25 FOLIAR SPRAYS

Plants can obtain all their non-gaseous requirements via the root system. However, most plant organs including woody parts can also absorbed nutrients from solutions (Wittwer, 1963). Although the leaves can only absorb small amounts of nutrients, foliar sprays can be used successfully to supplement nutrition. The efficiency 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 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 is 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 0,0025x4750g = 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 ±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 20x4,75 = 95mg Zn per tree or 20x4,75x416 = 39 520mg 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 spraying, 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 (unit of droplet size)	At 7 Bar (unit of droplet size)	At 10 Bar (unit of droplet size)	At 15 Bar (unit of droplet size)
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 into1 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 KNO_3 as from K_2SO_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 hours 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_3	1,22	2,31 (89%)	1,55 (27%)
Orchard A-K_2SO_4	1,19	1,58 (33%)	1,26 (6%)
Orchard B-KNO_3	0,65	1,86 (286%)	0,72 (11%)
Orchard B-K_2SO_4	0,68	0,92 (35%)	0,66 (-3%)

The improved absorption from potassium nitrate can partly being 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[R]	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 (wetters), will also improve absorption. When wetters 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 leaves 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 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 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 stomata per mm^2 on the underside and 40 per 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.