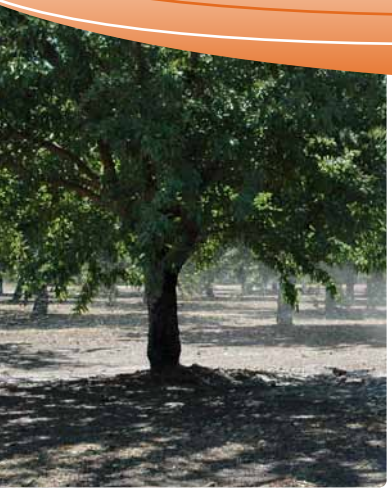
SUSTAINABLE
IRRIGATION MANAGEMENT UPDATE

Guidelines for Fertigating Citrus Orchards

Managing fertigation systems to achieve good productivity and avoiding fertiliser wastage and loss

NATIONAL PROGRAM FOR
Sustainable Irrigation



Key Messages for fertigating citrus trees

- Use tree nutrient status (according to leaf sampling protocols and interpretative standards) and other performance indicators (tree vigour, yield and fruit quality) to assess fertigation programs
- Adjust fertigation programs to match rootstock/scion vigour
- Inject dissolved mineral nutrients into irrigation water in the last half of an irrigation cycle
- Avoid nitrate concentrations in the soil solution above 150-200 mg/L
- Apply irrigation best practice to avoid movement of water and nutrients below the rootzone
- Leach salt from the rootzone during winter when soil nitrate levels are at their lowest to minimise nitrate leaching to ground waters

What is fertigation?

Fertigation is a term specially coined to describe the supply of dissolved mineral fertilisers to tree roots via irrigation water, generally as continual or very frequent doses throughout the growing season. The concept has been around for many decades, but it is only recently that fertigation has been more widely adopted, and it is now quite common on permanent plantings of tree crops, such as citrus. One implication of fertigation is that the fertility of the soil becomes less important to the health and productivity of the crop, which relies far more on the provision of nutrients to the rootzone via fertigation.

What are the advantages of fertigation?

Supplying most of the trees' mineral nutrient needs [i.e. nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S)] as dissolved fertilisers in the irrigation water offers a number of advantages; the main one being that the timing of supply of important nutrients such as N can be tailored to when the trees are actually taking up those nutrients. Potentially, this means that fertiliser use efficiency (i.e. the proportion of the nutrients applied that is taken up by the trees' roots) should be higher than if the trees' seasonal mineral nutrient needs are broadcast in one or two applications per growing season.

Other advantages include fuel savings and reduced traffic in the orchard, as nutrients are delivered by the irrigation water instead of the tractor.

Is there a downside to fertigating citrus trees?

Depending on fertigation system design and set up, and how it is used, the level of management input for fertigation may be greater compared to supplying fertiliser in the traditional way. Dissolved mineral fertilisers can be supplied to the trees more or less on a daily basis during spring and summer, which can require significant time spent loading and mixing fertilisers in fertigation tanks. In addition, the decision about how much of each nutrient is required at different growth phases across the season requires a greater level of management skill than a simple annual calculation.

Another thing to bear in mind is the need to use technical grade fertilisers, which are more costly than agricultural grade fertilisers because they contain far fewer impurities. Using agricultural grade fertilisers in a fertigation system can result in dripper blockages due to fine impurities that can get through filters. Care also needs to be exercised when mixing different fertilisers because reactions between certain elements can lead to the formation of insoluble precipitates that lead to dripper blockage (Treeby *et al.*, 2004).

Figure 1 Examples of tanks used to dissolve fertilisers in fertigation systems

The tank on the left is located in the field, and is used to dissolve small amounts of fertiliser and inject that solution into the irrigation line using a Venturi system. Tanks of this size generally only service a single irrigation block.

The two tanks on the right are used to dissolve two different fertilisers - that may be incompatible - and are injected at different times. Tanks of this size are used for fertilising whole orchards and may contain enough dissolved fertiliser for multiple irrigations.

A significant disadvantage of fertigation is the capital cost associated with the tanks to hold the dissolved fertilisers, the injection equipment and the control devices required. Several tanks may need to be installed if injecting multiple fertilisers that can't be dissolved together (**see Figure 1**). The need for some form of backup provision to cater for equipment or power failure also needs to be considered.

Approaches to fertigation

Fertigation equipment has become more sophisticated over time (Falivene and Treeby, 2011), and there are now more options available that can be used by citrus producers who wish to practice fertigation (Treeby *et al.,* 2011).

