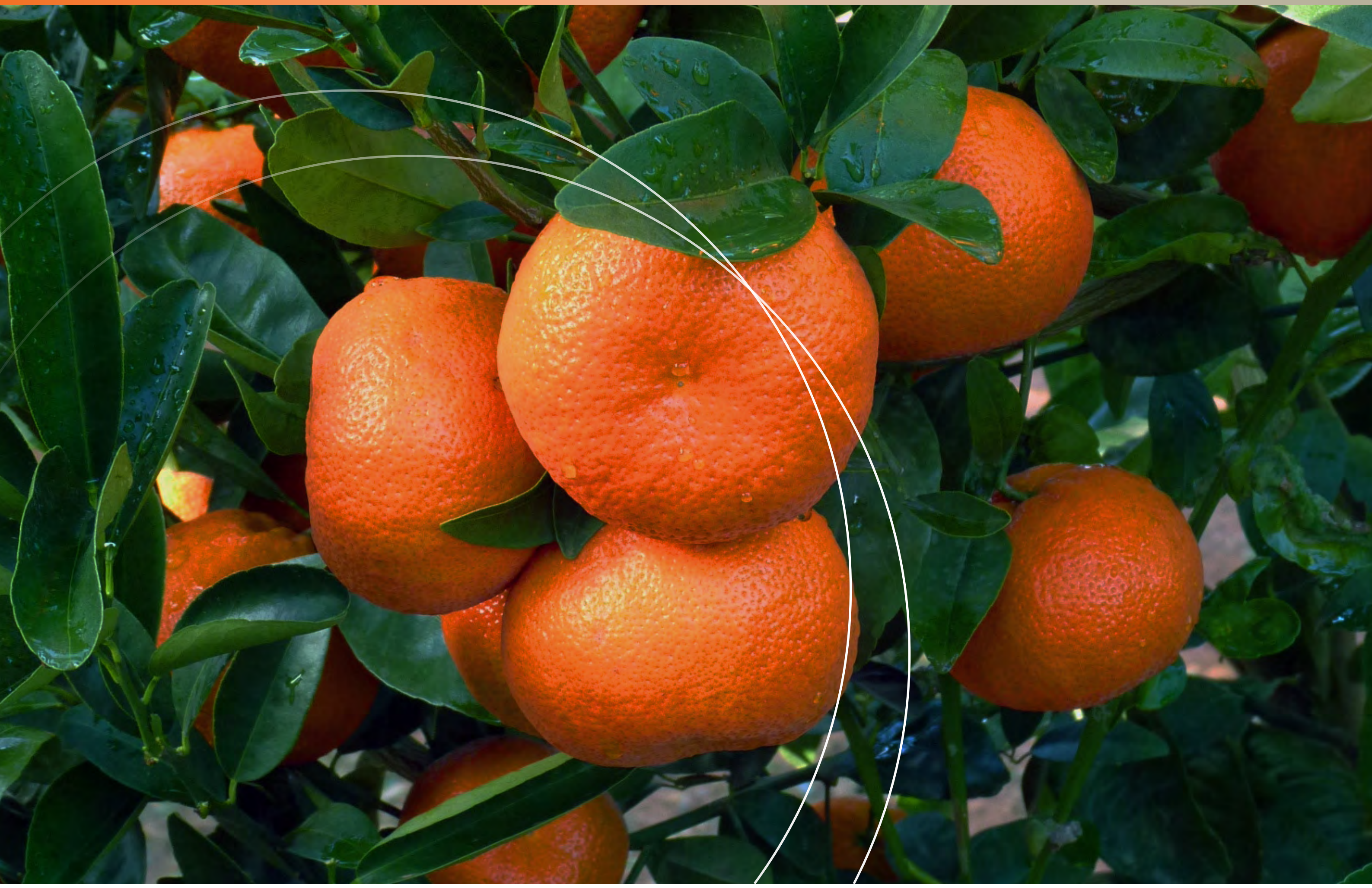
Department of Primary Industries

# Australian mandarin production manual



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Published by NSW Department of Primary Industries, 2017

First published 2017



National Library of Australia Cataloguing-in-Publication data:

Title: Australian mandarin production manual

Authors: Sandra Hardy, Patricia Barkley, Michael Treeby, Malcolm Smith and Graeme Sanderson

Editors: Michael Treeby and Sandra Hardy

Sub-editor: Valerie Draper

Design: Valerie Draper

Edition: 1st

ISBN 978 1 76058 056 8 (print

ISBN 978 1 76058 057 5 (web)

Format: Print and web

Subjects: Mandarin, Production, Australia, Handbooks, manuals.

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# Foreword

The Australian citrus industry finds itself competing with other citrus producing countries in export markets made up of increasingly more demanding consumers. The opening up of East Asian markets to imports of Australian citrus is providing Australian citrus producers unprecedented opportunities. The growing middle class in those markets is demanding consistently well coloured, good tasting, clean fruit. Demand for easy-peel citrus fruit – such as mandarins – is increasing around the world.

Consumers want easy-to-peel, sweet, juicy fruit that are seedless, or have the capacity to be seedless. Australia, with its clean and green image, is well placed to meet this demand. Annual Australian mandarin production is currently around 12 kT, representing about 20% of Australia's citrus production. Mandarin exports, representing 22% of citrus export volumes, are currently valued at over $95 million dollars annually to the Australian economy.

Consistently producing well coloured, good tasting mandarins is more demanding than producing other types of citrus, such as navel oranges. The rewards for getting it right are good, and the knowledge needed by Australian mandarin producers, or those who aspire to produce mandarins, is now readily accessible in this convenient package.

With funding support from the Australian Centre for International Agricultural Research (ACIAR), the NSW Department of Primary Industries (NSW DPI) has produced this manual to provide existing and aspiring mandarin producers with a summary of the production basics and the most current scientific research results. It is intended that this manual will serve to support decisions in the orchard establishment phase, as well as detailing the broader principles that underpin management strategies on a seasonal basis.

## Acknowledgements

NSW DPI and ACIAR provided funding for this manual as part of projects HORT/2005/142 – 'Improving mandarin production in Bhutan and Australia through the implementation of 'on-farm' best management practices', and HORT/2010/089 – 'Adapting integrated crop management technologies to commercial citrus enterprises in Bhutan and Australia'. These projects were undertaken from 2007 to 2017.

The authors would especially like to thank Valerie Draper (Professional Officer, NSW DPI) for her significant contribution in the typing, editing, design and layout of this manual.

The authors gratefully acknowledge the technical expertise and editorial assistance provided by the contributing authors from around Australia.

Thanks also to Julian Connellan for his initial draft of the manual and photographic contributions, when he was employed as a Project officer on the ACIAR project, 2008–2010, and to Dave Monks (Research Officer, NSW DPI) for his editorial assistance in the final stages of the production of this manual.

Thanks also to the many mandarin growers who have provided their time and assistance during the duration of the ACIAR projects.

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Sandra was the Australian project leader for the Australian Centre for International Agriculture Research (ACIAR) project, 'Improved management practices for mandarins in Bhutan and Australia' from 2007 until her retirement in 2013. Sandra was the NSW Coastal Cittgroup coordinator for the National Cittgroups program from 2003–2009 for Citrus Australia Limited (CAL), the peak industry body for citrus in Australia.

Sandra has an extensive publications record, with a focus on the provision of technical information in a clear and concise style using plain English. She is the author of *Growing lemons in Australia – a production manual*, and co-author of the *Fruit size management guides* and the *Spray Sense* series and book. She was editor of the NSW DPI quarterly *Coastal Fruitgrower's Newsletter* for over 20 years, producing 74 issues.
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Michael has authored and co-authored many scientific papers in the fields of plant nutrition and physiology. He was contributing author of vine nutrition and vineyard fertiliser management in the Australian *Grape production series*. Michael has also contributed to *Plant analysis: an interpretation manual*, and the 3rd edition of *Drip irrigation – a grape grower's guide*.
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# Contents

# Introduction

The first citrus to arrive in Australia were brought on the First Fleet in 1788. They included trees and seed of oranges, lemon and lime and were planted at Sydney and Norfolk Island. The first mandarins were probably brought to Australia through trade with China. In a catalogue of fruits cultivated in the Sydney Botanic Gardens in 1828, four varieties were listed: the Common mandarin, Fang-Kau ('superior quality'), Tuan-Kat ('few or no seeds') and Chu-Cha Kud ('small, sweet and red-skinned') [Bowman 1955].

The classification of citrus and its cultivated forms is complicated by its long history of cultivation and the ability of genera to readily cross-pollinate. Commercial citrus cultivars are derived from wild species of citrus native to the Sub-Himalayan tract, China and Western Malesia (most of modern day Indonesia, Malaysia, the Philippines and Papua New Guinea) [Mabberley 1997]. The term mandarin is the commercial or popular name (but not a taxonomic one) generally given to citrus trees that are smaller, bearing small sweet fruit with an orange flesh and rind, and are easy to peel (Wu et al. 2014).

Different approaches to classifying citrus and several naming conventions have been developed. The two best known systems were by Swingle and Reece (1967) and Tanaka (1977). The Swingle system divides the citrus genus into species (16 in all), then varieties and finally cultivars or hybrids. The Tanaka system provides a separate name for each citrus cultivar – resulting in 162 species. In 1997 Mabberley proposed a new Linnaean classification for edible citrus based on just three species and four hybrid groups.

*Citrus reticulata* Blanco is widely cited as the true species from which cultivated mandarins arose, but wild populations have not been definitively described. It appears that these classification systems that associate mandarins only with *C. reticulata* are too simplistic (Wu et al. 2014). Recent DNA sequencing of the citrus genome (Wu et al. 2014) found that all cultivated mandarins, such as Ponkan (Emperor) and Willowleaf mandarin, originally came from natural interbreeding between *Citrus maxima* (pummelo) and *Citrus reticulata* (wild mandarin). Some specific citrus genotypes are hybrids, such as Clementine mandarin, which is believed to be a chance seedling from a Mediterranean mandarin. However, it is more likely to be a hybrid of mandarin × sweet orange, as is W. Murcott (Afourer) [Wu et al. 2014].

Mandarins are a diverse group and are adapted to a broad range of climates, although some varieties have quite specific requirements. Fruit size is enhanced by heat and humidity, while fruit shape can be unfavourably affected by low humidity. Fruit quality parameters such as juice, sugar and acid content, as well as peel colour, are also influenced by local climatic conditions, particularly temperature and humidity. For more information see the chapters on Varieties, and Climate and phenology.

While other citrus types do not require pollination to produce fruit (i.e. are parthenocarpic), certain mandarins (e.g. Clementine and Minneola tangelo) do require cross-pollination to produce good crops. Mandarins can be seedy or virtually seedless and modern breeding programs are focussed on producing seedless varieties. Many mandarin varieties also have a pronounced tendency towards alternate bearing, producing a heavy crop one year followed by a light crop the next. So crop management strategies are an important part of commercial production. For more information see the chapter on Crop management.

