %	15-25	15-25
Sodium saturation %	<3,0	<3,0
pH(water)	7,0-7,5	>6,0
Resistance in ohms	>500	>500

### Applications of lime

Lime is added to increase the pH(water) of acid soils to between 6,5 and 7,0 and calcium and magnesium are applied at the same time.

Lime dissolves only slightly in water and for the best results, needs to be mixed with the soil. The deeper the mixing the better the pre-plant treatment.

The total area should be limed according to the lime requirement based on the soil analyses. Liming after planting is not as effective and the lime applications after planting cannot be mixed to the required depth.

The lime requirement can best be calculated from a lime requirement test done on the soil by the laboratory. In this process increments of calcium carbonate is applied to a sample of the wet soil and incubated for 24 hours. The mass lime required to increase the pH of the soil can then be calculated. The lime requirement can also be based on the level of exchangeable acid. Another method is to base the lime required of non-buffered soils on the concentration clay and the pH of the soil (Table 74).

**Table 74. The mass of lime (kg/ha-15cm depth) required to raise the pH(water) of soil with various concentrations of clay to 6,5.**

pH(water)	<5%	5-10	11-15	16-20	21-25	26-30	31-35	36-40
6,40	0	0	0	500	500	1000	1500	2000
6,30	0	250	500	500	1000	1500	2000	2500
6,20	250	500	750	1000	1500	2000	2500	3000
6,10	500	750	1250	1500	2000	2500	3000	3500
6,00	750	1000	1500	2000	2500	3000	3500	4000
5,90	1000	1500	2250	2500	3000	3500	4000	4500

5,80	1250	1750	2500	3000	3500	4000	4500	5000
5,70	1500	2000	2750	3500	4000	4500	5000	5500
5,60	1750	2250	3000	4000	4500	5000	5500	6000
5,50	2000	2500	3250	4500	5000	5500	6000	6500
5,40	2250	2750	3500	5000	5500	6000	6500	7000
5,30	2500	3000	3750	5500	6000	6500	7000	7500
5,20	2750	3250	4000	6000	6500	7000	7500	8000
5,10	3000	3500	4250	6500	7000	7500	8000	8250
5,00	3250	3750	4500	7000	7500	8000	8250	8500
4,90	3500	4000	4750	7250	7750	8250	8500	8750
4,80	3750	4250	5000	7500	8000	8500	8750	9000
4,70	4000	4500	5250	8000	8250	8750	9000	9250
4,60	4250	4750	5500	8250	8500	9000	9250	9500
4,50	4500	5000	5750	8500	8750	9250	9500	9750

### **Acidification of alkaline soils.**

The pH of alkaline soils can theoretically be reduced by acidifications to pH(water) of 6,50 but in practise this offers a few challenges to remove the increasing mass of salts that dissolves as the pH decreases. The acid requirement of a typical soil from the Sundays River Valley is 270ml sulphuric acid (85%, d =1,69 and 36,4N) or 158g S per m<sup>2</sup> 15cm deep. Acidification should be done gradually at the rate that allows for the removal of the excess salts before it damages the roots.

### **Application of gypsum.**

During soil preparation gypsum is incorporated into alkaline and neutral soils when the calcium saturation is less than 70%. At a calcium saturation of 70% the structure of the soil will be better maintained than at lower levels. A good soil structure promotes aeration, water penetration and hence root development and activity. Gypsum serves only as a source of Ca and S and will not change the pH of the soil.

Too much gypsum can be applied. If the calcium saturation exceeds 80%, less potassium will be available to the plants. When K is applied, it will displace Ca on the clay complex and less K will then be available to the plants. When gypsum is applied to a soil with a calcium saturation of less than 70%, the Ca will displace the K, Mg, Al, H and Na on the clay. These displaced cations are then available to the plants and can be leached from the soil.

### **Applications of phosphorus.**

Phosphate moves slowly through the soil profile and mechanical mixing is required to get the P down into the subsoil for the development of a healthy root system.

Phosphate can be supplemented by any phosphate fertiliser. Super phosphate is a popular source because all the P is in the water soluble form. Phosphate applications can be done in any of the following ways.

- When phosphate is applied in strips that will be the in-row areas (excluding the roads) less P will be required and the weed growth in the roads will also be reduced. It is important that the trees be planted in the middle of these strips which make this approach less attractive in practise.
- When ridges are used to increase the effective soil depth or to improve drainage, the P needs only to be mixed with the top 30cm layer of soil. Thereafter, the ridges can be prepared by moving the P-enriched soil to the ridges. The ridges must be 3 to 4 m wide and up to 500mm high.

- To apply phosphates to the plant hole only is not recommended for commercial citrus.

When the pH and P content of the soil has been optimised during soil preparation, it is usually not necessary to apply any additional P during the ensuing 5 to 10 years. This does not apply for drip irrigation where a much smaller volume of soil is utilised

### **Potassium and magnesium.**

If the soil analyses also indicate that potassium and/or magnesium are required, application can be done during soil preparation. Fruit from the first harvest is usually large with coarse skins. Young trees also absorbed potassium very efficiently which will aggravate the quality problem. For these reasons potassium should be applied with caution and only if the potassium status is really poor. Absorption of calcium and magnesium is less sensitive to poor aeration in the root zone than absorption of potassium and P. Absorption of K is very sensitive to poor aeration. Due to the efficient absorption of K by young trees, magnesium deficiency might be induced. The best way to correct the induced deficiency is by foliar sprays with magnesium nitrate. As the trees aged, the induced deficiency will disappear as the efficiency to absorb K diminishes. This diminishing ability to absorb K is due to a number of factors including compaction of the soil and diseases.