The simplest approach is to simply use the irrigation system as an alternative fertiliser delivery system for certain critical nutrients.

A more complex approach — known as "open hydroponics" — involves supplying the trees' entire nutrient needs in specially tailored, continually changing mixtures throughout the growing season via fertigation, and only to that part of the soil profile where the roots are confined. Root confinement is achieved by short frequent irrigations, and the whole approach seeks to control the roots' access to water and nutrients to a very high degree. Essentially the soil only acts as a physical support for the trees' roots, and as a short term storage facility for water and nutrients. This has some advantages, but an important disadvantage is that in the event of a failure in water supply, there is very little water stored in the soil to support the trees until water supply can be restored. There is a reasonable likelihood of the trees going into stress under these circumstances.

The equipment now available provides irrigators with many fertigation options, and it can be difficult to choose the best combination of equipment and management regime for a specific crop. Experience gained in a research project concerned with managing fertigation in citrus may be of use to irrigators considering investing in fertigation, or who have already done so but are yet to get the best out of the equipment.

When in an irrigation cycle should dissolved fertilisers be injected?

Results from field investigations and computer simulation modelling indicate that injecting nutrients early in the irrigation cycle can increase the risk of leaching of nutrients beyond the rootzone. Injection of nutrients later in the irrigation cycle means that less water is applied after the nutrients enter the soil, which in turn means that the nutrients move a smaller distance from the dripper before the end of the irrigation cycle. As a result, there is a much greater chance for them to be taken up by the roots and much less likelihood of the nutrients moving below the tree roots. It is of course important that there is a period of flushing at the end of each irrigation cycle, to ensure nutrients do not remain in the irrigation line, as this will encourage algae growth in the system, which can lead to blockages.

How can nitrate leaching be avoided?

- Nitrogen can be supplied to tree roots as ammonium (NH4+), as nitrate (NO3-), as urea [CO(NH2)2], or a combination of these.
- The N in urea is converted to ammonium, and the speed of that conversion is related to the soil type, soil temperature and soil moisture level.
- Ammonium is converted to nitrate in a process know as nitrification.
- The ammonium ion has a positive charge, and tends to stick to soil particles and is less prone to being leached.
- Nitrate has a negative charge, and is more prone to moving with water down the soil profile.
- Nitrate leached beneath the rootzone is a financial loss for the irrigator, and potentially a pollution problem if it makes its way to ground and surface waters.

Four measures can be used to prevent or minimise the downward movement of nitrate.

- Inject nitrate in the middle of, or late, in an irrigation event;
- Avoid excessive concentrations of nitrate in the soil solution. Research suggests that nitrate concentrations greater than 150-200 mg/L don't provide any additional benefit, and supplying more N fertiliser simply increases the risk of leaching by successive irrigation or rainfall events. Oversupplying N can also lead to fruit quality issues (Figure 2);
- Complete the N supply program by the end of summer/early autumn to allow depletion of nitrate in the soil by winter;
- Ensure that only the right amount of water is applied. Some movement of nitrate may be inevitable with each irrigation cycle, but overwatering is likely to speed up that process and move nitrate beyond the rootzone. Allowing for expected rainfall when calculating the depth of water to apply will also help reduce the likelihood of leaching.

Figure 2 Delayed colour development of a navel orange fruit

Delayed colour development can be related to excessive N supply. Early re-greening of Valencia oranges is also related to excessive N supply. Other fruit quality issues associated with inappropriate supply of mineral nutrients include puffy fruit, thick rinds, coarse rinds, thin rinds and poor shelf life (Hardy and Treeby, 2009)

Do trees on different rootstocks need to be fertigated differently?

Rootstocks are selected for a number of attributes including tolerance of soil-borne diseases, salt exclusion, tree vigour, yield and fruit quality. Little consideration is given to the ability of different rootstocks to take up and transport mineral nutrients to the scion. This is despite it being known for many years that the same citrus scion growing under the same conditions will have different levels of mineral nutrients in the leaves depending on the rootstock it is growing on (Smith et al., 1949 and Taylor and Dimsey, 1993) (**Figure 3**).

Australian and overseas research (Smith *et al.,* 1949; Taylor and Dimsey, 1993; Treeby *et al.,* 2012) suggests that trees on different rootstocks may have different mineral nutrient needs, and may need to be fertigated differently. The relative vigour of trees on different rootstocks is not related to just water and fertiliser supply; different types of plants grow at different rates under the same circumstances. Less vigorous rootstocks impart that lower vigour to scions, and supplying more water and fertiliser doesn't overcome that inherent trait.

