NSW DEPARTMENT OF
PRIMARY INDUSTRIES

Growing lemons in Australia- a production manual - Readers' Note

This document is part of a larger publication. The remaining parts and full version of the publication can be found at:

http://www.dpi.nsw.gov.au/agriculture/horticulture/citrus/lemon-manual

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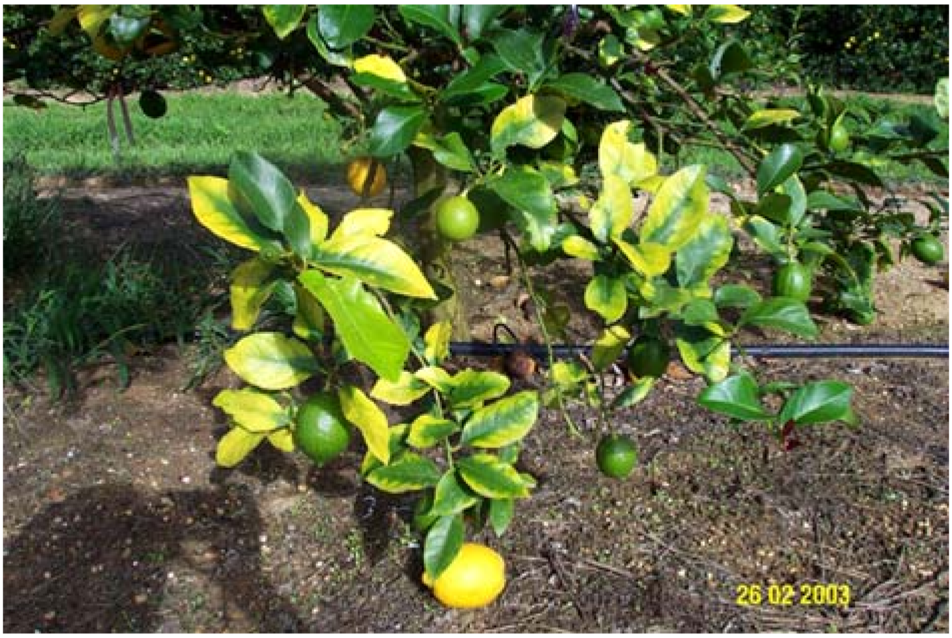
7. Nutrition

Introduction -- 2
Functions of the main nutrients ---------------------- 2
Leaf analysis -- 3
Soil analysis -- 6
Micronutrient deficiencies --------------------------- 10
Foliar sprays for micronutrient deficiencies --------- 12
General guide to plant nutrients in citrus ----------- 13



Magnesium deficiency symptoms

INTRODUCTION

For citrus trees to be healthy and productive, they require a range of mineral nutrients or elements which they extract from the soil. The level or concentration of these mineral nutrients in the leaves closely reflects the nutrient level in the plant and affects its vigour, health and fruitfulness. Rootstocks also can influence the trees ability to accumulate or exclude mineral elements.

A successful nutrition program must include consideration of the important nutrients: nitrogen, phosphorus, potassium, calcium, magnesium, manganese, zinc, copper, iron, sodium and boron; and the chloride ion. A general table summarising several aspects about plant nutrients in citrus is included at the end of this section. Plant nutrition is a complex process involving many elements and interactions.

A successful fertiliser program is evolved over a number of years through careful monitoring of nutrient levels in the soil, plant tissue and assessment of yields and fruit quality.

Functions of the main nutrients

Nitrogen (N): Important for the development of healthy shoots and fruit. It promotes fruit set and subsequent fruit sizing. Nitrogen levels affect yields.

Phosphorus (P): Maintains good fruit quality. Ensures sugar development and high juice content and is needed in balance with nitrogen to produce smooth rinds. Phosphorus has a role in sugar transport within the tree and in the development of roots, flowers and shoots. Phosphorus levels affect yields.

Potassium (K): Important for the maintenance of tree vigour and the development of fruit quality and size. It has a vital role in the development of Vitamin C. Increased potassium results in thinner peels, increased juice content, total acidity and absorbic acid. Potassium is also important for successful postharvest storage of fruit.

Magnesium (Mg): Necessary for chlorophyll development and seed development which in turn, plays a vital role in the production of key growth regulators.

Zinc (Zn): Aids in the formation and the function of chlorophyll and certain enzymes. Low levels of zinc result in small fruit with thick peels. Adequate levels of zinc are needed for successful development and set of flowers.