Mandarins are easy to peel compared to oranges, but their skin is much more sensitive to damage and so require careful handling. Generaly, most commercial varieties have a relatively short harvesting period compared to oranges. Mandarins typically do not store well on the tree, nor can they be stored for long periods after harvest. For more information see the chapter on Postharvest handling.

Mandarin varieties are commonly grouped for descriptive purposes (Reuther, Webber and Batchelor 1967; Saunt 2000) as follows:

### Satsuma mandarins

This group contains over 100 varieties. Until the 1980s they were principally grown in Japan, China and Spain. Satsuma mandarins are mostly seedless (due to ovule sterility) and the best quality fruit are grown in regions with cold winters. Trees tend to have a weeping habit and fruit have a very short optimum harvest period. Satsuma mandarins tend to store better than other mandarin types. They are also used to produce juice. Most varieties are early to mid season maturing. Varieties grown in Australia include Miho Wase and Okitsu Wase.

### Mediterranean mandarins

The Mediterranean mandarins are commonly referred to as the 'Willowleaf' mandarin because of their weeping habit and small narrow leaves. Most varieties are seedy and have a loose adhering peel which has a distinctive fragrance. The Imperial mandarin is believed to be a natural hybrid within the Mediterranean mandarins group, but is listed under Common mandarins.

### King mandarins

This group consists of only two varieties, King and Kunenbo. King is 'orange like' and thought to be a hybrid of an orange and a mandarin. The fruit of King are larger in size with a thick and rough rind. Both varieties are grown mainly in South-East Asia and Japan.

### Common mandarins

This group is made up of a large number of diverse varieties including some of the most important commercial varieties. Varieties in this group tend to have a more tightly adhering skin than some other groups. Common mandarins are divided into two subgroups – Clementines and others.

The Clementine mandarin originated in Algeria and is currently one of the most popular mandarins in the world. Clementine mandarins tend to produce high yields of small fruit. They require cross-pollination for good fruit set, but this also makes the fruit very seedy. Clementines are more suited to Mediterranean type climates rather than humid subtropical or tropical climates. Important varieties include Caffin, Clemenules, Fina, Marisol, Nour, Nules and Oroval.

The other subgroup comprises a large number of both natural and man-made hybrids. They have a diverse range of characteristics and include varieties such as Emperor, Encore, Fallglo, Fremont, Imperial, Kara, Kinnow, Murcott (Honey), Nova, Pixie and Sunburst.

### Tangors

Tangors are hybrids of mandarin and orange crosses. They include Afourer (W. Murcott), Ellendale, Mor, Or, Ortanique and Temple.

### Tangelos

Tangelos are mandarin × grapefruit or mandarin × pummelo hybrids and include Minneola, Orlando and Seminole.

## Australian plantings and production

Mandarins represent about 20% of Australia's citrus production, with Imperial, Afourer and Murcott the leading varieties. There are approximately 5,450 hectares planted to mandarins, representing about 24% of national citrus plantings (Citrus Australia Limited [CAL] 2015). Annual production is currently around 120 kt, of which about 40% is exported (CAL 2017).

The key Australian mandarin growing regions in order of importance are the Central Burnett and Emerald in Queensland with 53% of production, the Riverland (23%) and Murray Valley (20%) in southern Australia, Western Australia (3%) and the Riverina region in NSW (3%) [CAL 2016].

The main mandarin varieties grown in 2014 were (in order of total hectares) Murcott, Imperial, Afourer (W. Murcott), Daisy, Hickson, Avana Late and Nules Clementine. Imperial and Murcott comprise approximately 59% of the total number of trees (CAL 2015). Mandarin selections grown around Australia are listed in Table 1.

## World production and exports

Global production of mandarins for 2014/15 was forecast to be 27 million tonnes, which remains well below that of oranges, which was predicted to be 48.8 million tonnes (United States Department of Agriculture 2015).

In 2013 the top five producers of mandarins were China (15.2 kt), Spain (2.2 kt), Turkey (0.94 kt), Japan (0.90 kt) and Morocco (0.66 kt) (FAOSTAT 2015).

World mandarin exports in 2012 totalled 4.82 million tonnes, compared to orange exports of 6.63 million tonnes. The top five mandarin exporters were Spain (1.72 kt), China (0.82 kt), Turkey (0.41 kt), Pakistan (0.37 kt) and Morocco (0.34 kt) (FAOSTAT 2015).

Australian mandarin exports in 2016 were 49,000 tonnes (valued at $95M), representing 22% of citrus export volumes. The major export markets were China, the United Arab Emirates, Thailand, New Zealand and Indonesia (CAL 2017).

Table 1. Main mandarin varieties grown in Australia.

| Region | Dominant varieties | Other varieties grown (in order of number of trees) |
|---|---|---|
| Riverina, (NSW) | Afourer[1], Imperial, Dekopon[2] | Satsuma Okitsu Wase, Summerina, Honey Murcott, Amigo, Ellendale, Daisy. |
| Murray Valley, (SW NSW and NW Victoria) | Afourer, Imperial | Daisy, Amigo, Dekopon, Ellendale, Murcott, Gold Nugget, Orri, Caffin Clementine, Satsumas Miho Wase and Okitsu Wase, Mystique[3], Avana, Fallglo, Fewtrell, Emperor. |
| Riverland, (SA) | Afourer, Imperial | Nules Clementine, Honey Murcott, Daisy, Satsuma Okitsu Wase, Gold Nugget, Dekopon, Avana, Amigo, Murcott, Summerina, Satsuma Miho Wase, Ellendale, Topaz Ortanique, Murcott (Low seeded), Orri, Nectar, Hickson. |
| QLD | Imperial, Murcott, IrM1, IrM2[4] | Afourer, Avana, Goldup, Hickson, Taylor Lee, Nectar, Daisy, Fremont, Nova, Empress, Sunburst, TDE, Success, Gold Nugget, Alkantara, Monarch, Orri, Ellendale, Emperor. |
| WA | Afourer, Imperial | Hickson, Nules Clementine, Mystique, Daisy, Gold Nugget, Nectar, Satsumas Silverhill and Okitsu Wase, Murcott, Caffin Clementine, Kara, Emperor, Honey Murcott, Ellendale, Ortanique. |

Source: Citrus Australia Limited (CAL) 2016.
[1]W. Murcott.
[2]Also known as Sumo Citrus™ or Hallabong.
[3]A seedling selection of Ortanique originating in WA.
[4]Low-seeded Murcott selections developed by Qld DPI.

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# Orchard basics

## Introduction

Although mandarins are grown in a wide range of locations, the soils and local climatic conditions should be fully assessed before planting any trees. Establishing an orchard or replanting a block is a costly exercise and good planning will save time and money in the long term and ensure the future productivity of the trees.

## Site selection

Flat or gently sloping sites are best. Slopes of up to a 20% gradient can be planted to tree crops, but consider machinery access requirements. Steeper slopes can also be used, but may need to be terraced or contoured.

In Australia, north or north easterly aspects are best, providing maximum sunlight during the winter months. Southerly slopes tend to be shaded and cold in winter and westerly slopes are the hottest in summer. Ideally tree rows should be orientated to run north–south to obtain maximum sunlight throughout the day (Figure 1). Sites should not be prone to frequent temporary or prolonged periods of waterlogging.

## Soils

Preferred soil types for citrus are sandy loams, loams and clay loams, which generally will have good drainage, waterholding and nutrient storage capacity. Sandy soils are also suitable, but will require more careful management because of their poor nutrient and water holding capacity. At least one metre of well drained soil is needed to support the root system. Soils should be well drained and not prone to waterlogging. Avoid soils with high watertables. Avoid heavy clay soils or soils with impermeable layers as these can be subject to waterlogging and poor aeration. Surface and subsurface drains can be used to improve soil drainage.

Before planting any trees it is best to obtain soil maps of the area if available. A full soil survey of the site by a soil scientist is recommended. The money spent on a soil survey will be repaid many times over the life of the orchard. A soil survey involves digging soil pits or soil cores in a grid pattern at 50–100 m spacings across the site. The number of pits required will depend on the uniformity of the site. Soil pits allow visual assessment of soil type, depth and structure down the entire profile (Figure 2). They are useful for identifying the presence of any impermeable or other layers down the soil profile. Samples of the soil in the different layers are then taken for analysis of their chemical and physical properties.


Figure 1. Citrus trees planted in a north–south arrangement to optimise exposure to sunlight.

Soil survey data (soil profiles and descriptions, reports and maps) are also available on the following websites:

- *Australian Soil Resource Information System (ASRIS) database*
- *Queensland Spatial Catalogue – QSpatial*
- *NSW Office of Environment and Heritage eSPADE*
- *Victorian Soil Information System (VSIS).*

Soil surveys and analyses are used to identify any potential problems such as pH, fertility, salinity and drainage for which remedial actions may be required before planting. They are critical for good irrigation design and allow for the irrigation system to be accurately matched to the soil types and soil depths across a site. They are important for the selection of the most appropriate rootstock, as rootstocks vary in their tolerance to soil conditions such as pH and salinity.

Citrus will do best in soils with a pH in the range of 5.5–7.0 ($CaCl_2$ method) as this will ensure most soil minerals are available for use. The pH of the soil should be adjusted before planting. Acid soils can be treated to increase pH, but it is more difficult to change the pH of alkaline soils.

Acid soils need to be corrected by the addition of lime or dolomite to bring the pH above 6, otherwise aluminium and manganese availability will be excessive. For many years it was believed that highly alkaline soils (i.e. > pH 8) were unsuitable for citrus (Skene 1951), but subsequent experience has disproved this. For example, Mikhail and El-Zeftawi (1979) published the results of trials conducted in north western Victoria on soils of pH 9. Use of a lime tolerant rootstock (such as Cleopatra mandarin or sweet orange) and appropriate management allows alkaline soils, previously viewed as unsuitable, to be used for citrus. For more information see the chapter on Rootstocks.

Figure 2. Soil pits are critical to identify any potential soil problems and for irrigation design in new orchards.

Citrus are sensitive to soil salinity. Values greater than 1.7 dS/m will have an affect on yield. Citrus rootstocks vary in their tolerance to soil salinity. Cleopatra mandarin is the most salt tolerant while *C. trifoliata* is the least tolerant. For more information refer to the chapter on Rootstocks.

### Mounding

Soil depth and drainage can be improved by mounding in the tree row. When mounding soils do not dig into any clay layers. Mounding or ridging is the process whereby suitable topsoil is heaped up in the tree row to form a continuous ridge above the unsuitable subsoil layers (Figure 3). A detailed site survey should be undertaken to ensure the ridges and inter-row areas are graded and sloped correctly to drain water away from the trees.

Ridging increases the rooting volume of the topsoil and also improves surface and internal drainage. Ridges should be 40–60 cm high and 2.5–3.5 m wide. The crest of the ridge should slope slightly to the sides to allow excess water to run off. The inter-row trough should be wide enough to allow the safe use of picking ladders and movement of machinery without the wheels touching the ridges. Ridged soils tend to dry out faster than flat ground so monitoring soil moisture is critical.