Less fertiliser will be needed for trees on less vigorous rootstocks to achieve the same tree nutrient status as trees on more vigorous rootstocks, but the most important information needed to manage trees on different rootstocks is the nutrient status of the trees (i.e. % N, % P, % K, etc. in the leaves - see discussion below).

Do different varieties need to be fertigated differently?

Trees of the different citrus types (i.e. oranges, mandarins, grapefruit. lemons and limes) are obviously different in growth habit and size. The same considerations apply to managing the fertiliser supply to different citrus types as applies to trees on different rootstocks. The important information needed to assess the appropriateness of a fertigation program is the nutrient status of leaves. Measurements of nitrate concentration in the soil solution may also point to some adjustment of the fertigation program. These two points are discussed in detail below.

Differences between varieties of the same type of citrus (e.g. Leng navel and Lane Late navel or Imperial mandarin and Ellendale tangor) are less important (Taylor and Dimsey, 1993), but the same principle applies: use leaf analysis results to guide fertiliser management.

Figure 3 Mineral fertiliser needs will be determined by citrus type and the rootstock

Mandarin trees in the foreground showing chlorosis, and healthy navel orange trees in the background growing in the same soil type.

The differences in tree health are related to the different nutrient needs of mandarins versus navel oranges, and differences in the ability of the rootstocks used for mandarins and navel oranges to supply those needs. Ideally, these trees would be on different irrigation shifts to allow for specific fertigation programs to address the specific needs of each variety/rootstock combination.

How can a fertigation program be assessed?

A continual supply of large amounts of mineral nutrients to tree roots does not guarantee the uptake of those nutrients. Assessing the effectiveness of a fertigation program can be problematic; especially when it is remembered that the key citrus fruit performance indicators (yield, fruit size distribution and packout) are affected by a range of factors such as the previous season's crop load, tree age, variety, rootstock, bud line, crop size management, seasonal conditions as well as water and fertiliser availability.

Ideally, irrigators would like to be able to assess their fertigation program in real time, in order to make modifications during the growing season, but at present there are no established means to do so. It can be tempting to modify a program part way through a season based on how the trees look, but it is important to remember that trees have a large degree of "inertia"; that is, the appearance of trees in this season is as much a reflection of how well fertilised they were last season as it is of how they are being fertilised this season.

Leaf analysis

The only objective measure of fertiliser adequacy is a comparison of nutrient levels in leaves collected in February from the middle of non-fruiting spring extension growth against standard ranges (Robinson *et al.,* 1997) (see **Figure 4**). The advantage of this approach is that the standards are based on many measurements and trials over many years from all over the world, and are recognised as the best method of assessing tree nutrient status.

The disadvantage of this approach is that measurements are taken at just one point in the growing season. As a result, leaf analysis is best used to review the current fertigation program, and plan changes for the coming season.

SAMPLING LEAVES (from Hardy, 2007)

- Collect leaves in late February (southern Australia)
- Collect leaves early in the morning before the heat of the day
- Select healthy mature leaves from the middle of non-fruiting spring growth at about shoulder height from all sides of the tree
- Avoid shoots that have made a subsequent summer flush
- Collect at least 100-200 leaves from at least 20-25 trees across an irrigation block or variety/rootstock combination
- Rinse leaves in rain water to remove dust and other potential contaminants
- Allow leaves to air dry and then place in a paper bag
- Store samples in refrigerator until sent for analysis
- Send to a NATA-accredited laboratory.