Manganese (Mn): Has a key role in fruit production.

Iron (Fe): Plays a vital role in the development of leaves.

Calcium (Ca): Has a vital role in cell structure and strength and shelf life of fruit. Leaf tissue results may not be a good indicator of calcium levels in fruit.

In some regions irrigation water (such as Murrary River water) often has relatively high levels of sodium, boron and chloride. The level of these elements is important because they can have negative effects on growth when they occur in higher than optimal levels. They can invalidate subsequent interpretation of other elements if they are in the “too high” or “excess” category.

LEAF ANALYSIS

Regular use of leaf tissue analysis is an essential component of any nutrition program. Results from leaf analysis tell you what nutrients the plant has been able to extract from the soil and soil water. The correct interpretation of the results of tissue analysis from appropriately sampled leaves will enable you to:

- ☑ identify nutrient deficiencies and excesses;
- ☑ fine-tune fertiliser programs;
- ☑ deduce production costs;
- ☑ produce better quality fruit;
- ☑ produce larger and more consistent crops;
- ☑ monitor the effectiveness of fertiliser practices;
- ☑ monitor increases in salinity so that corrective action (such as improving water distribution or the amount of irrigation) can be taken before problems become severe.

Information from leaf analysis assists in decisions about what fertilisers need to be applied. The aim is to achieve optimum levels of each element in leaf tissue. Samples should be taken and analysed from individual blocks so that each block of trees of a particular age, cropping pattern and fruit quality can be compared to the set of leaf analysis standards.

The standards were first established in California (Embleton T.W., *et. al.*, 1973), but in 1987 these were modified for Australian growing conditions by Peter Gallasch (SARDI) and Ken Bevington (NSW Department of Primary Industries). A further revision occurred in 1996 and this document is available from SARDI in Fact sheet 23/80/96, titled “Citrus leaf analysis”.

For precise results, the correct leaves must be sampled. Select only the third and fourth leaf from five to seven month-old spring-flush, non-fruiting terminals. Identify these by their location, their colour and their typically pointed tips (“dog ears”). If non-standard leaves are sampled, the results will be of no value.

Sampling

- ☑ take 100 leaves from each sample area/block by selecting four from each of 25 trees;
- ☑ take equal numbers of leaves from the north and south sides of the trees;
- ☑ sample at least 20 trees, diagonally across a uniform area/block;
- ☑ sample leaves between mid February and early March, as this is the only time of the year when the current leaf tissue standards apply;
- ☑ keep leaves cool until they reach the laboratory;
- ☑ forward leaf tissue to a reliable laboratory for analysis;

- ☒ avoid sampling on very hot days;
- ☒ do not sample terminals that have produced a flush since spring;
- ☒ avoid damaged or discoloured leaves;
- ☒ avoid trees that are not typical of the block.

Leaf analyses carried out over a number of years will establish trends and allow fine-tuning of fertiliser programs. The cost of a sampling is small compared to the benefits gained. Applying only the necessary fertilisers reduces cost, waste and toxicity problems and improves fruit production and quality.

Leaf analysis may result in reduced or increased fertiliser applications, depending on the status of the block of trees.

Leaf analysis standards

The standards listed in Table 1 were established by analysing leaves of the same age and type from trees growing in a wide range of situations. The concentration of certain elements was found to be consistency correlated with yields and fruit quality. Improved yields and fruit quality were obtained from blocks where the concentration of elements fell within a particular range. The descriptions below show what action needs to be taken for each of the following levels.

Deficient. Yield and fruit quality or both are reduced. Special attention is required to increase the level of fertiliser applied to lift that particular nutrient level. Visual leaf symptoms may not always be evident.

Low. Increase the level of fertiliser being used or improve application efficiency to improve yield or fruit quality or both.

Satisfactory. Maintain the current fertiliser program unless corrective measures were taken last year, or if crop size has significantly changed. Yield and fruit quality should be at optimum levels.

High. No fertiliser of that element should be applied with the exception of nitrogen, which should be applied at a reduced rate. Fruit quality is likely to have been adversely affected and the cost of fertilisers will be reduced.

Excess. Yield or fruit quality or both will be reduced. No fertiliser of that element should be applied with the exception of nitrogen, which should be applied at a greatly reduced rate. The cost of fertilisers will be reduced.