The ability to absorb potassium is also a function of the ratio to other cations in the soil. These ratios are based on the mill-equivalent and not the actual concentrations of the cations. Examples of some of the well known ratios are;

- If the  $\text{Ca}+\text{Mg}+\text{Na}/\text{K} > 15$  the absorption of K is reduced. The ideal ratio is 10.
- $\text{K}/\text{Ca}+\text{Mg}+\text{K}+\text{Na} = 4,0$  to 5,0%.
- $\text{K}:\text{Mg} = 1:3$

During soil preparations these ratios can be corrected. Sometimes the ratios are so far off the ideal that one has to re-think before attempt to correct them. The mass of chemicals required to put the ratio straight can be so much that it can harm the trees.

### **Fertilisation of young non-bearing trees when irrigation is applied through microjets.**

Use a garden fork to dig hole in the prepared soil when planting the young trees. A spade will cause soil compaction on the sides. Wait for about six weeks before any fertilisers are applied. Generally the young trees require only nitrogen and foliar sprays with micro-nutrients. .

Remember the maximum benefit of the fertilisation program is only possible if all other practises (irrigation, weed control) are optimal. Also note the following basic requirements to care for young trees during transplanting.

- Proper soil preparation.
- Remove the bottom 30% (sandy soils) to 50% (clayey soils) of the growth medium when the trees are transplanted into sandy or loamy soils.
- Use a garden fork to prepare the planting hole.
- Irrigate as the planting progresses and do not wait until all the trees have been planted before the irrigation starts.
- Irrigate for about two weeks next to the stem and ensure that the ball of roots does not dry out.
- As soon as the roots penetrate the adjacent soil, reduce the irrigation.
- Protect the stems when applying herbicides.
- Control aphids, orange dog psilla, thrips, bud mite, red scale and ants.
- Ensure optimal conditions (sap flow, temperature and irrigation) when making applications to the stem.
- Apply phosphonates every second month during the summer (summer rain areas) or winter (winter rain areas).
- Sample the soil plus roots for nematode counts during the second year.
- Take leaf and soil samples during February to May to evaluate the nutritional status and convert to a program for bearing trees.

The following fertilisation program is applicable to most new orchards planted in well prepared soil.

Fertilisation during the first year after planting.

Split 350g limestone ammonium nitrate (LAN) per tree into 10 applications during August to March. Apply the last nitrogen in January in areas like Vaalharts where the winters are very cold. In areas with hot winters like Malelane the nitrogen can be stretched up to May. Potassium at a rate of 2x25g per tree can be applied where the potassium status in the soil is low. Do not mix the LAN and potassium chloride. Apply the fertilisers over an area from the stem to about 50cm beyond the drip line of the trees.

Mix 150g zinc oxide + 100g Solubor<sup>R</sup> + 200g manganese sulphate + 150g copper oxychloride + 1000g low biuret urea per 100 litre water and apply every 4 weeks. Wet the leaves only. If the water or soil contains enough boron, the Solubor<sup>R</sup> must be omitted.

Fertilisation during the second year after planting.

Increase the LAN to 700g per tree. Split and apply as during the first year. If required increase the potassium chloride to 2x50g per tree and apply as during the first year. Apply the foliar sprays as per the first year.

Take leaf samples during August from non-bearing twigs to monitor the nutritional status of the trees (See Figure 14 above).

Fertilisation during the third year after planting.

Increase the LAN to 1000g per tree. Split into 4 applications until December. Do not apply any potassium. Apply the foliar sprays but only until December.

Let a few trees set fruit. Take a leaf sample from fruit bearing twigs during February to May

#### **Fertilisation of young non-bearing trees irrigated by drippers.**

When drip irrigation is used, the trees must be fertigated. Fertigation starts when the trees have been transplanted in well prepared soil, six weeks after transplanting. The phosphate application can be reduced and placed in narrow strips where the dripper lines will be. However this is not practical.

Apply the same basic principles as with microjets. Put a dripper next to each stem and ensure that the root ball is wetted. Thereafter the drippers must be shifted gradually to be placed at a distance of about 500mm from the stem, during the sixth month. With drippers it is essential to ensure that the water and fertilisers do not penetrate deeper than the effective root system.

Fertigation during the first year after planting.

Split 30kg N + 10kg P + 20kg K + 10kg Ca + 10kg Mg + plus 10kg S per ha in at least weekly applications during August to March. In hot areas the fertigation can be extended to May.

Mix 150g zinc oxide + 100g Solubor<sup>R</sup> + 200g manganese sulphate + 150g copper oxychloride + 1000g low biuret urea per 100 litre water and apply every 4 weeks. Wet the leaves only. If the water or soil contains enough boron, the Solubor<sup>R</sup> must be omitted.

Fertigation during the second year after planting.

Split 50kg N + 20kg P + 30kg K + 10kg Ca + 10kg Mg + plus 10kg S per ha in at least weekly applications during August to March. In hot area the fertigation can be extended to May.

Apply the foliar sprays.

Take leaf samples during August from non-bearing twigs to monitor the nutritional status of the trees (See Figure 14 above).

Fertigation during the third year after planting.

If leaf analysis shows no adjustments the following program can be used.

Split 75kg N + 25kg P + 50kg K + 20kg Ca + 20kg Mg + plus 20kg S per ha into at least weekly applications during August to March. In hot area the fertigation can be extended to May.