Figure 3. Mounding soil in the tree row to increase soil depth and improve drainage. Notice the poor drainage in the inter-row area with ponding of water on the soil surface.

## Drainage

Orchard soils need to be well drained to prevent tree roots from being subject to waterlogging for prolonged periods. Waterlogging occurs whenever water enters the soil at a faster rate than it can drain away. It can be caused by heavy rainfall, over-irrigation, flooding or the presence of a permanent or temporary (perched) high watertable. The duration and severity of waterlogging is influenced by the amount of water in the system, the topography of the site, soil type and structure and the waterholding capacity of the soil.

When soils become saturated with water, gas diffusion and exchange between the soil and the atmosphere are impeded – resulting in changes in the concentration of gases such as oxygen ($O_2$) and carbon dioxide ($CO_2$). As oxygen levels become depleted root growth is slowed or stopped. Root tips can start to die after 24–48 hours. Waterlogging and reduced oxygen levels (referred to as anaerobic conditions) cause changes in soil biological and chemical processes and affect the root's ability to absorb water and nutrients. For more information on waterlogging refer to NSW DPI Primefact 1189 *'Impacts and management of flooding and waterlogging in citrus orchards'*.

Orchard drainage can be improved by using surface and subsurface drains or a combination of both. Surface drains are used for removing excess surface water caused by heavy rainfall, or intercepting water flows from higher ground, subsurface drains or run-off from other sources, such as roads or neighbouring properties. The size and type of surface drains depends on the amount of water to be removed or intercepted.

Subsurface drainage is used to remove excess subsurface water to a specific depth in the soil profile. The type of system required depends on soil type, topography and rainfall. There are various types of systems, including corrugated slotted PVC pipes, tile drains, mole drains, interceptor drains, as well as groundwater pumps. Subsurface drainage systems are expensive to install, but provide long term benefits and will ensure better orchard health and longevity. The selection and correct installation of the right type of subsurface drainage requires detailed physical and chemical characterisation of the soil, so a detailed soil survey of the site is essential.

## Water and irrigation

Mandarin trees need a reliable supply of good quality water all year round for good tree growth and the production of high quality fruit. Water is transported throughout the tree almost continuously from the soil to the roots, then into the various plant parts and finally into the leaves where it is released into the atmosphere as water vapour (transpiration) through tiny pores (known as stomata) on the leaf during daily cycles of photosynthesis (Figure 4). Stomata open in the early morning and peak water demand is usually in the early afternoon. Water use is highest in the warmer months between October and March and lowest during winter. Water is needed for photosynthesis and nutrient acquisition and uptake; it is critical for successful bud initiation, flowering, fruit set and fruit growth. Water stress during the growth stages of flowering, fruit set, cell division and the early stages of cell expansion can have a significant impact on tree yield and fruit quality.

Mandarin trees usually need between 7 and 12 ML/ha of water per year, depending on local weather conditions, soil type, tree age, variety, rootstock and planting density. Research has shown that mandarin trees use up to 30% more water than orange trees. Trees have some natural ability to withstand water shortages and their thick older leaves, low number of stomata on leaves, and waxy fruit help conserve water. The rootstock used also has a major effect on the tree's ability to withstand water shortages and waterlogging. For more information see the chapter on Rootstocks.

There are a number of factors (e.g. salinity, pH, chloride) that affect water quality and are detrimental to tree growth and development. Water samples should be taken from any water source intended for irrigation and tested by an accredited laboratory. The quality of irrigation water should also be monitored regularly because it can change over time and fluctuate with seasonal conditions (especially during droughts or floods). Before collecting any water samples check with the laboratory for any special sample collection and storage requirements.

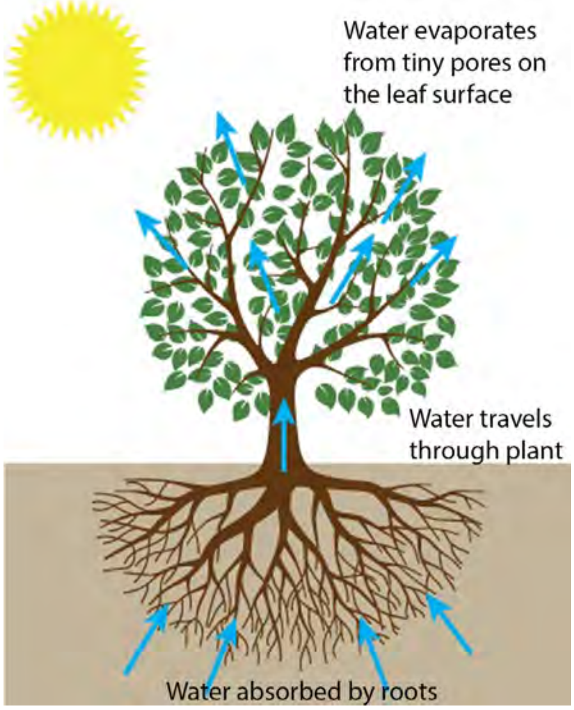


Figure 4. The transpiration process.
Source: tips.woodlandtree.com/images/transpirations.

Mandarins can be watered using any of the main irrigation systems commonly used in horticulture. In Australia most orchards use either under tree mini or microsprinklers or drip irrigation. Most new orchard developments have drip irrigation systems, which have a high level of water use efficiency.

The soil's physical properties strongly influence soil moisture and management. The soil type and its condition determine:

- how water moves through the soil profile (permeability, infiltration rate and drainage)
- the waterholding capacity (how much water the soil will hold and for how long)
- the rooting depth (how deep to water).

A comprehensive soil survey should be carried out to design an irrigation system tailored specifically to site conditions. For more information refer to the chapter on Irrigation.

## Scion and rootstock selection

The first step is to select and plant the right trees. Before ordering and buying any trees there are two important decisions to make:

1. selection of rootstock
2. selection of scion variety and clone.

### Rootstocks

The choice of a suitable rootstock is important for the long-term health and productivity of the orchard. Rootstock choice will be a compromise based on a number of factors including scion compatibility, horticultural performance (e.g. yield and fruit quality characteristics) and local soil conditions.

Rootstocks affect tree growth and productivity, fruit size, quality and maturity. Rootstocks also vary in their resistance to diseases, nematodes and soil conditions such as pH and salinity. Rootstock selection is particularly important in replant sites (see Orchard maintenance and redevelopment section). For more information refer to the chapter on Rootstocks.

### Scion varieties

Scion selection should be based on market requirements (including maturity time and seediness), local climatic conditions, management practices (e.g. requirement for netting to reduce seediness) and susceptibility to fungal diseases such as brown spot in summer rainfall areas. Domestic and export market requirements for fruit can be obtained by consulting with horticultural advisors, agents, exporters and fruit suppliers, as well as local and national industry organisations. For more information refer to the chapter on Varieties.

## Planting material

Citrus trees need to be pre-ordered from commercial nurseries 2–3 years in advance. When ordering trees specify the rootstock, variety and clone, budding height, tree height and structure.

Ensure the nursery uses propagation material from Auscitrus. In Australia the industry organisation that maintains and supplies citrus budwood and rootstock seed is the Australian Citrus Propagation Association Incorporated, trading as Auscitrus. Their propagation material is of the highest health status available in Australia. Seed trees are tested for psorosis and seed is heat treated to ensure freedom from Phytophthora species. Budwood supplied by Auscitrus is regularly tested to ensure freedom from exocortis and other graft transmissible pathogens. Budwood and seed trees are also checked for 'trueness to type'. Further information can be obtained from the Auscitrus website (*www.auscitrus.com.au*).

## Planting new trees

Make sure the planting site has been well prepared (Figure 5). Before planting do any necessary soil amelioration (e.g. pH adjustment). Ensure subsurface drainage (if required), irrigation and windbreaks are in place before planting. If sites are prone to waterlogging, or if topsoil is shallow, mound the tree rows. For replant sites, see the section on orchard redevelopment.

Citrus trees can be purchased either as bare-rooted or container grown trees. Container grown trees are now the most popular. Trees are usually planted in spring or autumn, depending on local climatic conditions.

Figure 5. Newly established trees showing tree guards and a cereal inter-row cover crop to stabilise soil.

For spring plantings, plant trees after the risk of any late frosts has passed. For autumn plantings ensure trees are established well before the onset of cold winter temperatures. Planting trees during the hot summer months should be avoided, and there is no advantage in planting trees during winter when soil temperatures are usually too low for root growth.

Bare-rooted trees are usually only supplied for planting in early spring. Bare rooted trees should not be allowed to dry out at any stage. The roots can be dipped in a mud slurry to keep them moist during planting.

For more information on planting and caring for young citrus trees refer to the *NSW DPI website.*

Planting material: best practice tips:

- ☑ Buy trees from a reputable NIASA (Nursery Industry Accreditation Scheme Australia) accredited nursery.
- ☑ Ensure the nursery uses Auscitrus budwood and seed which is pathogen-tested and true-to-type.
- ☑ Order early – specify rootstock and variety.
- ☑ The budding height of trees should be specified. It should be high enough to prevent collar rot and scion rooting. The recommended height is between 15–25 cm. The size and structure of nursery trees should also be discussed.
- ☑ Check the condition of the root ball before accepting tree delivery. The root system should be moist, with healthy fibrous roots. For bagged or potted trees, check for signs of root rot and root curling or winding, indicating trees are pot bound.
- ☑ Keep new trees well watered and the root ball moist until they can be planted. Wind and sun protection also helps if they cannot be planted immediately.
- ☒ It is illegal to transport citrus budwood and trees from Queensland to other states due to the danger of transmitting orange stem pitting strains of *citrus tristeza virus* (CTV).

Planting new trees: best practice tips:

- ☑ Plant trees to the same depth as they were grown in the nursery.
- ☑ When planting do not cover the bud union.
- ☑ Use trunk guards for protection against vertebrate pests and sunburn.
- ☑ Check tree guards (Figure 5) regularly for signs of ant activity. Ant activity can accumulate soil behind the tree guard which can lead to collar rot.
- ☑ Keep young trees well watered.
- ☑ Protect trees from wind using temporary or permanent windbreaks.
- ☑ Be careful using herbicides around young trees.
- ☑ Control weeds as they compete with newly planted trees for water and nutrients.

## Planting density

Trees are commonly planted at row spacings of between 5 and 7 m and tree spacings of between 3 and 5.5 m.

Closer tree spacings of 2 to 2.5 m are sometimes used to achieve early production. However every second tree may need to be removed after 4–5 years. With the cost of container grown trees and the impacts on tree growth and structure, many question the economics of this practice.

Double row plantings have been used in the past with trees commonly offset at 45°; however, this practice is now rare. A guide to the number of trees per hectare for various planting distances is outlined in Table 2.

Example: 10,000 sq m per ha ÷ 15 sq m per tree (for a 3 x 5 m spacing) = 666 trees per ha.