Interpretation of results

Observe tree health, fruit yield and quality. Note any symptoms such as zinc, magnesium, manganese and iron deficiencies or evidence of salt damage. Check your observations with the results and recommendations made by your leaf analysis service. If your observations and their recommendations do not match, seek further advice from someone more familiar with your local soils and production conditions. Leaf nutrient content is influenced by tree vigour, age, crop load and other aspects of management (for example, irrigation and soil management). These factors also influence yield and fruit quality.

For areas of Australia using salty water, tissue analysis is a very useful tool to give an early indication of the accumulation of salts requiring a change in irrigation or drainage practices.

In the past the over-use of nitrogen fertilisers was common. The overuse of nitrogen is costly and leads to the production of course-textured, thick-skinned fruit that is low in juice and soluble solids. Excess levels of nitrogen will also reduce yields.

Table 1. Leaf analysis standards for lemons in the Riverland and Sunraysia areas

(Elements in five-to seven-month-old, non-fruiting terminal citrus leaves expressed in percentage dry matter unless otherwise stated.) [Check the concentration of Calcium first to determine if the leaf sample contained the correct leaves.]

Element	Deficient	Too low	Satisfactory	Too high	Excess
Calcium (Ca)	<2.0	2.0 to 2.9	3.0 to 5.5	5.6 to 7.0[a]	>7.0
Sodium (Na)	-	-	<0.16	0.16 to 0.25	>0.25[b,c]
Chloride (Cl)	-	-	<0.30	0.30 to 0.60	>0.60[b,c]
Boron (B) ppm	<2.0	20 to 30	31 to l29	130 to 250	>250[b,c]
Major elements for citrus					
Nitrogen (N)	<2.2	2.2 to 2.39	2.4 to 2.69	2.7 to 3.0	>3.0
Phosphorus (P)	<0.09	0.09 to 0.13	0.14 to 0.16	0.17 to 0.30	>0.30
Potassium (K)	<0.4	0.4 to 0.69	0.7 to 1.49	1.5 to 2.0	>2.0
Elements, which give distinctive visual deficiency symptoms					
Magnesium (Mg)	<0.15	0.15 to 0.29	0.30 to 0.69	0.7 to 1.0	> 1.0
Zinc (Zn) ppm	<16	16 to 24	25 to 60	61 to 300	>300
Manganese (Mn) ppm	<16	16 to 24	25 to 60	61 to 300	>300
Iron (Fe) ppm	<35	35 to 49	50 to 129	130 to 400	>400
Copper (Cu) ppm	<3	3 to 5	6 to 15	16 to 20	> 20
Elements less critical under Riverland or Sunraysia conditions					
Sulphur (S)	<0.14	0.14 to 0.19	0.20 to 0.39	0.40 to 0.50	>0.50
Molybdenum (Mo) ppm	<0.06	0.06 to 0.09	0.1 to 3.0	3.1 to 100.	>100

a. Calcium in the too high range means the older leaves have been sampled and for these the table of standards does not apply. The first four "elements" in the table have been deliberately listed at the top of the table, as a sample which contains excessive or deficient levels of any of these elements, cannot be further interpreted, because leaves with too high or excess levels of salts create imbalances in the concentration of other elements in the leaves. Correct sampling of leaves and removal of the salt problem is needed before tissue analysis can be used to determine the plants need for other elements.

b. Excessive concentrations of sodium chloride or boron indicate that irrigation and drainage practices should be reviewed.

c. Too high levels of zinc, manganese, copper and iron indicate that surface contamination of leaves with foliar sprays or dust has occurred.

Leaf tissue from the lemon rootstock evaluation experiment at Renmark clearly indicated trees were very low in zinc. Following multiple foliar applications of this element (in the form of zinc sulphate) trees began to crop normally.

For more information on Citrus Nutrition refer to SARDI Factsheet No. 23/80.

SOIL ANALYSIS

Soil pits are useful for looking at soil conditions in the orchard

Soil analysis can provide information on soil texture, pH, the level of nutrients in the soil and nutrient ratios. Soil analysis results tell you what nutrients are in the soil. They do not tell you what is able to be taken up by the plant, leaf analysis provides this information. Soil analysis is of little value in highly alkaline soils as the extraction methods used in the laboratory do not simulate what the plant can extract. In neutral and acid soils the results of analysis is valuable and is used to help determine fertiliser requirements.

