2 NITROGEN

2.1 Role 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- (NH_4) en nitrate (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 fed 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 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 absorbed 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%), ±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. 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 efficient than plants with a high nitrogen status.

The first symptom of a nitrogen deficiency in 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 contains 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 younger 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 intensify and they are shed. This developes 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 a "normal" leaf stays green when dropped. The N-content of the dropped 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 contains slightly less nitrogen than "normal", (2,26 against 2,49% N).
- The twigs carry no leaves of the previous third and fourth growth cycles but only leaves of the last two growth 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 have remained on the trees. The total mass of nitrogen is split between much less (±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 reduction 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 more 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 increase 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 diseases and delayed colour break.

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

	Nitrogen applied x gram per tree	**Nitrogen applied 1,5x gram per tree**	**Nitrogen applied 2x gram per tree**
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.

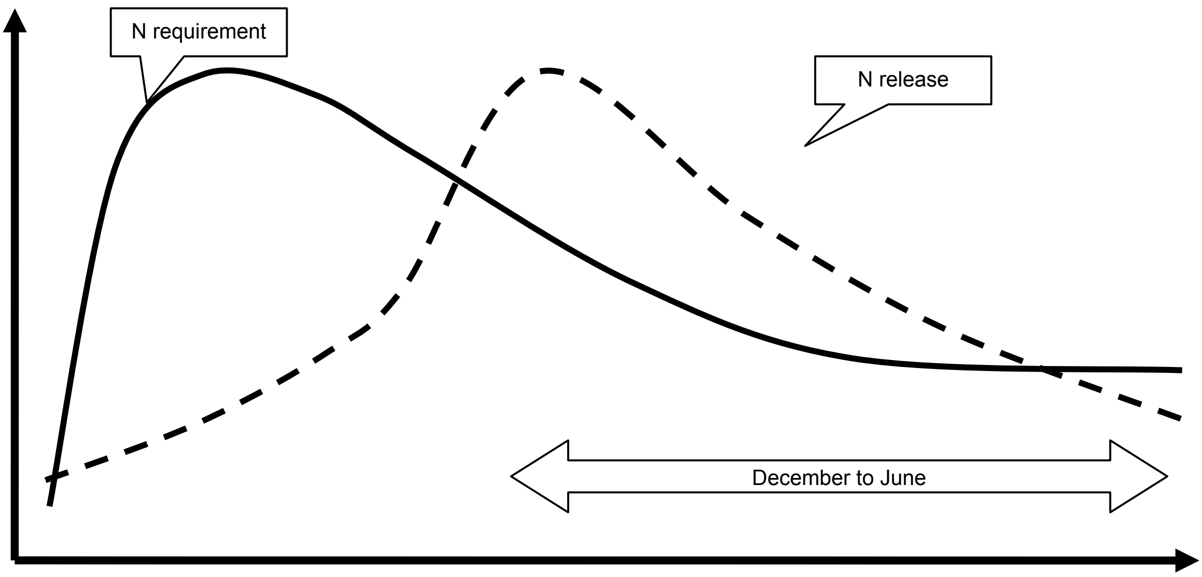

Figure 2. The nitrogen requirement of commercial citrus trees compared to the release of nitrogen from the organic fraction in the soil.

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 (NO_3^-) and ammonium (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.

$$\mathbf{NH_2\text{-}CO\text{-}NH_2 \rightarrow 2NH_4^+ + CO_3^{--}}$$
urea
$$\mathbf{(NH_2\text{-}CO\text{-}NH_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{--})}$$

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

$$\mathbf{2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + H_2O + 4H^+ + energy}$$
$$\mathbf{2NO_2^- + O_2 \rightarrow 2NO_3^- + energy}$$

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 is used quite extensively in the Sundays 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 (CO_3) and bicarbonates (HCO_3) as follows;

- In the first step all the carbonates are

converted to bicarbonates
($me\ CO_3 \times 2$) = $me\ HCO_3$ 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 $HCO_3 \times 74$ = 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 HCO_3. By removing the HCO_3 in this way NO_3-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 HCO_3.

me CO_3 + HCO_3	ml 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	NO_3	17% Ca
Magnesium nitrate	11	NO_3	9,5% Mg
Mono-ammonium phosphate	12	NH_4	22 - 26% P
Ammonium nitrate 19% solution	19	NO_3 NH_4	-
Ammonium sulphate	21	NH_4	24% S
Ammonium sulphate nitrate	27	NO_3 NH_4	13,5% S
Limestone ammonium nitrate	28	NO_3 NH_4	x% Ca
Ammonium nitrate Granules	34	NO_3 NH_4	-
Urea ammonium nitrate	32	NO_3 NH_4 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_4) is oxidised by *Nitrosomonas* sp. to nitrite (NO_2) and nitrite to nitrate (NO_3) by *Nitrobactor* spp. During these oxidation processes, acid ions (H^+) are produced which acidifies the environment. The origin of the ammonium has no bearing on the final result. All ammonium nitrogen, whether it is from fertilisers or organic material will be nitrified by the bacteria. These processes take about 14 to 21 days to be completed.

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + H_2O + 4H^+ + \text{energy}$$

utilised by the bacteria.

nitrite

$2NO_2^- + O_2 \rightarrow 2NO_3^- + \text{energy}$

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 $4H^+$ 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^2 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^+) 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 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^+) per kg N, generated from various nitrogen sources with the corresponding lost in Ca or base-ions.