Table 2. Number of trees per hectare at various planting distances.

| Distance between trees in row (m) | Distance between rows (m) | | |
|---|---|---|---|
| | 5 | 6 | 7 |
| 2.0 | 1000 | 833 | 714 |
| 2.5 | 800 | 666 | 571 |
| 3.0 | 666 | 555 | 476 |
| 3.5 | 571 | 476 | 408 |
| 4.0 | 500 | 416 | 357 |
| 4.5 | 444 | 370 | 317 |
| 5.0 | 400 | 333 | 285 |
| 5.5 | 363 | 303 | 259 |

## Frost protection

It is preferable to choose a frost-free site, but if this is not possible then frost mitigation strategies need to be put in place to reduce the risk to trees and fruit (Figure 6). In frost prone areas early maturing varieties may be preferable. There are two main types of frost:

An **advection frost** occurs when a large body of cold air moves into an area replacing the warmer air present. The cold air flows towards the lowest point in the orchard, but cold air can also accumulate in other areas where its movement is impeded, such as against embankments or windbreaks.

**Radiation frosts** are more common and occur when there are clear skies, low humidity and little or no wind. Under these conditions the heat accumulated during the day by soil and plant surfaces is rapidly lost, allowing heavy cold air to accumulate near the ground and temperatures to drop. The temperature falls faster near the radiating soil surface, causing a temperature inversion layer to occur.

Whether the soil surface and surrounding air temperature reaches zero degrees depends on the:

- amount of heat stored in the top 30 cm of soil during the day
- amount of heat lost by radiation at night. The rate of heat loss is faster on a clear still night. Fog, clouds and wind tend to protect crops from radiation frost
- flow of heat from the deeper soil to the radiating topsoil or plant surface
- moisture content of the air – the higher the amount of moisture vapour (humidity) in the air the less chance of frost.

Figure 6. Frost damage to young shoots.

Figure 7. Formation of icicles on a citrus tree due to premature shutdown of overhead irrigation during a frost.

## Managing frost risk

### *Irrigation*

The use of water to control frost depends on a balance between heat gain and heat loss. Heat is given off when water freezes. Generally heat loss is greatest at the onset of irrigation. Heat is lost as the water evaporates but once humidity begins to increase in the orchard and the evaporation rate slows, heat is gained. It is critical that irrigation is started before critical temperatures (1 °C ) are reached so that there is enough heat in the orchard to allow for the heat losses due to evaporation.

- Overhead irrigation

Overhead irrigation systems can be used as a form of frost control. The sprinklers are turned on when temperatures drop to 1 °C and are left running until the risk of frost has passed. A frost alarm can also be installed to provide a warning system when temperatures drop to dangerous levels. Adequate protection in most cases can be achieved with a system application rate of 2.5–3.5 mm/h using sprinklers with a rotating speed greater than 1 rotation/minute (Nicholas 2004). Higher application rates may be needed in harsh conditions where very low temperatures and winds may occur. However, large volumes of water can result in excessive loads of ice on trees (Figure 7) and can lead to waterlogged soils.

- Under tree irrigation systems

Under tree sprinklers, minisprinklers and microjets can also be used to provide some protection against frost. As the irrigation takes place stored heat in the water is released. However, due to a complex relationship between temperature and humidity there can be an initial short term drop in temperature. If significant quantities of water evaporate instead of freezing (which can occur when there is some wind) heat will be lost and this may increase tree damage. Great care must be taken when using under tree irrigation systems for frost protection.

### *Frost fans*

Frost fans or wind machines are widely used for frost protection for various horticultural crops. They work by mixing the warmer air which is 10–15 metres above the soil surface with the colder air close to the ground. Approximately 4–6 hectares can be protected by one machine (Figure 8).

Best practice tips to minimise frost damage:

- ☑ Plant early maturing varieties in frost prone sites.
- ☑ Harvest fruit from frost prone sites early.
- ☑ Remove weeds and keep inter-row areas mown short.
- ☑ Keep the soil moist.
- ☑ Remove any impediments to cold air flow.
- ☑ Thin any windbreaks that could stop the flow of cold air.
- ☒ Do not cultivate the soil.
- ☒ Avoid planting trees in frost-prone sites.
- ☒ Do not encourage a late autumn flush prior to winter.

Figure 8. One frost fan can protect 4–6 hectares.

## Protective netting

The nursery and greenhouse horticulture industries have been using netting for many years to manipulate plant physiology and morphology by modifying environmental conditions such as temperature, humidity and light. However in tree crops, netting has mostly been used for physical protection against unfavourable weather conditions such as wind and hail, and from pests such as birds, bats and insects. More recently, with the availability of coloured netting, there has been renewed interest in their use in tree crops to manipulate plant development and growth as well as providing crop protection.

In Australia permanent orchard netting is commonly used in high value deciduous fruit crops, such as stone fruit and apples, to protect against damage from hail, birds and bats. The use of netting for citrus plantings is a more recent development and is used to reduce damage from hail or wind as well as improving external fruit quality and Class 1 pack-out levels. For mandarins it is also used in the production of seedless fruit by preventing cross-pollination with other citrus varieties by bees (for further information see the chapter on Crop management). Retractable mechanical netting is used in California for this purpose, with the nets placed over trees only during flowering (Figure 9).

Figure 9. Retractable nets are used to exclude bees from Afourer mandarins during flowering in California.

Permanent overhead netting is expensive to install and a full cost-benefit analysis should be undertaken to ensure it is economically feasible. Initially the cost of installing this type of netting can be in the range of $30,000 to $50,000/ha with ongoing costs for maintenance and net replacement every 7–10 years.

The installation and use of one type of temporary retractable netting is being trialled on an orchard near Mildura to prevent Afourer mandarins from being pollinated by bees and to improve external fruit quality (Figure 10). This type of netting lasts about ten years and currently costs between $11,000 and $14,000/ha. The netting is applied with a boom attachment (capital cost of approximately $13,000) that runs over the tree row. Soil is then shovelled on to the base of the nets in mounds every 2–3 m. A team of 5–7 people is required to install the netting: one to drive the tractor, two on either side of the tractor to help position the netting and a ground crew of three to ensure the netting is in place and weighted down with small piles of soil. Seven people can install 7–10 ha/ day. Net retrieval is slightly quicker (Citrus Australia 2014, Sampson 2014).

Figure 10. Retractable netting installed over Afourer mandarin trees on an orchard near Mildura, Victoria.

In Australia most research on the effects of netting on tree crops has been done for deciduous fruit crops. A seven year study by Middleton and Waters (2002) on the effects of hail netting in apple orchards at Stanthorpe (Qld), Orange (NSW) and Drouin (Victoria) showed that with netting:

- sunlight levels (photosynthetically active radiation or PAR) were reduced by 12–27% depending on net type, mesh size and colour
- humidity increased by up to 10–15%
- wind speeds were 50% lower
- there was a slight reduction in daytime temperatures of 1–3 °C on warm to hot days
- there was little effect on night time temperatures
- there was no frost protection.

Published research on the use and effects of netting in commercial citrus orchards is limited. One of the most recent studies on the use of nets has come out of Israel (Wachsmann et al. 2014). The trial assessed a series of 4 photoselective ColorNets (red, yellow, white and transparent) in a 2 ha block of commercial Orri mandarins on sour orange rootstock. Each experimental plot was 0.4 ha with a similar-sized un-netted (control) plot. The nets were a double-slope construction with a maximum height of 6 m and a minimum height of 4.5 m installed over 3 year old trees. Initial shading percentages of nets were: 25%, 24%, 18% and 13% for red, yellow, white and transparent, respectively. The study assessed the effects of the nets on the microclimate and the productivity and physiology of trees.

Results indicated:

- average monthly minimum temperatures during summer in the Northern Hemisphere (May to September) were similar under all nets, but 0.5 °C higher than the control. For monthly average maximum temperatures the maximum difference among all treatments including the control was 1 °C.
- average relative humidity from May to October was significantly lower in the control than under all nets.
- average wind speeds above the canopy were 70% lower and in the canopy were reduced by between 85–90% under the nets relative to the un-netted trees.
- stomatal conductance was lower under the red and yellow nets compared with all other treatments including the control.
- water consumption and transpiration rates were reduced in trees under the net. All nets, especially the white and transparent nets, significantly reduced water consumption by up to 20%.
- the average yield in control trees and those under the yellow net were significantly lower than in trees under the white, transparent and red nets. The highest yield in 4 of the 6 years of the experiment was from trees grown under the white and transparent nets. There were no consistent differences in fruit size.
- from the multi-year averages, control fruit had a lower TSS/TA ratio (as a result of increased acidity) than the fruit grown under the nets, which were all similar.
- water use efficiency (WUE) based on yield (kg/tree), was highest for trees under the white nets and lowest for those of the control.

Overall, trees grown underneath nets showed reduced water consumption, an increase in yield and enhanced WUE. The use of bright nets (white and transparent) has an advantage over dark nets (red and yellow) in that trees had less vegetative growth (requiring less pruning) and because of the smaller canopy volume, had lower stomatal conductance, lower water consumption and a higher WUE. However, specific cultivar-dependent effects should be assessed. Figure 11 is a diagrammatic representation of the overall effects of nets on a range of tree parameters, compared to the un-netted trees.

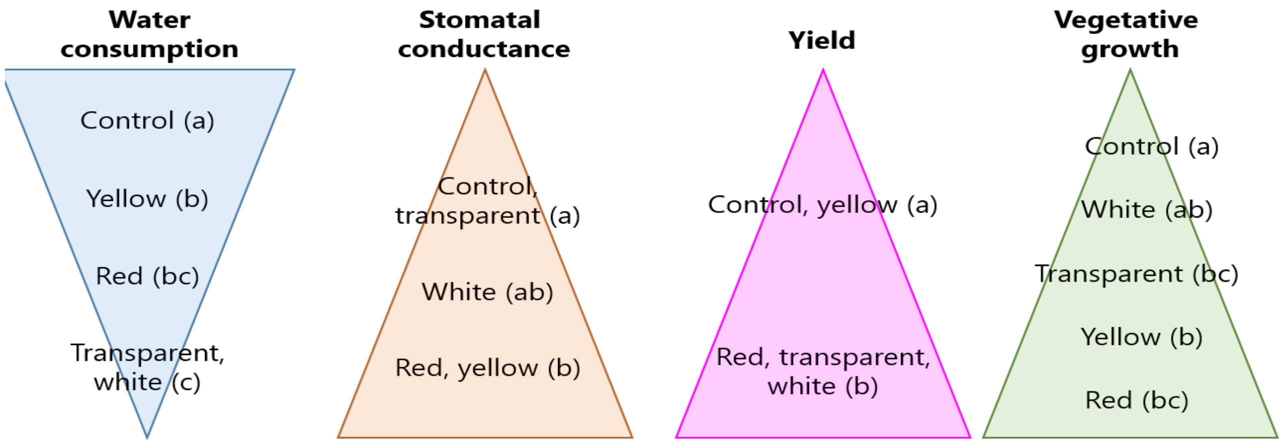


Figure 11. Summary of the overall effects on trees under nets, based on statistical analysis of data. Treatments followed by the same lower case letter (shown in parenthesis) are not significantly different. Nets that gave the best result for each parameter are listed across the bottom of the diagram. Adapted from: Wachsmann et al. 2014.