The best time for sampling is before your main ground fertiliser application which normally occurs mid to late winter. It can often be done at the same time as your plant analysis. However, to avoid errors, sampling should not be done within two months of any fertiliser application to the soil. A sample size of about 400 g is required for analysis. The depth at which the sample is taken is also important and is specified by the analysis company. Soil tests at two depths, 0-15 cm and 15-30 cm are normally used in tree crops.

A representative soil sample of a block or paddock is a composite sample made up of 20-30 individual samples which are mixed together into the one sample. Different soil types should not be mixed together. Soil samples are normally taken in the plant row and within the effective root zone of the tree (ie halfway between the treeline and the trunk).

When soil samples are analysed at testing laboratories a comprehensive report should be provided outlining the results and suggested fertiliser recommendations.

General Interpretation Guide for Soil Analysis

Extracted from ''Understanding your Soil Test'', Bernie McMullen, Coastal Fruitgrowers Newsletter, Spring 1995.

pH testing

Soil pH measures the acidity or alkalinity of the soil solution on a scale from 0 to 14, with 7 as neutral. pH can be measured in calcium chloride ($CaCl2$) or water. pH measured in water is 0.5-0.8 higher than pH measured in $CaCl2$.

Remember that the pH scale is logarithmic; that is, each number going down the scale is 10 times more acid than the number above. For example, soil with pH 5 is 10 times more acid than one with pH 6.

Photo by Greg Moulds

pH can be measured using a simple field kit

The pH level can be raised by the addition of lime or dolomite (which also provides magnesium). The quantities needed are determined by the soil type (more lime is needed on heavy clays than on sand) and the degree of acidity.

Organic carbon

Organic carbon is an estimate of the soil organic matter (humus) content. The percentage of organic carbon in organic matter is relatively constant and can be assessed as:

Spreading chicken manure to improve organic matter content

Percentage of organic matter = percentage of organic carbon x 1.6.

The benefits of organic matter include:

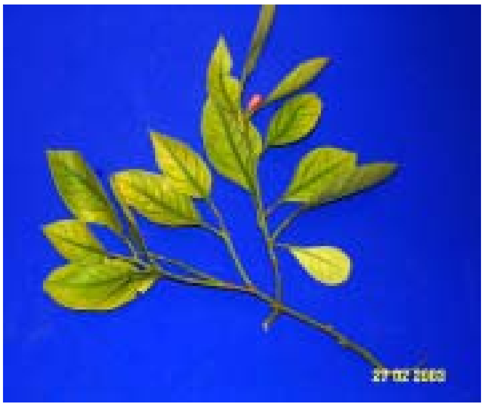
- ☑ improves soil structure;
- ☑ provides nutrients;
- ☑ improves cation exchange capacity;
- ☑ provides mulch.

If the soil shows an organic carbon percentage under three, then organic matter levels are low. A reading of less than one is very low. Organic matter levels are increased by:

- reduced cultivation;
- addition of plant materials either as manure, cover crops, permanent swards or mulches.

Nitrogen (N)

Nitrogen is one of the key elements in plant growth. Most soil testing laboratories measure the nitrate (NO_3) content of soil and express the results as mg/kg or parts per million (ppm) present as nitrate.



Severe nitrogen deficiency symptoms

Horticultural crops require high levels of nitrogen. A few points to note include:

- nitrate forms of nitrogen leach very easily;
- soil type and organic matter levels affect soil levels, with heavier soils and higher organic matter levels having a greater capacity to retain nitrogen.

Nitrate levels of less than 40 mg/kg are considered low for horticulture in most situations.

Phosphorus (P)

Phosphorus is another key element for plant growth. It stimulates root development, early growth and hastens maturity. Most laboratories analyse phosphorus using either the Bray or Colwell method. In each instance results are measured in ppm or mg/kg. A reading below 50 mg/kg is considered low for horticulture and a reading less than 20 mg/kg is very low. At a pH less than 5, phosphorous is fixed to the soil, iron and aluminium particles and is much less available to the plant.

Phosphorous is not very mobile. In permanent crops it is best applied at planting. Dry conditions hinder the uptake of phosphorous.

Potassium (K)
Potassium increases plant vigour and disease resistance as well as improving fruit quality. Soil test readings are in milli equivalents per 100 grams of soil (m.e./l00 g). Requirements vary between crops, but as a rule of thumb, a reading of less than 0.5 m.e./l00 g indicates a shortage. Below pH 5.5, immobilisation of potassium increases rapidly. Dry soils have lower potassium availability.