Apply the foliar sprays.

Let a few trees set fruit. Take a leaf sample from fruit bearing twigs during February to May

If the water application is monitored the concentration of nutrients can be kept constant during the first three years. The water requirement and therefore the nutrient application will increase with increase in tree size. If for instance the water requirement doubles from year one to year two, the mass of nutrients applied will also double. The masses applied will therefore be close to the recommended rate of 50kg N, 20kg P etc.

To prevent the accumulation of micro-nutrients in the root zone, the concentrations must be reduced to 20% of a single strength Hoagland solution (Table 54) except perhaps iron. The rest of the requirement must be applied by means of foliar sprays. It is potentially hazardous to accumulate elements like copper in the root zone. If the pH drops for some or other reason, the concentration of soluble copper may reach toxic levels.

## **28. FERTILISATION OF BEARING TREES.**

The most important requirement of a good fertilisation program is that it must only supply those elements that the trees cannot obtain in sufficient quantities from the soil and water to maintain optimal levels for all 14 nutrient elements. The other aim is to supply the required fertilisers at the lowest cost to render the highest income. That does not implicate that the cheapest fertiliser must be applied. A balanced fertiliser mix does not exist, except perhaps with fertigation and drippers where the water and soil contribute nothing to the nutrient program. But even with single line drippers, the composition of the water needs to be considered and can supply the complete requirement for calcium, magnesium and sulphur. The possibility that a mix like 3:1:5 will satisfy the requirements of all orchards on a farm is very slim. A balanced nutritional status is the results of the ability of the roots to absorb the required nutrients, in the required quantities/ratio. Experience confirmed that trees in the same orchard may have a different nutritional status.

The concept of a “balanced” fertilisation program or nutritional status is used often out of context and is sometimes misused to press a certain sales point. Guano was at a stage regarded as being a “balanced” fertiliser although the sea birds have no knowledge of citrus and they only want to get rid of the guano. A certain fertiliser may be balanced for a specific condition, but can be totally off target for the 90% of other applications. The only balanced fertilisation program is the one that is prepared for a specific orchard. Others are based on averages and usually applies too much (usually phosphorus) of one or more of the nutrients.

The following information is required to formulate an effective fertilisation program.

- The current nutritional status (leaf analyses).
- The historical nutritional status, especially that of the previous season (data base).
- Current composition of the soil.
- Current composition of the irrigation water.
- Historical composition of the soil and water.
- Information on the crop for the last two seasons.
- Estimates on the current crop.
- Fertilisers and foliar sprays applied.
- Practises to improve fruit set, fruit thinning, fruit size etc.

These information needs to be evaluated together with all the other information discussed in the previous chapters to formulate a fertilisation program for the coming season.

### **Nutritional status.**

The nutritional status is measured by leaf analyses. Leaf analyses summarise the ability of the trees to set an optimal crop and grow it to maturity. The nutritional status is measured before fruit set and will remain stable until the first nitrogen is applied. The current nutritional status is the accumulated effects of all the inputs including the previous fertilisation program. The success of all the inputs is measured by means of the yield, fruit size and fruit quality. If the accumulated inputs

result in an optimal crop the fertilisation program must be repeated. If any looming imbalance is detected it need to be corrected during the coming season.

Unfortunately many other factors than fertilisation will affect yields and quality. It is therefore possible to maintain an optimal nutritional status but still not produce an optimal crop. In such a case the impact of any possible nutrient deficiency, excess or imbalance must be ruled out, before other factors are considered. Sometimes it is possible to counteract the effect of another factor, by adjusting the fertilisation program. A well know example is creasing. Although the incidence of creasing is primarily due to climatic conditions, the expression of creasing can be hidden by promoting thicker skins through higher N and K and a lower P levels.

The following steps indicates the processes that needs to be followed when evaluation the nutritional status of the trees.

- Compare the results of leaf analyses with the set of norms.

This is a simple process to indicate which elements are not present in optimal concentrations.

- Compare the results with the previous ones, if available.

This will indicate whether the fertilisation program applied resulted in any changes and to indicate trends. For instance, if the current concentration of P is 0,12%, it means an optimal status. However, compared to that of the previous season (0,14) it means a decrease and one can expect the next analyses will indicate a too low status unless some P is applied. If the results of two seasons ago are available, a much clearer picture will be available. When microjets are used for irrigation, P is not applied every year. Therefore it is important to follow the trend of concentration of P rather than the actual concentration. When drip irrigation is used, P has to be supplied continuously and the trend in the example will be used to change the concentration in the nutrient solution.

The type of irrigation used in the above example is irrelevant. The analytical results indicate that the P supply was too low. Whether it is supplied through the irrigation water or from the reserves in the soil, the rate must be increased. How this is done depends on the irrigation system. With microjets supers needs to be banded and with drippers the concentration in the nutrient solution must be increased.

The same argument applies to all other nutrient elements. When the supply is too low, it has to be increased. The supply can also be increased by improving the efficiency of the fertilisers. For instance when the supply of nitrogen is too low, the efficiency can perhaps being improved by split applications that will supply N to the plants over a longer period. The supply of N will then be improved without increasing the mass of N.

Other methods to increase the supply of nutrients are foliar sprays. The zinc status of the trees can effectively being improved by a foliar spray which is preferred to soil applications. Even with foliar sprays can the efficiency of the spray being improved by acidification.

From the above it is clear that more than a set of leaf analyses data is required to formulate an effective fertilisation program.

- Evaluating the previous fertilisation program.