Other reported experiences using permanent overhead netting on citrus crops include:

- early results from a trial near Carnarvon (WA) using permanent windbreak netting over newly planted navel orange trees showed that 2 year old trees inside the net had statistically significant larger rootstock and scion circumferences, higher yield and higher numbers of Class 1 fruit than trees outside the net (Annells, Shackles & Lawson 2008).
- in a trial in Morocco using netting over 20 clones of Clementine mandarins, a 35% saving in water use was reported, but some varieties had not flowered well (Ashby 2002).

A trial of red and white netting is currently underway on a citrus orchard in the Murray Valley (Figure 12).

Figure 12. A citrus orchard in the Murray Valley trialling red and white netting.

### Netting for the prevention of cross-pollination

The production of seedless fruit in varieties that would naturally produce seeds (e.g. Afourer, Nules Clementine) if cross-pollinated with a compatible pollen source (e.g. Valencia orange or other fertile mandarin varieties) has become an important marketing strategy. For more information on seediness see the chapter on Crop management.

In citrus, cross pollination with other cultivars is mainly through bees (Moffett & Rodney 1971). The distance that pollen can be transported by bees was determined by Chao et al. (2005) in California using molecular markers. Pollen from Nules Clementine and Afourer mandarins reached 500 and 960 m, respectively. Gambetta et al. (2013) found in Uruguay that for Afourer mandarin under open pollination there was a low percentage of seedless fruit (7% and 34%), whereas it reached 98–99% under anti-bee nets.

In order to prevent cross-pollination of these self-incompatible varieties (e.g. Clementine mandarins, Afourer, Page) they have to be either grown physically isolated from other compatible varieties or protected with netting to exclude bees during flowering. Permanent exclusion netting or temporary retractable netting can be used.

## Wind protection

Wind damage is one of the most important causes of citrus fruit blemish. Wind can cause fruit scarring, reduced tree growth and yield, limb breakages and root damage in young trees.

Providing some form of permanent wind protection is essential in the production of good quality fruit. The majority (95%) of wind blemish to fruit occurs in the first 12 weeks after petal fall (Freeman 1973), after which the fruit become quite resistant to damage.

As soon as the petals fall and the small immature fruit are exposed, wind blemish to the rind can occur with any movement of leaves, branches, twigs and other fruit. Leaf margins from hard old leaves are the main cause of wind damage to fruit (Freeman 1973).

From the published literature some of the quantifiable benefits of using windbreaks for protecting orange trees include:

- improved Grade 1 packouts. Grade 1 packouts were 53–67% in protected blocks compared with 30–40% in unprotected blocks (Relevant 1987; Freeman 1976).
- improved yields due to increased fruit set and size. Yield increases between 13% and 16% were recorded (Freeman 1976).
- increased tree canopy growth of between 8% and 12% (Freeman 1976).

Windbreaks can be constructed using artificial materials such as netting or mesh (Figure 13) or by planting a living windbreak of suitable tree species (Figure 14). Short term windbreaks using grasses (e.g. Sudax or Jumbo sorghum), are sometimes used to protect young trees whilst the main windbreak is being established (Figure 15).

Ideally permanent windbreaks should be in place well before tree establishment. Windbreaks need to be well designed and maintained in order to do their job effectively. The main aim of a windbreak is to filter and break the force of prevailing winds but not stop air flow completely. Windbreaks should be placed at right angles to the prevailing winds to provide maximum protection. The height of a windbreak governs how much of the orchard is protected. The zone of most protection extends for a distance of six times the effective height of the windbreak (Figure 16):

Zone of protection = (windbreak height – crop height) x 6.

For example, the zone of maximum protection for a 14 m high windbreak protecting 4 m high citrus trees, will be 60 m on the ground. However, some protection is still provided for a distance of 10 times the effective height. Another critical factor is permeability, or how much wind is let through. Ideal permeability is between 45 and 55%. For more detailed information on windbreak design for citrus orchards see the NSW DPI Fact Sheet *'Windbreaks for citrus fact sheet'*.

Some varieties may also be adversely affected by living windbreaks. For example, in some subtropical areas it may be necessary to consider using artificial windbreaks because tall living windbreaks can cause shading and keep citrus foliage wet for too long. This applies when growing varieties that are susceptible to *Alternaria alternata* or brown spot. Mandarin varieties such as Murcott and Nova require good air movement for rapid drying (skirting, good air drainage and no shade). In this instance if rind blemish is to be reduced then artificial windbreak material should be considered.

Figure 13. A row of young trees protected with temporary shade cloth enclosures on the windward sides of the block.

Figure 14. Australian native, *Casuarina cunninghamiana* (River Oak), trees used as windbreaks for citrus at Dareton Primary Industries Institute, NSW.

Figure 15. Newly established trees with an inter-row planting of Sudax (right of photo) to protect trees while they are young.

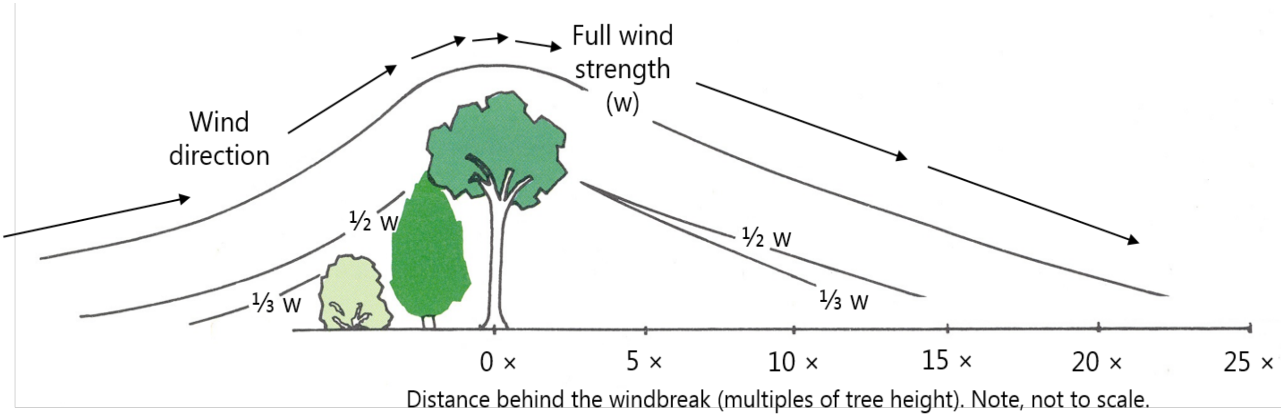


Figure 16. Conceptual presentation of the reduction in wind velocity provided by a windbreak . Source: Wakefield 1989. Line drawing by Shirley Turner.

## Weed management

Citrus trees have a relatively shallow fibrous root system so weed control is an important part of orchard management as weeds compete with trees for water and nutrients. Weeds can also be a host of some pests (e.g. mites and thrips) and can act as a pathway for some insect pests (such as Fuller's rose weevil) to enter tree canopies.

Citrus trees are planted in rows that should be kept weed free, with the inter-row area typically planted with a permanent sod of grass, clovers and medics. Some grasses (e.g. Rhodes grass) are a good pollen source for predatory mites during flowering, and in Queensland every second row is left un-slashed to encourage these natural predators. As trees age their canopies gradually shade the under tree area reducing weed growth in the tree row. Weeds are controlled using a combination of herbicides and/or mulching.

Mulches of straw, rice hulls or compost can be used to suppress weed growth, especially in young plantings. The depth of the mulch needs to be at least 100 mm and will need to be replenished as it breaks down. Additional nitrogen fertiliser is usually required to reduce the nitrogen 'drawdown' effect as the organic matter is broken down. Mulch material should be free draining. If the mulch holds too much moisture it may cause poor aeration and/or a build up of the fungal-like organisms that cause root and collar rots (e.g. *Phytophthora*). In Queensland mulch is also used to cover the leaf litter to prevent the ascospores of *Guignardia* (the fungus that causes black spot) from being shot into the canopy. Mulches should be kept well away from the tree trunk to avoid collar rot.

The addition of organic matter to the soil through the use of mulch has added benefits, such as improving the water and nutrient holding capacity of the soil, keeping the surface roots cooler, providing a food source for soil microorganisms and generally improving soil health.

Mulching will not control all weeds and the strategic use of knockdown herbicides may be required periodically.

Weed control in orchards is undertaken using a combination of knockdown and residual herbicides registered for use in citrus. Recently there has been a trend to move away from a dependence on residual herbicides due to concerns about their long term effects on tree and soil health.

Care should be taken when applying herbicides near or around young trees. Young trees (<3 years old) are especially sensitive to herbicide damage because young bark can absorb some herbicide sprays such as glyphosate.

For more information on registered herbicides for use in citrus orchards refer to the *APVMA PubCRIS* website.

## Orchard maintenance and redevelopment

The productive capacity of a block of mandarin trees is directly related to the canopy area and the percentage of that canopy area which is capable of intercepting sunlight and therefore setting a crop.

As trees grow their productive capacity increases up to a point (about year 10) where it stabilises for a few years then declines. This is largely due to increased shading in the canopy. Regular annual pruning programs introduced into citrus orchards in the past twenty years have extended the productive capacity of trees by continually renewing the fruit bearing wood and reducing shading in the canopy.

The removal and replacement of a block of trees is an expensive operation, both in terms of temporary loss of production as well as tree replacement costs. Orchardists need to plan their tree replacement program carefully. Ideally an orchard should have no more than 20% of trees in a non-bearing state. Most orchardists aim to replace around 5% of their trees annually. Tree replacement can be done by either replanting or reworking existing trees.

## Replanting

Citrus trees generally do not grow as well when planted on soils that have been growing citrus or grape vines for longer than 10 years, compared to trees grown on virgin soil.

It appears there are a combination of factors that contribute to this poor growth, including:

- high pest (e.g. citrus nematode) and pathogen (e.g. *Phytophthora*) loads which are detrimental to tree growth
- soil conditions such as salinity, compaction, unsuitable pH and nutrition
- toxins released from decaying citrus roots
- residual herbicides.

Before replanting into old citrus soil it is best to rest the block for at least 18 months. The old trees need to be removed and the soil deep ripped to remove any compacted layers and residual tree roots. Plant the block with green manure crops to improve soil health. Suitable green manure crops include legumes or biofumigant brassica crops, such as forage rape and Indian mustard, which can reduce populations of citrus nematode as long as good growth is achieved. Many legumes are capable of fixing between 100–200 kg nitrogen/hectare/year. However, decaying green manure crops can also increase levels of root rot fungi, so allow sufficient time for the manures to thoroughly decompose. Chemical fumigation can also be used, but given the cost, it is only warranted if there is a very high nematode population.

