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.

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

$$2NO_2^- + O_2 \rightarrow 2NO_3^- + energy$$

The **$4H^+$** 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 H^+ on root activity.
- The direct effect of the elevated concentrations of aluminium and heavy metals.
- The indirect effect on the availability of the nutritional elements.

The direct effect of the concentration of the 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 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 NO_3 is reduced.

The highest concentration of available P, namely $HPO_4^{- -}$ and $H_2PO_4^-$ 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^+ 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_2 and with water it forms sulphurous acid (H_2SO_3). 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 and electrical imbalance. To balance this H^+ 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_4^{--} in these salt, like in gypsum (calcium sulphate) or potassium sulphate contribute little to the acidification. To acidify H^+ ions must be produced.

Reactions that acidify the soil can be summarized as follows.

- $(NH_4)_2SO_4 \rightarrow 2NO_2^- + 8H^+$ a biological reaction.
- $S \rightarrow SO_2 + H_2O \rightarrow H_2SO_3 \rightarrow 2H^+ + SO_3^{--}$ a chemical reaction.
- S + *Thiobaccillus* sp $\rightarrow H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$ a biological reaction.
- $Al_2(SO_4)_3 + H_2O \rightarrow 2Al(OH)_3 + H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$ a chemical reaction.
- $FeSO_4 + H_2O \rightarrow Fe(OH)_3 + H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$ a chemical reaction.

The reaction of gypsum or potassium sulphate, when applied to the soil creates no H^+.

- $CaSO_4 \rightarrow Ca^{++} + SO_4^{--}$

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^2 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 (CO_2). In water there are three different species of CO_2 present namely CO_3^{--}, HCO_3^- and H_2CO_3. When 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.

CO_2 under pressure $\rightarrow H_2CO_3 \rightarrow HCO_3^- + H^+$

The pH of soda water is for the same reason ±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.