Gathering information on previous applications is not to spy on anyone but to add to the value of leaf analyses and to improve on the previous program.

The basic information required is **W<sub>2</sub>H<sub>2</sub>**. **W**hat, **W**hen, **H**ow much and **H**ow was the fertiliser applied.

What is applied?

All fertilisers are not equally effective under all conditions. By changing the source of a nutrient, the supply of that nutrient can be improved. Examples of such possibilities are listed in Table 75.

**Table 75. List some benefits arising from changing the source of the nutrient elements.**

Source and condition	Alternative source or method of application	Benefits
Urea on sandy and cold soils.	Ammonium nitrate in AN19 or LAN	The hydrolyses of urea is slow in cold and sandy soils. Unhydrolysed urea will leach very easily. Use urea when the soil temperature >15°
Urea spread out on alkaline soils.	Ammonium nitrate in AN19 or LAN of ammonium sulphate	Volatilisation can be reduced and with ammonium sulphate acidification is higher which will increase the availability of iron.
Ammonium nitrate in AN19 or LAN and urea	Ammonium sulphate	When sulphur is also required.
Ammonium nitrate in AN19 or urea with drippers and high concentrations of Cl	Potassium or calcium nitrate	The application of nitrates, especially calcium nitrate suppress the effect of Cl
Soil applications of N when root rot is a problem.	Foliar sprays with urea or potassium nitrate.	Bypass the root system and increase the supply. The mass that can be applied by foliar sprays is limited.
MAP broad cast	Super phosphate banded	Reduce fixation of P
Phosphoric acid through drippers	MAP	The combination of $\text{NH}_4^+$ and $\text{H}_2\text{PO}_4^-$ stimulate root development
Phosphates and acid soils	Lime	By increasing the pH more P will be mobilised and could satisfy the demand.
Phosphates through drippers in an acid soil g	$\text{NO}_3:\text{NH}_4$	Change the ratio to 80:20 or even 100:0 until the pH is neutral. More P gets mobilised at a neutral pH.
Potassium chloride and drippers	Potassium nitrate	The combination of K and $\text{NO}_3$ is more effective
Potassium chloride and alkaline soils	Apply potassium chloride at low rates over a prolonged period. (Low dosage high frequency.)	Without changing the source or mass, potassium will be utilised better.

- Evaluating crop data.

Crop data includes yield, fruit size and several quality parameters. By evaluating more than one year's data, information is gathered aiding in formulating a more purposeful fertilisation program. Examples include alternate bearing, when the incidence of too small fruit and creasing increase during the "on year" too coarse fruit from young trees or trees carrying a small crop, too green fruit etc. The more information supplied, the better the fertilisation program.

- Condition of the trees.

The hidden deficiency symptoms of nitrogen and magnesium (see chapters 2 and 5) can reduce the value of leaf analyses and even worse create erroneous deductions. Therefore is it necessary to have information about the foliar coverage of the trees. Deficiencies of calcium and iron cannot be detected by leaf analyses and additional information is required.

A hidden nitrogen deficiency indicates a lower nitrogen status as what the leaf analyses show and this will have an impact on yield and even fruit size. This can only be identified by a visual inspection of the trees.

Information on climate and skin qualities is required to shed more light on possible calcium deficiencies.

Like nitrogen the hidden magnesium deficiency will only be detected by visual inspection. Too small fruit notwithstanding an optimal potassium status might be due to a too low magnesium status.

Only under very rare conditions will an iron deficiency be identified by leaf analyses. Visual inspection is required. An iron deficiency can result in losses in yield and quality although the leaf analyses indicate an optimal nutritional status.

### **Application of fertilisers.**

As far as application of fertilisers is concerned, the mass, timing and method are the most important aspects.

- **Mass.**

The aim of a good fertilisation program is to optimise the nutritional status of the trees at the lowest input cost. The mass is determined on the basis of applying a certain mass of fertilisers, then evaluate the result after about 8 to 9 months (leaf and crop analyses) and the adjust the previous program.

For instance if 1000g LAN was applied at the right time and the leaf analyses indicates a low nitrogen status and the yield was acceptable but can be better, the conclusion will be to increase the LAN application. But if the information on the mass of LAN applied was incorrect and only 650g was applied then the conclusion is to increase the 650g.

It is also important to realise that two adjacent and identical orchards can have different nutritional status although they were treated exactly the same. For this reason a leaf sample should not represent too many trees. The ideal is a maximum of 1000 trees per sample.

Another method to determine the mass of fertilisers to apply is to calculate the mass removed by the crop (Table 2). For instance if 150kg navel fruit is produced per tree the mass of nitrogen removed will be  $150 \times 2500 / 1000 = 375$ g nitrogen which is equal to the application required. This is only a starting point and must be refined based on analyses of the nutritional status and crop information.