Rootstock choice is especially important when replanting. As with any citrus planting, rootstock choice should be matched to soil conditions. Some rootstocks such as rough lemon, Cleopatra mandarin and sweet orange are very susceptible to Phytophthora root and collar rots and citrus nematode. Ideally they should not be used in replant sites. For more information see the chapter on Rootstocks.

## Reworking or topworking trees

An alternative to planting new trees is to rework healthy existing citrus trees over to current or new mandarin varieties. The new scion should make good growth because of the well established root system and produce good yields of fruit in 3–5 years.

Reworking trees can be an expensive option if a professional contractor needs to be engaged. Reworking should only be carried out on healthy productive trees using 'high health status', good quality budwood sourced from Auscitrus.

If you are reworking into the existing scion, the new scion must be compatible with the existing scion (which will end up being the inter-stock). However, the existing rootstock will still influence the growth, yield and fruit quality characteristics of the new scion.

Australian research has shown that reworking most navel and Valencia oranges over to a range of mandarin varieties has been mostly successful. However, compatibility is not known for all variety combinations. In trials done in the 1960s (Cox 1967), some mandarins, namely Satsuma, Kara, Emperor and Hickson, grew more slowly in the first year but produced more rapid growth later. A summary of the health risks in reworking some known rootstock-scion combinations is set out in Table 3.

Hickson mandarins should not be reworked to other varieties, because the stress of topworking often exacerbates crotch rot to which this mandarin is very susceptible.

Grapefruit and lemon scions should not be reworked over to mandarins because the results can be unpredictable due to the presence of the *citrus tristeza virus* (CTV) in either the original scion or the new variety to be topworked. CTV exists as mild and severe strains in nearly every citrus tree and the strains form a complex which differs for every citrus variety. The CTV complex in either the original scion or the new variety to be topworked may interact to produce potentially disastrous results. For more information on CTV see the chapter on Diseases.

Some of these problems can be overcome by grafting (crown method) directly into the rootstock after the scion has been completely removed. *Citrus trifoliata* and the citranges are resistant to most Australian strains of CTV.

There are various methods used to rework trees. Trees are most commonly reworked into the existing scion. Techniques for reworking older trees include budding into regrowth shoots, limb grafting and crown grafting or, for young trees (<5 years old), budding directly into the limbs.

Table 3. Summary of the health risks in reworking mandarins onto existing scions.

| Tree to be topworked | | Grafting wood |
|---|---|---|
| Rootstock | Scion | Mandarin |
| *Citrus trifoliata*, Citrange | Valencia or navel | S[1] |
| Rough lemon, Sweet orange | Valencia or navel | S |
| *Citrus trifoliata*, Citrange | mandarin | S[1] |
| Rough lemon, Sweet orange | mandarin | S |

S = Satisfactory, S[1] = Satisfactory if grafting wood is free of exocortis or tatter leaf virus.

The method used to rework trees in variety evaluation blocks at the NSW DPI Research Station at Dareton is limb grafting. For more detailed information refer to Bass (1993) or the NSW DPI Primefact 756 *'Reworking citrus trees'*.

All pruning and grafting equipment should be sterilised with at least a 1% sodium hypochlorite (NaOCl) solution. For household bleach (5.25% NaOCl), mix 1 part with 4.25 parts water and for commercial products (12.5% NaOCl) mix 1 part with 11.5 parts water.

Dilution rate = (% NaOCl of bleach product ÷ by % NaOCl of solution required) – 1 = parts of water required. For example: (12.5 ÷ 1) – 1 = 11.5 parts water. So, 100 mls of bleach (12.5% NaOCl) should be mixed with 1150 mls of water to make a 1% solution.
NB. Chlorine products are corrosive to metals.

### *Budding into regrowth shoots*

The tree is cut back in late winter/early spring to a height of 1–1.2 m leaving 3–5 scaffold limbs. Two strong shoots are selected from the spring regrowth on each limb and any remaining shoots are removed. The shoots should be staked to prevent breakage. In summer-early autumn a bud of the new scion is inserted into the base of each shoot using a shield bud. The bud is completely covered with budding tape, which is removed 4–6 weeks later when the bud has taken. The new scion shoots need to be topped later to encourage branching. Suckers below the bud sites need to be removed.

### *Crown grafting*

This is the most difficult method for achieving good results. The top of the tree is cut off through the trunk below the scaffold branches. The scion needs to be completely removed if you need to rework straight into the rootstock. Three to five grafting sticks of the new scion are inserted under the bark around the perimeter of the trunk following the same method used for limb grafting.

### *Limb budding*

Young trees (<5 years old) can be reworked without the need for severe pruning. Budding can be done in spring or late summer/early autumn. Select 3–5 scaffold branches (<40 mm in diameter) and remove the growth above the budding site immediately prior to budding. Follow the method used for budding into regrowth shoots.

### *Limb grafting*

This is the most common method used for reworking trees. Trees to be reworked are pruned back to their main scaffold branches in late winter or early spring, leaving 1–2 limbs as nurse branches (Figure 17). One year old budsticks are grafted into the scaffold branches (Figure 18) in early to late spring when the bark is easily lifted.

Figure 17. Limb grafting: trees to be reworked are cut back leaving 1–2 nurse limbs.

Figure 18. Limb grafting: when the bark can lift easily, sticks of the new scion are inserted into the stump of each scaffold branch.

### *Patch budding*

Patch or top budding is commonly used in Spain to change mandarin trees over to a new variety. A patch of bark (30 mm x 40 mm) containing at least one bud from the new scion is grafted onto selected scaffold branches in November/December (Southern Hemisphere) when the cambium is actively growing.

A rectangular patch of bark with the longer sides parallel to the axis of the top-side of the scaffold branch is removed and the new scion patch inserted so that it fits snuggly up against all four sides of the existing cambium (Figure 19). The patch is best cut from both the branch and budstick by two parallel cuts using a double-bladed knife to provide an exact fit.

The patch is held in place with tape wound around the whole branch. After the bud takes, the tape is removed and the branches of the old scion above the new bud are gradually cut back.

Patch budding is more commonly used on smaller, younger trees. One problem with patch budding older, larger branches is that the bark of the existing tree is much thicker than the bark of the new scion, making it more difficult to get good contact between the cambium layers. It can also be difficult to get enough new scion material to make the patch.

Figure 19. Patch budding trees is commonly used in Spain to rework young mandarin trees over to a new variety.

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# Climate and phenology

## Climate

Citrus is grown commercially from 40°north (viz. Corsica and Japan) to almost 40°south (viz. New Zealand); across a broad range of climates ranging from equatorial hot, humid climates through to warm tropical and even cooler maritime climates. The main commercial citrus growing regions are located in the 20–40° latitude belt in each hemisphere.

Most commercial citrus types, including mandarins, are thought to have originated in the humid subtropical climates of China, the Sub-Himalayan tract and Western Malesia (Mabberley 1997). Citrus trees generally have flat broad evergreen leaves, thin succulent bark and a moderately shallow and spreading root system; characteristics not well suited to withstanding temperature extremes or drought. Most major commercial varieties have been selected for their suitability to grow in cooler subtropical or temperate climates.

It is mainly low temperatures that restrict the geographic distribution of commercial citrus production. Temperature presents major limitations for vegetative growth as well as for fruit development and maturation. Frost and freezing temperatures can damage fruit, 'burn' foliage and kill mature trees. Very little growth occurs on citrus trees at temperatures below 13 °C.

Climate has a major influence on tree and fruit growth and fruit quality. Mandarins have the widest diversity in their adaptability to climate, with some cultivars having very narrow climatic requirements, and others a very broad tolerance to climatic conditions. For example, good quality Clementine mandarins are produced in many climatically different regions around the world, but the best quality Satsuma mandarins are only produced in cooler regions such as Japan.

The local microclimate can be as significant to profitability as the regional climate. For example, an orchard may be located in a mandarin growing region with an ideal climate for tree survival and maximum yield of high quality fruit. Yet, if a particular site is more exposed to prevailing winds than other sites, windy conditions may lead to significant wind scarring of the fruit, making it unacceptable for the fresh market because of its poor appearance (Castle & Gmitter 1999). Fruit susceptibility to some physiological disorders such as splitting can also be dependent on local climatic conditions.

Mandarins are the most heat resistant citrus type, and good flavour seems to be enhanced by a period of relatively hot weather during the latter part of the growing season. Mandarin varieties also have a broad range of total heat requirements and hence maturity times. Other climatic factors such as day/night temperature fluctuations, rainfall, wind and humidity also have an impact on tree and fruit growth, fruit size, external and internal fruit quality, colour and shape. However, temperature is the most important factor; affecting all the market sensitive fruit characteristics including size and shape as well as acid and sugar content and ratio, rind thickness and colour.

Mandarin fruit size and shape are markedly influenced by heat and atmospheric humidity. Low humidity causes the axis to lengthen and fruit to become rounder and less oblate (flat). Under humid subtropical conditions mandarins tend to be larger, mature earlier and have a more obovate (elongated) shape. Under cooler humid conditions fruit tend to be smaller with a flatter shape and usually have no necks [e.g. Dancy, Kara and Satsuma mandarins] (Reuther 1973). It is the cool temperatures in the pre-harvest maturation period (growth Stage III) that produces the flatter Satsuma mandarins (Kurihara 1969).

Under humid subtropical conditions rind texture is smoother, but peel quality can be compromised by higher pest and disease pressures. Internal and external fruit colour are better in areas with cool to cold overnight temperatures prior to harvest. In cooler climates fruit mature later, acid levels are higher, peel colour is excellent, but fruit can have coarser rinds.

Internal quality is also affected by climate; cooler, subtropical areas are preferable for the production of oranges and mandarins for the fresh fruit market (Goldschmidt 1997). Fruit developing in hot tropical climates tend to be juicier and have high total soluble solids (TSS) content relative to acid content, which is an advantage for the processing industry. Fruit developing in warm climates reach marketable sugar:acid ratios sooner than cooler locations, but these fruit are also low in acid resulting in poor eating quality, especially low-acid cultivars. Ease of peeling, core openness and flesh texture are all influenced by temperature and humidity, and interact strongly with seasonal conditions.

Tropical climates also affect the general behaviour of trees. Vegetative leaf flushes are not dependent on the cycles of cold and warm temperatures, but are governed instead by wet and dry periods. Rind colour is a major problem in the tropics as warm temperatures interfere with the loss of chlorophyll and the synthesis of carotenoids. In general, citrus fruit in the tropics remain greenish and pale; oranges and mandarins, in particular, do not attain an attractive rind colour. The combination of high temperature and high humidity result in tender fruit that senesce rapidly, are highly susceptible to peel blemishes and have short postharvest storage potential. Mandarin and tangelo varieties suitable for the tropics include Fremont, King, Temple, Emperor, Orlando and San Jacinto.