Electrical conductivity (EC)

Table 1: Multiplication factors for converting EC (1 : 5) to an approximate value of EC_e

Soil texture	Multiplication factor
Loamy sand, clayey sand	25
Sandy loam, fine sandy loam, light sandy clay loam	20
Loam, loam fine sandy, silt loam, sandy clay loam	15
Clay loam, silty clay loam, fine sandy clay loam	12.5
Sandy clay, silty clay, light clay	10
Light medium clay	9
Medium clay	7.5
Heavy clay	6

This is a measure of salinity or the excess salt content of soils. At high levels of salt in the soil, plants are not able to absorb sufficient water.

The EC figure reported should be multiplied by a factor depending on the texture of the soil. The factors are listed in Table 1.

Conventionally, saline soils are defined as those having an Ec_e value of greater than 4ds/m. However, it is important to realise that the sensitivity of plants to salinity varies greatly with different species.

The Ec_e value for lemons is 1.7 ds/m. This is the maximum Ec_e value for no yield reduction. However, it is emphasised this figure is intended as a guide only; factors such as stage of growth (seedlings are usually more sensitive than mature plants), crop management, fertiliser application rates and placement, irrigation type, water quality and soil drainage all affect the occurrence and severity of salt toxicity.

Cation exchange-capacity (CEC)

CEC is a measure of the ability of soil to attract and hold cations by electrical attraction. The surfaces of clays and soil organic matter generally have net negative electric charges. This is, neutralised by positively charged ions (cations). Because they are held by electrical charges, they can be replaced by other cations. This process is known as cation exchange. The concentrations of these cations are expressed as milli equivalents per 100 grams soil (m.e./100g). This takes account of their different valencies and atomic weights. The total quantity of cations that a soil can hold is called the cation exchange capacity (CEC).

The five most abundant cations in soil are calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), sodium (Na+), and aluminium ($A1^{3+}$). The cations manganese (Mn^{2+}), iron (Fe^{2+}), copper (Cu^{2+}) and zinc (Zn^{2+}) are usually present in only trace amounts and so do not contribute significantly to the exchangeable soluble cation complement.

It is therefore common practice to measure the concentrations of only the five most abundant cations. Their concentrations may be summed to give an approximate value of CEC (sometimes called the effective CEC). The individual cations may then be expressed as a percentage of the CEC.

Sandy soils and acid soils that have been strongly leached often have very low levels of exchangeable calcium and magnesium, and plant growth may be limited as a result. Also, exchangeable potassium levels below 0.2m.e./100 g suggest that a response to the application of potassium fertiliser is possible, particularly where heavy removal of potassium by harvesting of the crop occurs. There is considerable evidence, however, that the proportions of the various cations of the CEC (expressed as a percentage) are more relevant to plant performance than the actual levels.

A guide to desirable ranges for many plants are:

- calcium ---------------- 65-80%
- magnesium ----------- 10-15%
- potassium ------------- 1-5%
- sodium ---------------- 0-1%
- aluminium ------------ less than 5%

Values of exchangeable magnesium greater than 20% may induce potassium deficiency. Conversely, values of exchangeable potassium above 10% may result in magnesium deficiency.

Soils having values of exchangeable sodium exceeding 6% are described as sodic. The clay particles in such soils are liable to disperse on wetting, causing structure to deteriorate, with resultant problems for agricultural production.

A ratio of exchangeable calcium to exchangeable magnesium less than 2 is also thought to favour clay dispersion.

Exchangeable aluminium is usually present in the soil at pH (CaCl2) levels of less than 5.0, and is always associated with low levels of exchangeable calcium and magnesium.

When aluminium levels reach 20-30%, most agricultural plant species perform poorly and the response to superphosphate application is reduced. However, some plants are sensitive to much lower levels than 20-30%.

MICRONUTRIENT DEFICIENCIES

Micronutrients commonly low in citrus are zinc, manganese and magnesium. These deficiencies can be a result of too low or too high soil pH, nutrient imbalances, or naturally low nutrient levels in the soil. Nutrient deficiencies can be more easily diagnosed using plant analysis. Visual symptoms can be used but take care as sometimes they can be confusing, particularly when deficiencies of several nutrients occur at the same time. Deficiency problems can be alleviated either by improving soil pH, or by application of the required nutrient (soil, fertigation or foliar) or a combination of both.

Foliar Application

Foliar application is commonly used to correct micronutrient deficiencies especially if they are a consequence of soil pH. Foliar application of nutrients is most effective when applied to young flush growth, $^1/_3$rd to $^2/_3$rds full leaf size. Mature foliage has a thick waxy cuticle which may reduce uptake of these nutrients.