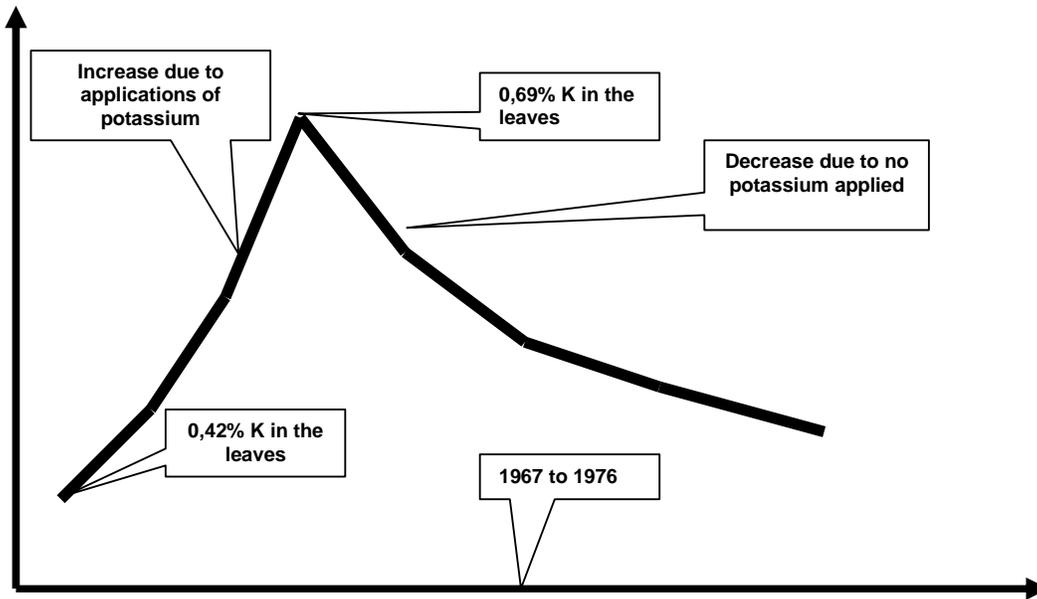
Adjustments can also be based on the leaf analyses. If the leaf analyses indicate a high status, then the 375g can be reduced.

The same removal figures can be used to evaluate the efficiency of the nitrogen application. For example if a crop of 150kg per tree was produced with an application of 500g N per tree the efficiency rate is  $150 \times 2500 \div 1000 = 375 \div 500 \times 100 = 75\%$ . This means that 25% of the applied N is not reflected in the yield. With young trees this is acceptable due to nitrogen required for vegetative growth. In mature trees an efficiency rate of 80 to 100% is acceptable. If the efficiency rate is more than 100%, the trees receive N from another source. This then needs to be investigated.

The efficiency of a phosphorus application can only be evaluated by the maintenance of or the increase in the P status of the trees. It cannot be calculated in the same manner as the efficiency rate of N. This can however be done with drippers and hydroponics. With other systems supers is applied once or twice in a period of 5 to 7 years. There is also no relation between the mass of P applied and the leaf status or between the concentration P in the soil and that in the leaf. Banded P increase the P status of the leaves on average by 0,02 to 0,04% (from 0,11 to 0,13 or 0,15) but will be able to maintain it at a sufficient level form years ahead. Such an application will not raise the P status to 0,25%. The effect is not dramatic but long lasting.

P should be applied continuously at low concentrations when drippers of hydroponics are used.

In sandy soils a dramatic effect is noticed after an application of potassium. The potassium status of the trees increases almost immediately (Coetzee, 1977). With clayey soils the reaction on applications of potassium is slow (Figure 17). Sometimes the reaction is only a slow down of the decline in the potassium status (Figure 18).



**Figure 16. The quick responds in the potassium status of the leaves after applications or withdrawal of potassium in sandy soils.**

Another useful evaluation of the potassium status is to consider the potassium saturation of (%K) and the mass of K available in the soil (Table 67). The evaluation must determine if the soil contains at least 3 to 4 times the mass of K that is required by one crop. For example a crop of 150kg fruit per tree is expected. At a spacing of 7x6m only 22mg K/kg soil is required. At an efficiency rate of 25% 88mg K/kg soil will satisfy the requirement. Compare that with the soil analyses report. If the soil contains less than the required 88mg then an application is essential.

The %K is calculated by expressing K as a percentage of the total concentration of cations. (Chapter 26 just after Table 66). The purpose will be to keep the K saturation between 5 and 7,5%.

If the soil contains enough potassium but the K status in the leaves is low, other methods than soil applications need to be used to increase the status. Foliar sprays or frequent applications at low concentrations can be tried (See Chapter 4 Table 15). This can easily be done with drippers and hydroponic systems.

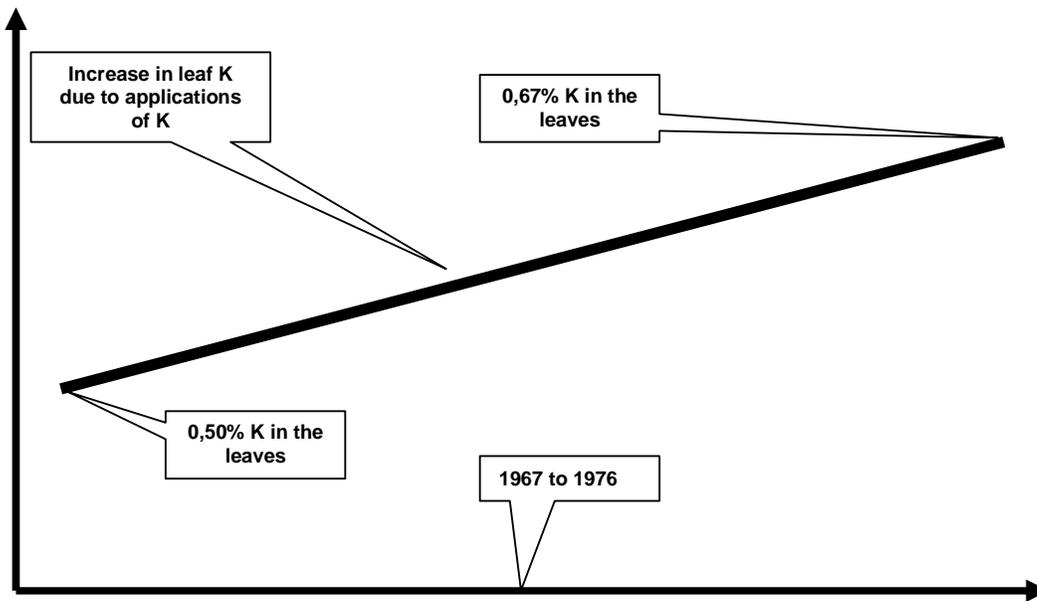


Figure 17. The slow responds of the potassium status of the leaves on application of K to a loamy soil.

