3 PHOSPHOROUS

3.1 Role in citrus production.

The reaction of tree crops on fertilisation with phosphorous is less spectacular than that of annuals. Trees have the ability to absorbed phosphorous (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.

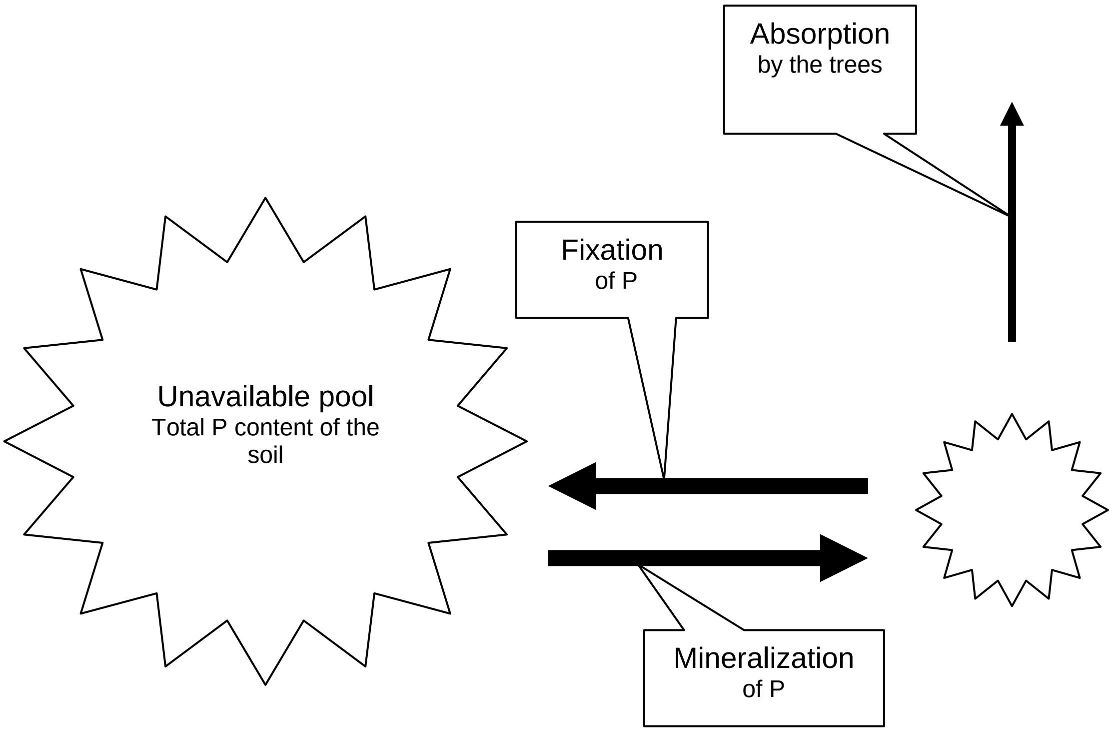

Figure 4. Illustration of the interaction between the available and unavailable pools of phosphorous in the soil.

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 HPO_4^{-} $^{-}$ and $H_2PO_4^{-}$ 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

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

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

A phosphorous 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 have 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 phosphorous
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 phosphorous
CAS = Citric acid soluble phosphorous
* 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 phosphorous is present as mono- and di-calcium phosphate. In water it will supply the available forms of $H_2PO_4^-$ and HPO_4^{--} 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	$Ca_3(PO_4)_2$	2,0
Di-calcium phosphate	$CaHPO_4$	31,6
Mono-calcium phosphate	$Ca(HPO_4)_2$	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 (H_3PO_4) required to lower the pH to 6,00-6,50 will be determined by the concentration of carbonates (CO_3) and bicarbonates (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_3 x 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 x 28,6 = ml H_3PO_4* 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_3 in the water.

me CO_3 + HCO_3	ml H_3PO_4 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 phosphorous

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 phosphorous 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.

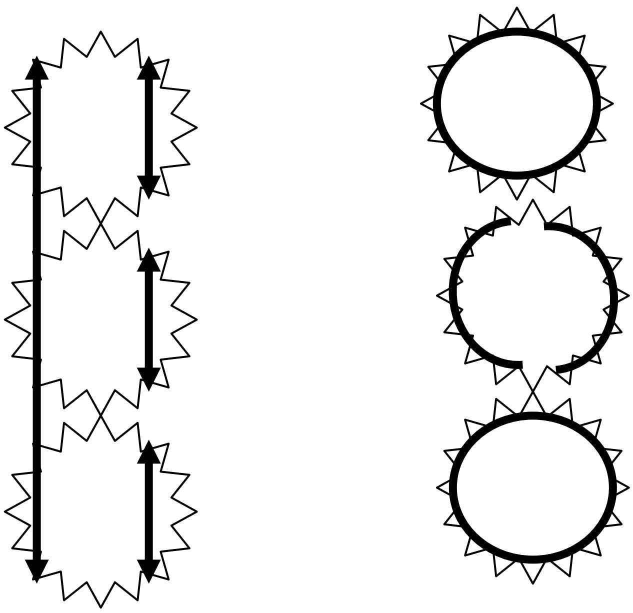

Figure 5. Illustration of the various methods of banding super phosphates.

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 $15m^2$ 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 phosphorous 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 NH_4^+ and $H_2PO_4^-$ 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.

$Ca(NO_3)_2$ 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 phosphorous 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.