Traditionally on the Central Coast of NSW foliar applications of zinc, manganese and magnesium were applied once a year in spring. However, more recently citrus growers have been making two applications annually, in spring and summer, with good results.

Magnesium deficiency

Magnesium deficiency is chiefly a problem of acid leached soils. Symptoms develop on mature leaves at any time of the year, but most usually as the fruit is maturing, especially in limbs bearing a heavy crop. Yellow blotches start near the edges of the leaves, and eventually coalesce to form yellow bands on each side of the midrib. These areas enlarge until only a triangular-shaped area at the base of the leaf remain green.

Manganese deficiency

Magnesium deficiency symptoms

Manganese deficiency

Manganese deficiency occurs in acid soils where the manganese content is low or in alkaline soils, where manganese may be present but unavailable to the plant.

Manganese deficiency is indicated when leaves become mottled with lighter green or yellowish green areas between the major veins. The veins themselves and bands of tissue on each side remain green. Leaf size is usually normal. Both young and mature leaves may show symptoms. Where the deficiency is mild the pattern gradually disappears as the leaves age, but if the deficiency is severe the pattern persists in mature leaves.

Zinc deficiency

Zinc deficiency affects citrus growing on both acid and alkaline soils but is usually more severe on alkaline soils. Excessive use of phosphate fertilisers can accentuate zinc deficiency.

Leaves are small and abnormally narrow and rather crowded on short stems; this produces a bunched appearance. Areas between the main lateral veins are whitish yellow. This mottling, which first appears between the main veins, is shown in the young growth and persists as the leaf ages. There is considerable dieback of the smaller twigs with production of multiple buds and numerous small, weak shoots, so that the trees become bushy and stunted. Mild early stages of zinc deficiency resemble those of manganese deficiency. Zinc and manganese deficiencies can occur in combination and may be treated with a combination spray.

Iron deficiency

Trees suffer from iron deficiency mostly in calcareous soils with high pH (alkaline) values. High levels of phosphorous can also induce iron deficiency.

The younger leaves are light green to pale yellow with a network of darker green veins. In general, leaf size is normal and the shoots are not shortened. In severe cases the leaves become very pale, even whitish, and the colour of the smaller veins fades until only a little green remains in the midrib. Dieback occurs, little or no fruit is carried and new growth is poor.

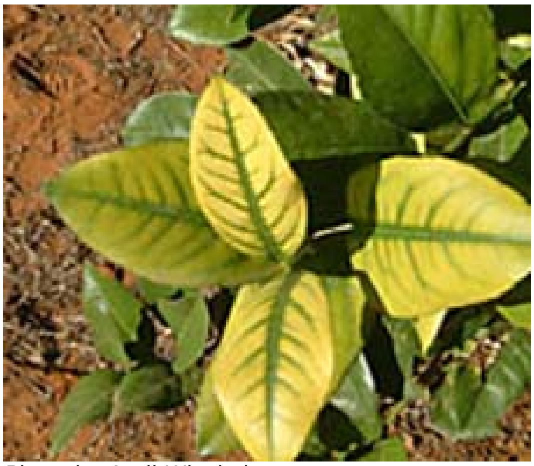


Photo by April Winchel

Iron deficiency symptoms

Foliar sprays for micronutrient deficiencies

Nutrient deficiency	Treatment	Application rate per 100 L water	Timing	Remarks
MAGNESIUM	Magnesium nitrate or Magnesium sulfate+ Calcium nitrate	1 kg 1 kg + 1 kg	When young flush leaves ½-$^2/_3$ expanded	Repeat sprays each year. Mix magnesium sulfate in a half full vat, then add calcium nitrate separately while agitator is running. Then fill vat.
ZINC	Zinc sulfate (23% as zinc heptahydrate) or Commercial liquid preparations or Zinc sulfate (23%) + hydrated lime	150 g Follow maker's instructions 200 g + 500 g	When spring flush leaves ½-$^2/_3$ expanded	This spray is simple to mix and causes minimum residue. This spray leaves a white residue but is more durable if rain is likely within 48 hours.
MANGANESE	Manganese sulfate or Commercial liquid preparations	100 g Follow maker's instructions	When spring flush leaves ½-$^2/_3$ expanded	500 g urea is often added to improve uptake of manganese. Do not spray if rain is expected within 48 hours.
ZINC AND MANGANESE	Zinc sulfate (23% Zn) + Manganese sulfate or Commercial preparations containing both elements or Zinc sulfate (23% Zn) + Manganese sulfate + hydrated lime	150 g + 100 g Follow maker's instructions 500 g + 300 g + 250 g	When spring flush leaves ½-$^2/_3$ expanded	These two deficiencies often occur together. A combined spray is an effective means for controlling both. Should not be used if rain is expected within 48 hours. The first spray is usually preferred to this one as it leaves less residue on fruit and leaves. More desirable if rain is likely within 48 hours.