Satsuma mandarin is the most cold tolerant type of commercial citrus and has a low total heat requirement. They are not commercially acceptable when grown in the warmer production areas of the subtropics and are restricted to the upper and colder portions of subtropical zones. The Satsuma producing regions of Japan are the most favourable for producing fruit of excellent quality. Satsuma fruit growth is superior at temperatures between 20 °C and 25 °C, particularly during Stage I of fruit growth (Kurihara 1973, Marsh et al. 1999). Cool night time temperatures two months prior to harvest promote more rapid breakdown of chlorophyll.

Some mandarin selections (e.g. Avana, Fremont, Kinnow and Thorny) have a high heat requirement and are grown in the hot dry environments around the Mediterranean and in the Middle East. Clementine mandarin cultivars have a low total heat requirement for fruit maturity. In areas of high total heat, Clementines mature early – only slightly later than Satsuma mandarins. Such regions (e.g. the Mediterranean Basin and Morocco) favour the production of good sized Clementine fruit with excellent eating quality.

Mandarin selections grown around Australia are listed in Table 4. The main mandarin types grown around the world are summarised in Table 5.

## Australian mandarin growing regions

The key Australian mandarin growing regions in order of importance are the Central Burnett in Queensland, the Riverland and Murray Valley in southern Australia, Western Australia and the Riverina region in NSW (Figure 20). There are approximately 5,450 hectares planted to mandarins and production is currently between 110 kT and 130 kT (20% of total citrus production). Queensland leads mandarin production with about 53%, followed by South Australia (23%), the Murray Valley (20%), the Riverina and other parts of NSW (3%) and Western Australia (3%) (Citrus Australia Limited 2016).

Many of the major citrus growing regions around the world have what is termed a "Mediterranean" climate. A typical Mediterranean climate is characterized by warm to hot, dry summers and cool to cold, wet winters, as seen in some regions of countries bordering the Mediterranean Basin; namely, parts of Spain, Italy, Greece, Turkey, Morocco, Algeria, and Tunisia.


Figure 20. Major and minor citrus growing regions in Australia. Source: Citrus Australia, www.oranges.com.au.

Table 4. Main mandarin varieties grown in Australia.

| Region | Dominant varieties | Other varieties grown (in order of number of trees) |
|---|---|---|
| Riverina (NSW) | Imperial, Afourer[1], Dekopon[2] | Satsuma Okitsu Wase, Summerina, Honey Murcott, Amigo, Ellendale, Daisy |
| Murray Valley (SW NSW and NW Victoria) | Afourer, Imperial | Daisy, Amigo, Dekopon, Ellendale, Murcott, Gold Nugget, Orri, Caffin Clementine, Satsumas Miho Wase and Okitsu Wase, Mystique[3], Avana, Fallglo, Fewtrell, Emperor |
| Riverland (SA) | Afourer, Imperial | Nules Clementine, Honey Murcott, Daisy, Satsuma Okitsu Wase, Gold Nugget, Dekopon, Avana, Amigo, Murcott, Summerina, Satsuma Miho Wase, Ellendale, Topaz Ortanique, Murcott (Low seeded), Orri, Nectar, Hickson |
| QLD | Imperial, Murcott, IrM1, IrM2[4] | Afourer, Avana, Goldup, Hickson, Taylor Lee, Nectar, Daisy, Fremont, Nova, Empress, Sunburst, TDE, Success, Gold Nugget, Alkantara, Monarch, Orri, Ellendale, Emperor |
| WA | Afourer, Imperial | Hickson, Nules Clementine, Mystique[3], Daisy, Gold Nugget, Nectar, Satsumas Silverhill and Okitsu Wase, Murcott, Caffin Clementine, Kara, Emperor, Honey Murcott, Ellendale, Ortanique |

[1]W. Murcott
[2]Also known as Sumo Citrus™ or Hallabong (Korea) and Shiranui (Japan)
[3]A seeding selection of Ortanique originating in WA
[4]Low-seeded Murcott selections developed by Qld DPI
Source: Citrus Australia Limited (CAL), pers. comm., January 2016.

Table 5. Main mandarin varieties grown in other citrus producing countries.

| Country | Major mandarin varieties grown |
|---|---|
| South Africa[1] | Clementines: Nules, Marisol, SRA, Oroval, Esbal, Clemenpons, Oronules, Nadorcott (Afourer), Nova, Or (Orri), Minneola, Mor, B17, Tambor, Naartjie, Thoro Temple, Sonet, B24 (African Sunset). Satsumas: Miho Wase, Owari, Kuno, Miyagawa Wase, Okitsu Wase, Aoshima |
| Japan | Satsumas: Miyagawa Wase, Nakate Unshui, Okitsu, Miyamoto, Yamakawa, Tokimori, Aoshima Iyokan, Dekopon (sold under the name Sumo Citrus™ in the United States and Australia), Ehime Mikan, Harehime, Ponkan, Setoka, Haruka, Kiyomi, Kara, Beni Madonna, Kanpei |
| China | Ponkan, Satsumas |
| India[2] | Kinnow, Sangtra, Coorg, Nagpur, Khasi |
| Pakistan | Kinnow |
| Italy | Clementines: Comune or Oroval and Montreal, SRA 63, Fedele IAM-UBA, Fedele IAM-UBA, Spinoso VCR, Hernandina VCR, Ruby VCR, Avana Tardivo di Ciaculli, Fortune, Tacle, Clara, Satsuma Miyagawa |
| Spain | Nova, Fortune<br>Clementines: Clemenules or Nules, Fina, Oroval, Marisol, Oronules, Clemenpons, Esbal, Loretina and Hernandina<br>Satsumas: Clausellina, Okitsu and Owari |
| California[3] | Clementines: Algerian, Caffin, Clemenules (Nules), Fina Sodea, Oro Grande, Gold Nugget, Fairchild, Pixie, Shasta Gold, Tango (Seedless W. Murcott); W. Murcott (Afourer); Minneola tangelo; Tangor/Temples: Royal Mandarin |
| Chile | Clementines, Afourer, Clemengold |
| Argentina[4] | Clementina, Clemenvilla, Ellendale, Malvasio, Montenegrina, Clemenules, Murcott, Ortanique, Tango |
| Uruguay[5] | Satsuma mandarins: Okitsu and Owari.<br>Clementines: Marisol, Fina and Nules<br>Clemenvilla, Murcott, Afourer, Ortanique, Salteñitas |
| Peru[6] | Minneola tangelo, Satsumas, Afourer, Clementines |

Sources: [1]http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Citrus%20Annual_Pretoria_South%20Africa%20-%20Republic%20of_12-15-2014.pdf
[2]Pujari, S 2015
[3]http://calcitrusquality.org/wp-content/uploads/2014-Citrus-Acreage-Rpt.pdf
[4]http://www.chilealimentos.com/2013/phocadownload/Alimentos_Procesados/citrus%20semi-annual_buenos%20aires_argentina_6-13-2014.pdf and Balbi, 2014
[5]http://www.freshplaza.com/news_detail.asp?id=95647#SlideFrame_1
[6]http://www.freshplaza.com/news_detail.asp?id=107918#SlideFrame_1.

Other citrus growing areas with this type of climate include parts of California, Chile and the south western corner of South Africa. Australian regions with a true Mediterranean climate include the south western corner of Western Australia and the south eastern corner of South Australia.

The Riverland and Murray Valley growing areas have a warm dry climate, with high evaporation rates and low average annual rainfall (250–300 mm), which is fairly evenly distributed throughout the year. Average monthly maximum temperatures in the Riverland are slightly higher than in the Murray Valley and average minimum temperatures slightly lower. Fruit grown in these two areas usually have superior peel quality (colour and texture), mature later and usually have higher acid levels than those grown in the warmer parts of Queensland and northern Australia. Satsuma and Clementine mandarins do well in these regions.

The Riverina region in southern NSW is characterised by hot summers and cool winters. Annual average rainfall (around 400 mm) is higher than that of the Riverland and Murray Valley regions and is also fairly evenly distributed throughout the year. Average monthly maximum temperatures are similar to the Murray Valley, but average minimum monthly temperatures are slightly lower during winter and early spring. This region has a larger diurnal range in daily temperatures, particularly during spring and summer, with day and night time temperature differences of 14–16 °C. The Riverina region has a more humid climate than the Murray Valley and Riverland regions, with more frequent fog and heavier dew. The cooler conditions close to harvest mean that fruit develop good peel colour.

There are extensive citrus plantings in the more humid subtropical regions of south eastern Queensland around the Central Burnett towns of Gayndah and Mundubbera. The climate is characterised by warm to hot, wet and humid summers and mild to cool dry winters. Average annual rainfall is around 750 mm with the highest falls between December and March. This region also has a diurnal temperature range of 13 °C to 17 °C between late autumn and early spring. Fruits from these subtropical regions mature early and usually have good sugar and low acid levels. Higher rainfall and humidity make the effective management of pests and fungal diseases critical to ensuring good external peel quality. Peel colour is generally good, particularly for late varieties that mature during the cooler winter months.

The citrus growing region centred near Emerald also has a humid subtropical climate similar to that of Central Burnett. However, daytime temperatures in Emerald tend to be warmer especially during spring and summer, and night temperatures throughout the year are also slightly warmer. Emerald is somewhat drier with an average annual rainfall of around 560 mm falling mostly in late spring and summer.

In Western Australia, mandarins are mostly grown in the south-west corner in an arc from Gingin in the north to Bunbury in the south. The south-west corner of WA has a typical Mediterranean climate with warm summers and cool wet winters. Annual rainfall is between 650 and 750 mm, falling predominantly in winter. The northern growing region around Carnarvon (mostly grapefruit) has a semi-arid climate with hot dry summers, and occasional tropical cyclones bring heavy rain and strong winds. Annual average rainfall is around 220 mm, falling predominantly during winter.

Smaller citrus plantings are also located in the more temperate coastal regions of northern and central NSW. These areas are characterised by warm summers and mild winters with good rainfall. However higher pest and disease pressures can often reduce external rind quality. Fruit grown in these areas have good flavour and mature slightly later than in the warmer subtropical regions of Queensland. There are also smaller citrus plantings of mostly oranges in the drier inland areas of central and northern NSW; namely around Forbes, Narromine, Gunnedah and Moree. These regions tend to have hot dry summers and cold winters.

Small plantings of citrus (mostly lemons and limes) have also been established in the hot, wet, humid tropical regions of northern Queensland (Mareeba), the Northern Territory (Darwin and Katherine) and Western Australia (Kununurra). The climate in these areas is characterised by high average temperatures and distinct wet and dry seasons.

long term climatic averages for some of the main citrus growing areas in Australia including maximum (Table 6) and minimum temperatures (Table 7), monthly diurnal temperature ranges (Table 8) and average monthly rainfall (Table 9) are useful when describing the general climatic conditions of a region and making comparisons between areas.

## Effective heat units

Citrus vegetative and fruit growth are dependent on the amount of heat received, and each variety has an optimum temperature range, if no other factors (such as water) are limiting. The optimum temperature range for growth is generally considered to be between 13 °C and 35 °C for citrus. The cumulative hours of heat within this range are referred to as growing degree days (GDD) or effective heat units, or, more simply heat units. Heat units can be used to assess the suitability of an area for growing citrus. More specifically, heat units can be used for estimating the length of the phenological (growth) cycle and for predicting fruit maturity times. When assessing an area for growing citrus it is also equally important to know the incidence of very cold temperatures (< −2 °C) and frosts.