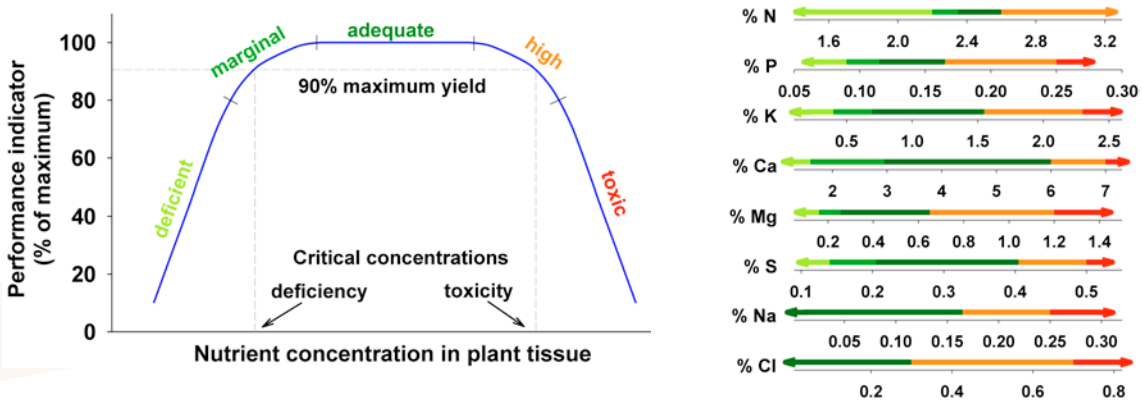


Figure 4

Typical relationship between plant tissue nutrient levels and response by plants (left) (Smith and Loneragan, 1997) and standard macronutrient ranges used for interpreting citrus leaf mineral levels based on that relationship (right) (Robinson et al., 1997)

Soil solutionanalysis

Soil solution (water and nutrient mix in the soil surrounding the roots) can be extracted by means of ceramic sampling devices embedded in the soil profile, and analysis of the nutrients and other chemicals in the solution may be informative (Falivene, 2011). The sampling devices are available commercially, but can also be assembled from readily available materials.

INSTALLING SOIL SOLUTION SAMPLERS

Soil solution samplers are constructed of very similar materials to tensiometers, and their proper functioning relies on correct installation in much the same way as tensiometers.

- Solution samplers should be installed into undisturbed soil, and on a slight angle to avoid creating a preferential pathway for water access
- Excavate an access hole a little larger than the diameter of the solution sampler, to just less than the full depth at which the sampler tip is to be installed
- Use a hollow pipe of the same or slightly smaller diameter than the solution sampler tip to make a hole just longer than the tip at the bottom of the access hole
- Push the solution sampler straight into the hole created, but DO NOT TWIST. Depending on the design of the solution sampler, a piece of PVC pipe may be useful as an extension when performing this step
- Repack the soil around the shaft of the solution sampler, and finish off flush with the soil surface, or slightly raised, to prevent water ponding around the solution sampler.

Care must be taken when installing the samplers to ensure good contact between the ceramic cup and the soil (**Figure 5)** (see box above). Failure to ensure good contact between the soil and the device means that it is unlikely that soil solution can be extracted unless the soil is completely saturated. The volume of soil solution that can be extracted is very dependent on how wet the soil is, and reliable samples can only be extracted within 24-48 hours after irrigation, depending on the depth of the sampling device and the length of the irrigation.

Figure 5 Ceramic cup sampling devices removed from a navel orange planting at Dareton

The ceramic sampler on the left is stained indicating good contact with the soil, but the ceramic sampler on the right shows very little staining suggesting poor contact with the soil.

The electrical conductivity and concentration of some nutrients in the soil solution can be measured with small hand-held devices and test strips. However, experience suggests that while EC and nitrate (NO3-) measurements are reasonably reliable, measurements of potassium (K+) and phosphate (PO43-) are less so. In addition, nitrate measurements can be quite variable, and it would be unwise to rely on a single measurement from a single ceramic sampling device. Despite nitrate generally being the major anion (negatively charged ion) in the soil solution, experience also suggests that EC is not a particularly reliable indication of the concentration of nitrate in the soil solution, especially at depth.

Interpreting soil solution analysis

Obtaining a measurement of nitrate in the soil solution is one thing, but the real value is in relating that measurement to the fertigation program. It needs to be remembered that interpretation of nitrate measurements in the soil solution is a far less developed technology than that of leaf nutrient standards. Nonetheless, measurements of tree growth and N uptake suggest that citrus rootstocks do not take up any more N or

grow any better when the concentration of nitrate in the soil solution is in excess of 150-200 mg/L (or 35-45 mg NO3--N/L) and there are no other apparent limiting factors (e.g. other mineral nutrients, water, temperature, light, *etc.*).

At the other extreme, nitrate concentrations in the soil solution below 10 mg/L (2.26 mg NO3--N/L) can be expected without any N fertiliser being supplied, and reflect the actions of soil organisms breaking down organic matter in the soil. This level of nitrate in the soil solution is not sufficient for the needs of vigorous productive trees.

Figure 6 shows the average nitrate concentrations measured in the soil solution extracted at 3 depths beneath drip irrigated navel orange trees at Dareton over two irrigation seasons. Also shown are the amounts of irrigation applied, the effective rainfall and the amounts and timing of N applied to the trees over that period.