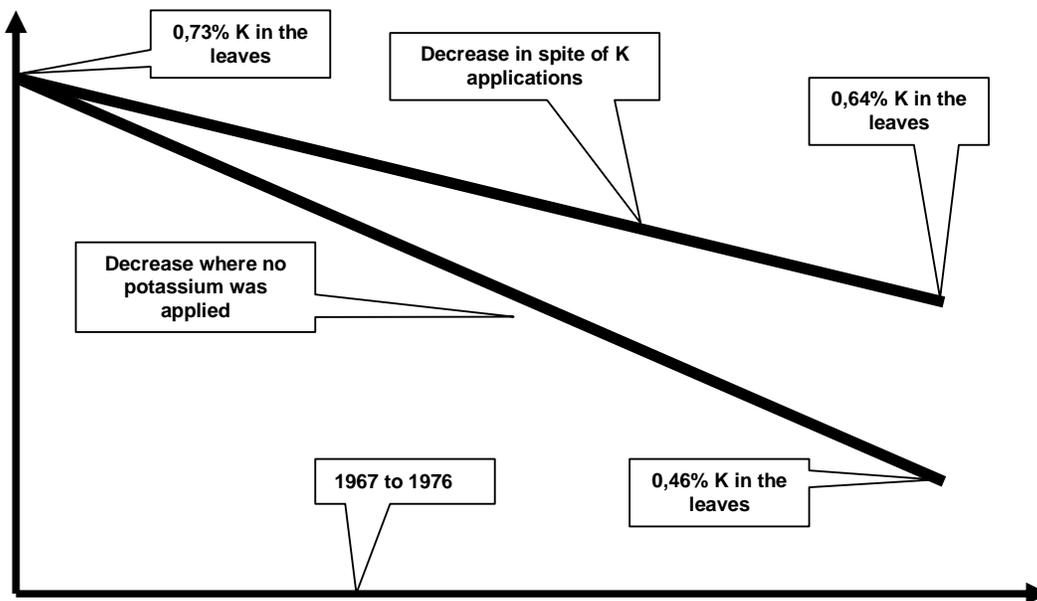


Figure 18. The masked responds of the leaf potassium status on applications of potassium to silty and alkaline soils.

Applications of calcium are based on the calcium saturation of the soil (just following Table 66) and the time when a calcium deficiency will impact the most on quality (cell division). In alkaline and neutral soils, calcium is applied as calcium sulphate (gypsum) in August or through the drippers as calcium nitrate from August to October. When the pH needs correction, liming will also supply Ca.

Applications of magnesium are based on the same approach as that of potassium. Evaluate the leaf status, calculate what is available in the soil and then decide how to correct or maintain the magnesium status. Soil applications and/or foliar sprays can be used. Some waters contain enough magnesium to satisfy the entire requirement of the trees. Do not allow the magnesium status to drop below 0,20%. Once at such a low level it will take time to raise the level to normal.

Remember that applications of potassium will suppress the absorption of magnesium. Keep an eye on the magnesium status when foliar sprays with potassium nitrate are done.

Sulphur is evaluated on the leaf content, the concentration of S in the water and how much S is applied indirectly by other fertilisers. On acidic sandy soils sulphur needs to be applied annually.

The application rate of fertilisers for commercial orchards should never be based on average tree age or tree size. It can only be used as a starting point when no other information is available.

- **Times of application**

Applications of fertilisers at the incorrect time can reduce the value of leaf analyses but if such information is not available, it will lead to total misinterpretation of the results. For example if N was applied shortly before the leaves were sampled, the high nitrogen status will indicate a too high application rate, which will be completely the wrong deduction.

Therefore supply the actual mass and time of the fertiliser's applications to the person who must compile a fertilisation program.

Application times are synchronised with the phenology of the trees in order to optimise profit. However, for some elements and treatment alternative times may be used (Table 76).

When a serious deficiency arises, it is always a sound policy to correct that before blossom. The trees already start in May with preparations for the new crop. Any deficiency during that period will have a serious impact on profitability. An important consideration with early applications is that it must not have a detrimental effect on the current crop.

**Table 76. Alternative times of application of foliar sprays on citrus.**

<b>Element or product</b>	<b>Preferred time</b>	<b>Alternative times</b>
Urea	Pre-blossom	No alternative
Urea	October	November to January except where colour is a problem then not later than November.
Urea on Satsuma and Shamouti	Post harvest	No alternative
Potassium nitrate	Pre-blossom	No alternative
Potassium nitrate	November	After fruit drop to January except where colour is a problem then not later than December.
Potassium nitrate	Post harvest	Only for satsumas or Shamouti. No alternative
Potassium nitrate	August or September	Up to January but the earlier the better
Potassium formulations containing no available N	August or September	Up to January but the earlier the better
Magnesium nitrate	Pre-blossom	No alternative
Magnesium nitrate	October	November to January.
Magnesium formulations containing no available N	August or September	Up to January but the earlier the better
Copper suspensions	Pre-blossom	On mature fruit.
Copper solutions	Pre-blossom	When little wind scaring is expected.
Manganese	October	November to April.
Zinc	October	November to April.
Boron	October	November to April.
Molybdenum	October	November to April.