Source	me H^+	kg Ca
Ammonium sulphate	180	-3,0
Ammonium sulphate nitrate	144	-2,0
Ammonium nitrate Urea Ammonia	36	-1,0
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.

$NH_4^+ + OH^- \leftrightarrow NH_3 + H_2O$

In alkaline soils the presence of carbonates will be responsible for the reaction to shift to the right, forming NH_3 which is a gas and will escape into the atmosphere.

$NH_4^+ + CO_3^{--} \rightarrow NH_3 + CO_2 + H_2O$

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 (NH_4^+) is utilised in a passive manner by diffusion and needs to be "detoxified" in the plant. The pH of the cytoplasm is ±7,5 and will convert all NH_4^+ to NH_3. The NH_3 is phytotoxic (poisonous to plants) and must be detoxified. In this process carboxyl groups from carbohydrates are utilised to bind the 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 advantages 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 absorbed 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°C will reduce the uptake of K and yellowing can also developed. 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 absorbed nitrate. That is one reason why the absorption is not suppressed by chlorides (Cl^-) or sulphates ($SO_4^=$). The absorption is an active process supported by the presence of Ca^{++} and K^+ and suppressed by the presence of NH_4^+. Nitrates are converted to amine nitrogen (protein) in the leaves before it can be utilised. This process like nitrification requires molybdenum.

$$NO_3^{-}N + 8H^+ + 8e^- = \underset{\text{amine}}{NH_2^+} + 3H_2O$$

Nitrate can be used to control the pH in the root zone and importantly on the surface of the roots. When NO_3^- is absorbed an OH^- ion is excreted to balance the charges in the medium. This OH^- is responsible for increasing the pH. An increase in the absorption of $NO_3^{-}N$ 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 NO_3-N compared to NH_4-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°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).

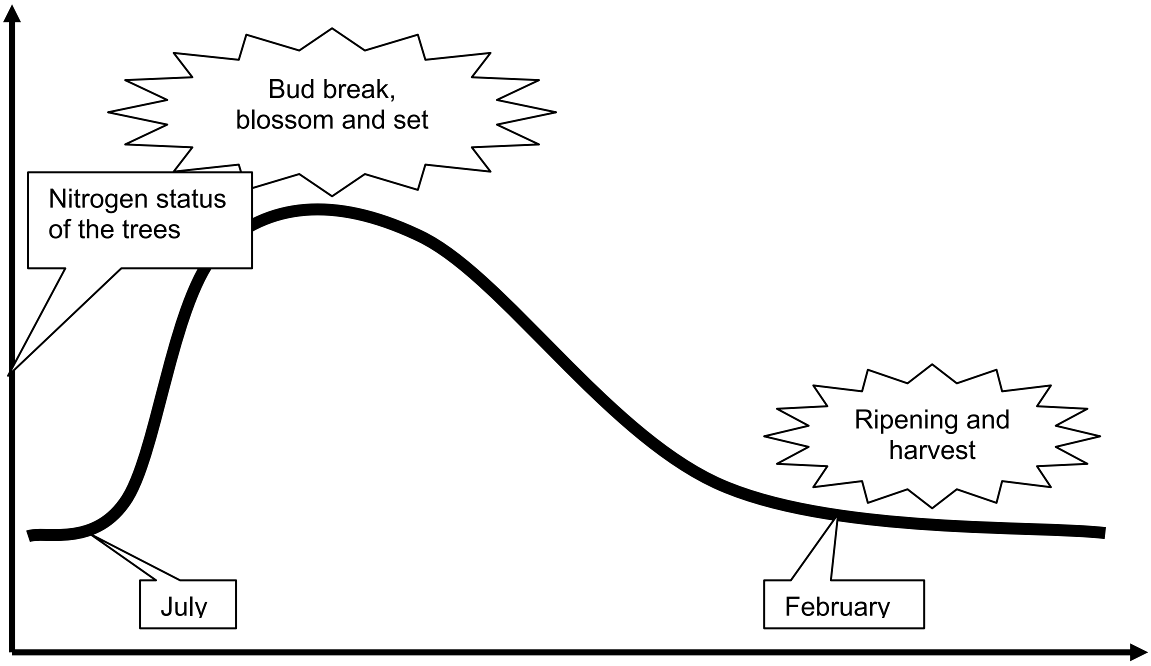

Figure 3. The seasonal variation in the nitrogen status of the trees to ensure yield and quality.

What ever 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.

Clay content of the soil (%)	% N to be applied in July/Aug	% N to be applied in August/Sept	% N to be applied in September/Oct	% N to be applied in Oct/Nov
< 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 proof 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 reduces 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 1000 kg 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 40x2750g N = 110 000g is removed by the crop.
- Assume that 200kg N per ha (200 000g N) was applied during the previous season.
- N efficiency is therefore = 40x2750 ÷ 200 000 x 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 NH_4^+: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 NH_4^+:NO_3^- . The higher the NH_4^+ component, the more acid will be generated and the lower the pH. A ratio of 20NH_4^+ to 80NO_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 K^+, Ca++ and Mg^{++} will be absorbed compared to all ammonium nitrogen.

Ammonium nitrogen (NH_4^+) is absorbed in a passive process and needs to be “detoxify”. Growth is reduced, chlorosis appears 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 harding-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.

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 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 NH_4-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(ing) done but three foliar sprays of 1% solution and 10 litres per tree will be required.

Foliar sprays with 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.