Significant nitrate concentrations were only seen immediately after N fertiliser was applied, and concentrations dropped away quickly following the cessation of supply in autumn. Large doses of N resulted in nitrate concentrations in the soil solution well in excess of 200 mg/L.

Nitrate concentrations at depth increased as each season progressed, indicating that some nitrate movement past the rootzone may be inevitable following each irrigation event.

Nitrate concentrations in winter were so low that applying a sufficiently large irrigation during winter to leach salt out of the soil profile was unlikely to cause significant nitrate leaching, provided that no N fertiliser had been supplied immediately prior to the leaching irrigation.

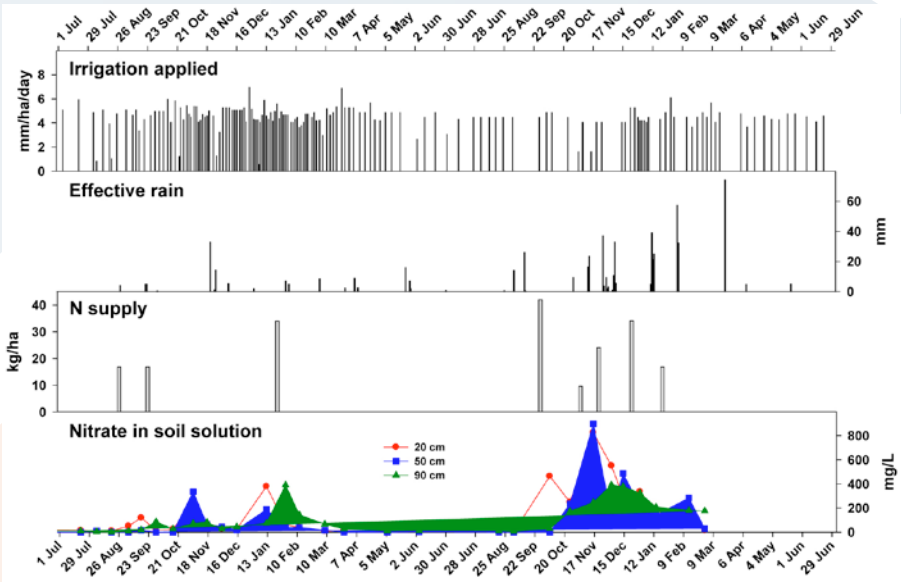
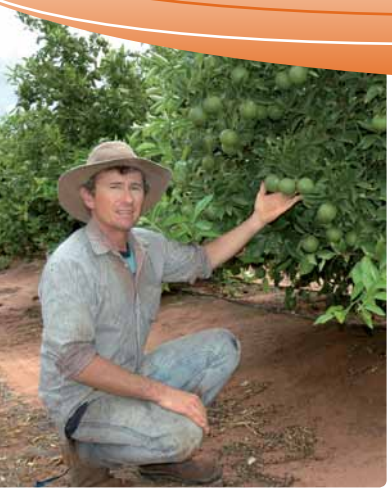


Figure 6

Measurements of nitrate in soil solution extracted from a drip-irrigated navel orange orchard at Dareton, with rainfall, irrigation and N fertiliser supply records for the 2009-10 and 2010-11 irrigation seasons



EXPRESSING NITRATE CONCENTRATIONS

Care needs to be exercised when expressing, sourcing information about and comparing nitrate concentrations in soil solution and bulk soil.

Nitrate concentrations can be expressed simply as concentration of nitrate (mg NO3-/L of soil solution, or mg NO3-/kg of soil), or as concentration of nitrogen that is present in the NO3- form (mg NO3--N /L of soil solution or mg NO3--N/kg of soil).

Both are valid, but it is important when making any comparisons with published data or results from different laboratories or different equipment to make sure that the same units are used.

To convert mg NO3- to mg NO3--N multiply by 0.226.

To convert mg NO3--N to mg NO3- multiply by 4.43.

Is the investment in fertigation equipment justified?

The step from broadcasting dry fertilisers to fertigating citrus trees is recognised as advantageous (Alva et al., 2008). However, local and overseas experience suggests that best practice drip irrigation and applying mineral fertilisers in one or two large doses via the irrigation system results in similar tree growth and yield as the more intensive approaches to fertigation (i.e. frequent short irrigations with daily injection of small amounts of dissolved mineral fertilisers) (Treeby et al., 2012). But, objective comparisons of different irrigation and fertigation approaches over the long term have not been carried out, and those observations that have been made have been on young trees.

Further reading

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