Key References

- **The Citrus Industry**, Volume II, 1968. Edited by Reuther, W., Batchelor, L. D. and Webber, H. J.
- **Plant Analysis an Interpretation Manual**, 1997. Edited by Reuter, D. J. and Robinson, J. B.
- Weir, R. G. and Sarooshi, R. **Citrus Nutrition Agfact** H2.3.11. 1991.

General Guide to Plant Nutrients in Citrus

Element	Deficiency Symptoms	Excess Symptoms	Uses in Plant	Movement in the Plant	Movement in the Soil	pH Effects	Reactions with other Elements	Availability	Other Information
Nitrogen (N)	**Old leaves** Pale green-yellow leaves. Stunted growth. Thin foliage cover & dieback of twigs. Poor fruit set & fruit size. Fruit quality good.	Promotes luxurious vegetative growth. Poor fruit quality & shorter storage lfe. Fruit thick-skinned large, puffy, delayed maturity, regreening increased. % and quality of juice declines.	Cell growth and chlorophyll formation.	Mobile	Mobile		High nitrogen levels (>2.6) reduces accumulation of boron or sulfur in leaves. Effects of too much nitrogen worse when phosphorous low.	Only nitrate and ammonium forms used by plants. The conversion of nitrogen to these forms dependent on microbial activity, which is greatest in pH range of 5.5-8.5. During cooler months apply in readily available forms	Easily leached in sandy soils. Lost in waterlogged soils. Affects of too much nitrogen worsen when phosphorous is low.
Phosphorus (P)	**Old leaves** Dull bronzed green leaves. Reduced flower formation. Misshapen fruit, open centres, thick coarse rinds. Fruit pulpy, lower juice, more acid.	Decrease in fruit size, % juice increases, peel thickness decrease. Regreening increases slightly.	Cell division, growth and young cells.	Mobile	Mobile	Most available in range 6-7. Not a lot tied up by soil in this range.	Too much phosphorous can accentuate the effects of zinc deficiency and inhibits copper utilisation.	Some available & some unavailable in soils. This unavailable form acts as a future reserve. Phosphorous accumulated in upper soil layer. Most available in neutral to slightly acid soils. Australian soils are low in natural phosphorous. In alkaline soils it becomes fixed as calcium compounds and in acid soils as compounds of iron and aluminium.	Compacted soils reduce phosphorous uptake. Phosphorous needs to be regularly applied so the plant has access to available forms. Losses from soil only in erosion of soil particles or in very sandy soils. Higher losses at pH 6-7.
Potassium (K)	**Old leaves** Slower tree growth, small leaves and heavy leaf fall. Fruit small, skin thing, smooth, colours early, splits easily, more creasing. Severe deficiency causes heavy fruit/flower drop.	In oranges delays maturity, increased rind thickness, rough, increased regreening.	Metabolic processes. Quality & ability to resist stress & disease. Improves use of phosphorous & nitrogen. Important role in water relations in plant.	Mobile	Mobile	High pH induces a deficiency	Too much potassium can accentuate magnesium deficiency and reduce calcium uptake.	Soils contain large amounts but most is unavailable. Taken up from soil solution in far greater amounts than necessary.	Deficiency upsets water usage & slows growth.