- **Methods to apply fertilisers.**

Drippers.

The method used to apply the fertilisers will depend on the irrigation equipment available. With single line drippers, it is essential to apply the fertilisers with every irrigation. The frequency of applications will be determined by the volume of water that can be held in the root zone and the requirements of the trees. If the tree requires 75 litres water per day and the root volume can hold 10 litres, then water must be applied 8 times per day. Nutrients must be applied with each irrigation.

The same principles are applicable when double line drippers are used. The volume of soil treated can however be so large that water need only to be applied once or less per day. With double line drippers at least one application of fertilisers should be done every week. If the soil contains less than 5% clay daily irrigation will most probably be required with double line drippers.

The EC of the nutrient solution must be increased with both double and single line drippers during rainy days or time with a low evapotranspiration rate. The mass of nutrients applied during sunny days must be maintained during rainy weather.

Fertilisers should be applied during 90 to 100% of the duration of an irrigation cycle.

Another important issue is that the EC of the nutrient solution must be kept constant and any major variation over a short period must be avoided. A special cycle to clean the root zone is not a good idea. To keep the EC constant the concentration of one element (e.g. potassium) must be reduced when the concentration of another one (calcium) needs to be increased. For example when the requirement for N is high during spring, the concentration of K can be reduced to keep the EC constant. When more K is required during early summer, less N and Ca can be applied to facilitate the higher K concentration without changing the EC.

Gypsum but not lime, can be applied in small basins below each dripper to supply Ca and S. Lime will precipitate elements like P, Fe, Cu, Mn and Zn.

During fertigation the salts including the micro-nutrients will move to the outer perimeter of the wetted zone. This can be a hazardous situation when the pH of this zone of accumulation drops. At a lower pH more micro-nutrients like copper will dissolve and can reach toxic concentrations. It is therefore advisable to apply Cu, Mn, Zn and B at rates of 20-25% of the optimal concentration in nutrient solutions and supplement it with foliar sprays. Perhaps iron can be excluded from this list.

The pH of the root zone can be controlled by changing the ratio of  $\text{NO}_3:\text{NH}_4$ . Lime is not soluble enough to be used in drip systems. Hydroxides can not be used due to the high pH (>9,00) that might damage the roots.

Microjets

Some of the fertilisers can also be applied through the microjet system. Fertigation with N, K, Mg, S, Fe and B can be done successfully through the microjets. Calcium can also be applied with success but not P.

When N, Mg and S fertilisers are being applied through the water, the fertilisers should be introduced during the last quarter of the irrigation cycle followed by just enough water to clean the system. Do not split the applications too much or apply fertilisers with each irrigation. Follow the guideline in Table 10.

However, to improve the efficiency of potassium applications, small dosages of 100g KCl per tree (or 100mg K per litre water) can be applied during the entire length of the cycle during September to December until the recommended dosage is applied (Table 15).

Mechanical and applications by hand.

Mechanical or applications by hand are based on the same principles. Splitting of N and K fertilisers is done based on the clay content of the soil (Table 10). Phosphates must not be broadcast but banded (Figure 5).

The major advantage of mechanical and hand applications are that the cheapest type of fertilisers can be used.

### Goals.

The main purpose of a good fertilisation program is to optimise the concentration of all the nutrients. Once this is obtained, fertilisation will not be the reason for suboptimal yields. Certain factors cannot be controlled, but with a balanced nutritional status, at least one variable is under control. With an optimal nutrient status, the trees can survive adverse cold, heat or drought conditions much better. Once the optimal status is obtained, fine tuning can be used to manipulate the trees.

The second aim is to obtain an optimal nutrient status at the lowest cost. By monitoring the inputs (fertilisers) and results (leaf analyses and production) only those elements that are in short supply need to be supplemented. With microjets it can mean that only N and Zn need to be applied.

The third aim is to produce quality fruit that can withstand packing and handling the best in order to give the consumer value for money.

## 29. USEFUL TABLES

**Table 77. Solubility of fertilisers.**

Source	Gram per 100ml	kg per 100 litre	Kg per 1000 litre
Ammonium nitrate	118,3	118,3	1183
Ammonium sulphate	70,6	70,6	706
Ammonium phosphate Mono	22,7	22,7	227
Borax	2,01	2,01	20,1
Boric acid	6,35	6,35	63,5
Calcium nitrate	226,0	226,0	2260
Calcium sulphate	0,24	0,24	2,40
DAP	57,5	57,5	575
Magnesium nitrate	125,0	125,0	1250
Magnesium sulphate	71,0	71,0	710
Potassium chloride	23,8	23,8	238
Potassium nitrate	13,3	13,3	133
Potassium sulphate	12,0	12,0	120
Urea	100,0	100,0	1000
Ammonium molybdate	43,0	43,0	430
Copper sulphate	31,6	31,6	316
Iron sulphate	15,6	15,6	156
Manganese sulphate-5H <sub>2</sub> O	124,5	124,5	1245
Sodium molybdate-2H <sub>2</sub> O	56,2	56,2	562
Zinc sulphate	96,5	96,5	965