General Guide to Plant Nutrients in Citrus

Element	Deficiency Symptoms	Excess Symptoms	Uses in Plant	Movement in the Plant	Movement in the Soil	pH Effects	Reactions with other Elements	Availability	Other Information
Sulfur(S)	**Young leaves** Stunted, small leaves. Pale green-yellow with lighter veins.		Chlorophyll & protein formation	Immobile	Mobile	High pH induces a deficiency		Available to plants only in sulfate forms. Most sulfur present in the organic matter.	Sulfate forms easily leached. Can lower pH.
Calcium (Ca)	**Young leaves** Stunted roots, fruit quality problems	Reduction in availability of trace elements. Iron chlorosis.	Functioning of growing points and nitrogen metabolism.	Immobile	Immobile	Deficient in low pH (acid) soils.	Heavy applications of potassium induce deficiencies, especially in acid soils.	Low calcium in soils often associated with low pH, high aluminium and manganese levels.	Easily dissolved in acid soil water.
Magnesium (Mg)	**Old leaves** Yellowing towards apex of leaves with a triangular area remaining green at base. Defoliation, twig dieback. Decline in yield and size.		Chlorophyll formation and transport of phosphorous.	Mobile	Attaches to clay particles.	Deficient in sandy, acid soils	Heavy applications of potassium induce deficiencies. Manganese deficiency more acute when nitrogen levels low.		Important in cation exchange.
Copper (Cu)	**Young leaves** Dieback of twigs. Dark brown gum pockets on young shoots. Rind can be brown, with gum stained areas, split fruit.	Stunted growth. Toxic to plant roots.		Immobile	Mobile in acid soils.	Becomes unavailable as pH rises above 7.0	Excess induces iron deficiency.	Dependent on pH, organic matter content, presence of aluminium, molybdenum & iron.	Copper levels can be reduced by increasing the organic matter content of soil.
Zinc (Zn)	**Young leaves** Creamy white to yellow blotches in leaves. Small, narrow leaves. Retarded terminal growth, reduced leaf size. Small twigs die. Lowers yield, tree vigour, fruit small, poor quality		Chlorophyll formation, protein synthesis and water usage.	Immobile	Mobile in acid soils.	Unavailable above pH 6.0	High phosphorous induces zinc deficiency by rendering it unavailable.	High levels of Organic matter, over liming & overuse of poultry manure can reduce zinc availability. More available when soil temperatures are warm.	Nitrogen materials favour zinc availability. Symptoms more pronounced on north side (sunny) of tree.

General Guide to Plant Nutrients in Citrus

Element	Deficiency Symptoms	Excess Symptoms	Uses in Plant	Movement in the Plant	Movement in the Soil	pH Effects	Reactions with other Elements	Availability	Other Information
Manganese (Mn)	**Young leaves** Mottled pale green leaves, reduced cropping and growth. Intervienal yellowing. Slight loss in yield.	Bright yellowing on leaf edges (old), dark brown tar spots on leaves	Chlorophyll & nitrogen metabolism	Immobile	Mobile in acid and water-logged soils	Becomes unavailable as pH rises above 5.5.	High levels can induce an iron deficiency.	More available in waterlogged conditions. At low pH (acid) manganese toxicity becomes a problem.	Symptoms more noticeable on southern side of tree.
Iron (Fe)	**Young leaves** Chlorosis of leaves, stunted abnormal growth. Tips/margins and veins stay green longest. Yield reduced. Lemons are more prone to iron chlorosis.		Chlorophyll formation	Immobile	Mobile in waterlogged soils.	Becomes deficient as pH rises above 7.0	High iron levels can induce a manganese deficiency. Fixes phosphorous.	In very acid soils, phosphates can be tied up by soluble iron & aluminium ions. High water table & water logged conditions aggravate problem.	
Boron (B)	**Young leaves** Lopsided fruit heavy fruit shedding & yellow leaf veins. Fruit has grey to brown internal patches with gum pockets throughout rind & flesh. Loss of fruit quality & production.	Yellow, dead leaf tips, leaf fall and dieback. Yield decline. Lemons appear to be more susceptible to an excess of boron.	Uptake, use of calcium. Cell division. Flower/fruit formation & quality.	Immobile	Mobile		Calcium renders boron insoluble therefore used to overcome an excess.	Available forms found in soil solution. Dry periods and over liming can induce a deficiency.	Easily leached. Narrow range between levels of deficiency and toxicity.
Molybdenum (Mo)	**Old leaves** Symptoms similar to nitrogen. Yellow spots on leaves in spring.		Used in nitrate reduction	Mobile				Deficient in acid soils which contain iron or aluminium oxides.	
Aluminium (Al)	Stunted root growth. Lack of root hairs				Immobile	As pH rises above 5.5 Al solubility increases	Fixes phosphorus.	Aluminium toxicity in acid soils.	
Sodium (Na)	**Old leaves**	Leaf burn, leaf fall & dieback			Mobile	A problem in alkaline soils.	Sodium ions displaced by calcium.		