**Table 78. Compatibility of fertilisers in the concentrated form**

	1	2	3	4	5	6	7	8	9	10	11	12	13
1.Mono-ammonium phosphate	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
2.Ammonium nitrate	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3.Ammonium sulphate	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
4.Nitric acid	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y
5.Urea	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y
6.Di-ammonium phosphate	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	N	N
7.Phosphoric acid	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y
8.Mono-potassium phosphate	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	N	N	N
9.Potassium nitrate	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y
10.Potassium sulphate	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	N	Y	Y
11.Calcium nitrate	N	Y	N	Y	Y	N	Y	N	Y	N	-	N	Y
12.Magnesium sulphate	N	Y	Y	Y	Y	N	Y	N	Y	Y	N	-	Y
13.Magnesium nitrate	N	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y	-

**Table 79. Compatibility of chemicals used for foliar sprays.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.Potassium nitrate	-	-	N	N	N	N	N	N	N	Y	Y	N	-	Y
2.Calcium nitrate	-	-	N	N	N	N	N	N	N	Y	Y	N	-	Y
3.Copper hydroxide	N	N	-	-	N	N	Y	N	N	Y	Y	N	Y	Y
4.Copper oxychloride	N	N	-	-	N	N	Y	N	N	Y	Y	N	Y	Y
5.Magnesium nitrate	N	N	N	N	-	Y	Y	N	N	Y	Y	Y	Y	Y
6.Manganese nitrate	N	N	N	N	Y	-	-	N	N	Y	Y	Y	Y	Y
7.Manganese sulphate	N	N	N	N	Y	-	-	N	N	Y	Y	Y	Y	Y
8.Mono-ammonium phosphate	N	N	N	N	N	N	N	-	-	Y	Y	N	Y	Y
9.Mono-potassium phosphate	N	N	N	N	N	N	N	-	-	Y	Y	N	Y	Y
10.Sodium borate	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y
11.Sodium molybdate	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	Y
12.Zinc nitrate	N	N	N	N	Y	Y	Y	N	N	Y	Y	-	Y	Y
13.Zinc oxide	Y	Y	Y	Y	N	N	Y	N	N	Y	Y	-	-	Y
14.Urea	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-

- Compatibility of potassium nitrate and sulphate at a 4% concentration are given in the table. Less concentrated solutions or adjustments to pH 6,0 may be more compatible with other chemicals. .
- Any chemical that will increase the pH of zinc nitrate must be avoided. .
- Any chemical that will decrease the pH of copper oxychloride must be avoided.
- Micro nutrient like Cu, Zn and Mn must preferably not being mixed with phosphates.

- Chelates are not mentioned in the table due to their abundance. Enquire at the local distributor about compatibility.

**Table 80. Conversion table of electrical conductivity (EC) of water and nutrient solutions**

<b>A</b>	<b>B</b>	<b>C</b>
milli-Siemens per cm $\text{mScm}^{-1}$	<b>100</b>	milli-Siemens per m $\text{mSm}^{-1}$
Siemens per cm $\text{Scm}^{-1}$	<b>1000</b>	milli-Siemens per cm $\text{mScm}^{-1}$
Siemens per m $\text{Sm}^{-1}$	<b>1000</b>	milli-Siemens per m $\text{mSm}^{-1}$
mikro-Siemens per cm $\mu\text{Scm}^{-1}$	<b>1000</b>	milli-Siemens per cm $\text{mScm}^{-1}$
Siemens per m $\text{mSm}^{-1}$	<b>1000</b>	milli-Siemens per m $\text{mSm}^{-1}$
mikro-Siemens per m $\mu\text{Sm}^{-1}$	<b>1000</b>	milli-Siemens per m $\text{mSm}^{-1}$
mikro-Siemens per dm $\mu\text{Sdm}^{-1}$	<b>10</b>	mikro-Siemens per m $\mu\text{Sm}^{-1}$
milli-Siemens per dm $\text{mSdm}^{-1}$	<b>10</b>	milli-Siemens per m $\text{mSm}^{-1}$
milli-Siemens per m $\text{mSm}^{-1}$	<b>10</b>	mikro-Siemens per cm $\mu\text{Scm}^{-1}$

$$A \times B = C$$

$$A = C \div B$$

**Table 81. Conversions between gram N, ml nitric acid, ammonium nitrate(AN19), Potassium nitrate, calcium nitrate and LAN**

<b>gram N in</b>	<b>ml nitric acid 113g per litre</b>	<b>ml AN19 215g per litre</b>	<b>gram potassium nitrate 130g per kg</b>	<b>gram Calcium nitrate 120g per kg</b>	<b>gram LAN 280g per kg</b>
10	88	47	77	83	36
20	177	93	154	167	71
30	265	140	231	250	107
40	354	186	308	333	143
50	442	233	385	417	179

**Table 82. Conversion between gram P, ml phosphoric acid, gram super phosphate and gram mono-ammonium phosphate**

<b>gram P in</b>	<b>ml phosphoric acid 358g per litre</b>	<b>gram single supers 105g per kg</b>	<b>gram MAP 260g per kg</b>
10	28	95	38
20	56	190	77
30	84	286	115
40	112	381	154
50	140	476	192

**Table 83. Conversion between K, potassium sulphate, potassium nitrate and mono-potassium phosphate.**

<b>gram K</b>	<b>gram potassium sulphate</b>	<b>gram potassium nitrate</b>	<b>gram MKP 287g per kg</b>
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	<b>450g per kg</b>	<b>380g per kg</b>	
10	22	26	35
20	44	53	70
30	67	79	105
40	89	105	139
50	111	132	174

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