There are several methods used to calculate heat units. The common method used is relatively straight forward. The heat accumulated each day is determined by adding together the maximum and minimum temperatures and dividing the total by two to obtain a daily average. The crop-specific threshold temperature (13 °C for citrus) is then subtracted from this average. The final value then represents the daily heat units useful for crop growth:

Daily heat units = [(max °C + min °C) ÷ 2] − 13

The heat units for each day are then added to determine the accumulated weekly, monthly or yearly heat units. Yearly heat units are sometimes referred to as 'GDD 365'. When calculating daily heat units all results below zero (negative results) are not used. Additionally all maximum temperatures above 35 °C (≥ 35·1) are changed to 35. This information can also be used to generate maps of heat unit distribution across the country (Figure 21).

In the late 1990s the NSW Department of Primary Industries (DPI) was funded through Horticulture Australia Limited to undertake Project CT 98016 '*Heat unit mapping as an aid to selection and evaluation of citrus cultivars*'. As part of that project, long term (1890-1980) average temperature (minimum and maximum) data from the Australian Bureau of Meteorology were used to calculate cumulative heat units or GDD 365 for Australia (Table 10).

Heat units can also be used to highlight the differences between different growing regions in Australia. High heat unit accumulation results in faster growth and earlier maturity, whereas low heat unit accumulation delays growth and maturity. This is evident in Table 11 for Imperial mandarin maturity times in various regions in Australia.

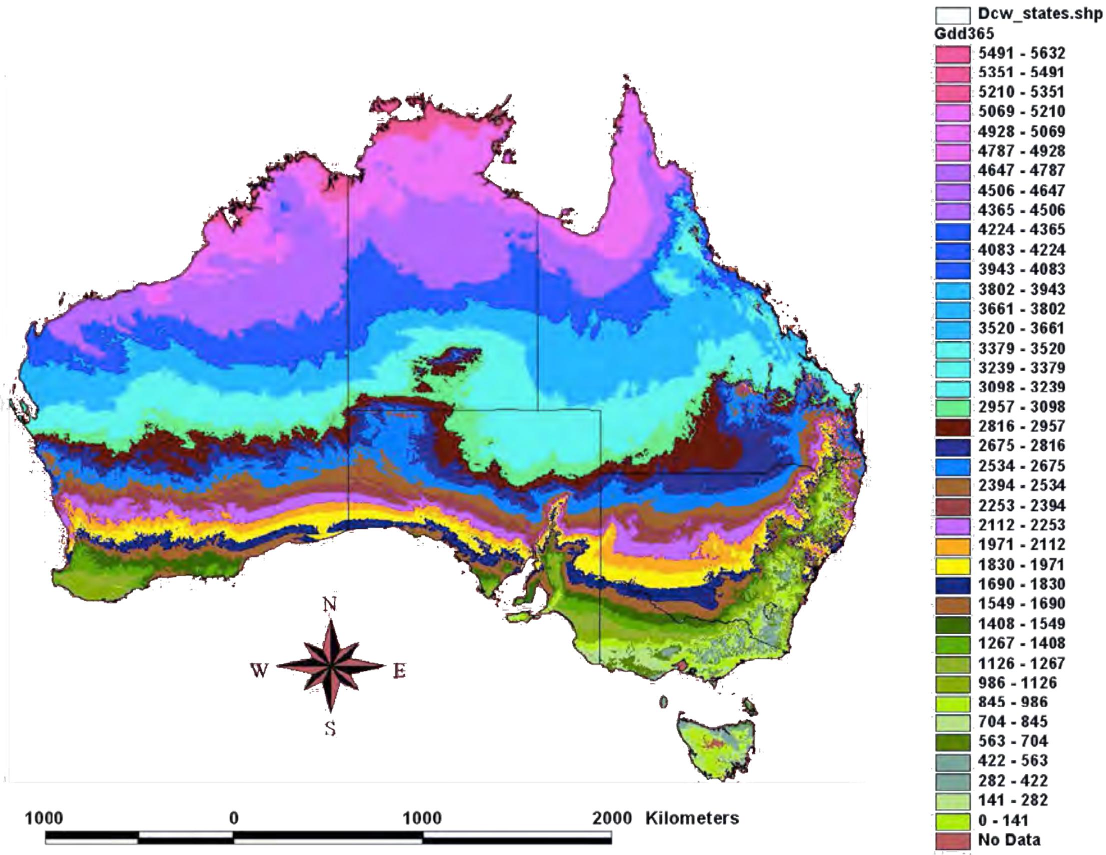


Figure 21. Map depicting distribution of heat unit ranges across Australia.

Climate and phenology

Table 6. Long term average monthly maximum temperatures for some of the main Australian citrus growing regions.

| Location | Latitude | Longitude | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Darwin NT | −12.37 | 130.80 | 31.8 | 31.4 | 31.9 | 32.7 | 32.0 | 30.6 | 30.6 | 31.4 | 32.6 | 33.3 | 33.3 | 32.6 |
| Katherine NT | −14.45 | 132.29 | 34.9 | 34.3 | 34.5 | 34.0 | 32.1 | 29.9 | 30.1 | 32.5 | 35.4 | 37.7 | 38.0 | 36.5 |
| Emerald QLD | −23.50 | 148.15 | 34.4 | 33.3 | 32.6 | 29.8 | 26.2 | 23.2 | 23.2 | 25.3 | 29.0 | 31.7 | 33.3 | 34.2 |
| Carnarvon WA | −24.85 | 113.63 | 31.3 | 32.5 | 31.6 | 29.1 | 26.2 | 23.4 | 22.3 | 23.1 | 24.4 | 26.0 | 27.6 | 29.3 |
| Gayndah QLD | −25.61 | 151.61 | 32.8 | 32.0 | 30.9 | 28.6 | 25.2 | 22.4 | 21.9 | 23.8 | 26.9 | 29.5 | 31.6 | 32.8 |
| Gingin WA | −31.35 | 115.92 | 33.5 | 33.3 | 30.6 | 26.4 | 22.0 | 18.9 | 17.8 | 18.4 | 20.0 | 23.4 | 27.2 | 30.3 |
| Bunbury WA | −33.33 | 115.64 | 29.7 | 30.1 | 27.8 | 24.3 | 21.1 | 18.4 | 17.3 | 17.7 | 18.5 | 21.0 | 24.4 | 27.3 |
| Gosford NSW | −33.43 | 151.34 | 27.0 | 26.3 | 24.6 | 21.7 | 18.5 | 15.8 | 15.3 | 17.3 | 20.5 | 22.7 | 24.3 | 26.0 |
| Renmark SA | −34.17 | 140.72 | 33.6 | 32.6 | 28.8 | 24.5 | 20.1 | 16.8 | 16.3 | 18.7 | 22.2 | 25.2 | 29.0 | 31.0 |
| Mildura VIC | −34.20 | 142.16 | 32.3 | 31.7 | 28.3 | 23.6 | 19.1 | 16.0 | 15.4 | 17.3 | 20.6 | 24.1 | 27.6 | 30.2 |
| Griffith NSW | −34.28 | 146.02 | 33.0 | 32.1 | 28.6 | 23.9 | 19.2 | 15.5 | 14.5 | 16.6 | 20.0 | 24.0 | 28.1 | 30.8 |

Source: Commonwealth of Australia, Bureau of Meteorology (www.bom.gov.au).

Table 7. Long term average monthly minimum temperatures for some of the main Australian citrus growing regions.

| Location | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Darwin NT | 24.8 | 24.7 | 24.5 | 24.0 | 22.1 | 19.9 | 19.3 | 20.3 | 23.0 | 24.9 | 25.3 | 25.3 |
| Katherine NT | 23.9 | 23.7 | 22.9 | 20.4 | 17.1 | 14.0 | 13.2 | 15.5 | 19.6 | 23.6 | 24.7 | 24.4 |
| Emerald QLD | 22.2 | 21.9 | 20.2 | 16.9 | 12.9 | 10.1 | 8.9 | 9.9 | 13.5 | 17.0 | 19.5 | 21.3 |
| Carnarvon WA | 22.5 | 23.4 | 22.1 | 19.1 | 14.9 | 12.3 | 10.9 | 11.6 | 13.9 | 16.4 | 18.6 | 20.7 |
| Gayndah QLD | 20.1 | 19.9 | 18.1 | 14.3 | 10.3 | 7.5 | 5.9 | 6.8 | 10.2 | 14.1 | 17.0 | 19.1 |
| Gingin WA | 17.0 | 17.6 | 16.0 | 13.4 | 10.8 | 9.4 | 8.4 | 8.2 | 8.8 | 10.1 | 12.5 | 14.5 |
| Bunbury WA | 15.4 | 15.9 | 14.1 | 11.8 | 9.5 | 8.0 | 7.0 | 7.6 | 8.6 | 9.4 | 12.2 | 13.6 |
| Gosford NSW | 16.8 | 16.8 | 15.1 | 12.0 | 9.1 | 7.3 | 6.0 | 6.7 | 9.3 | 11.4 | 13.7 | 15.3 |
| Renmark SA | 16.3 | 16.2 | 12.8 | 8.9 | 6.6 | 4.6 | 3.8 | 4.4 | 6.8 | 8.8 | 12.4 | 14.1 |
| Mildura VIC | 16.7 | 16.5 | 13.8 | 10.1 | 7.4 | 5.2 | 4.3 | 5.2 | 7.4 | 9.8 | 12.5 | 14.8 |
| Griffith NSW | 17.0 | 17.4 | 14.2 | 10.1 | 7.2 | 4.5 | 3.5 | 3.8 | 5.9 | 9.0 | 12.7 | 15.1 |

Source: Commonwealth of Australia, Bureau of Meteorology (www.bom.gov.au).

Table 8. Long term average monthly diurnal temperature range for some of the main Australian citrus growing regions.

| Location | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Darwin NT | 7.4 | 6.7 | 7.4 | 8.7 | 9.9 | 10.7 | 11.3 | 11.1 | 9.6 | 8.4 | 8.0 | 7.3 |
| Katherine NT | 11.0 | 10.6 | 11.6 | 13.6 | 15.0 | 15.9 | 17.0 | 17.0 | 15.8 | 14.1 | 13.3 | 12.1 |
| Emerald QLD | 12.2 | 11.4 | 12.4 | 12.9 | 13.3 | 13.1 | 14.3 | 15.4 | 15.5 | 14.7 | 13.8 | 12.9 |
| Carnarvon WA | 8.8 | 9.1 | 9.5 | 10.0 | 11.3 | 11.1 | 11.4 | 11.5 | 10.5 | 9.6 | 9.0 | 8.6 |
| Gayndah QLD | 12.7 | 12.1 | 12.8 | 14.3 | 14.9 | 14.9 | 16.0 | 17.0 | 16.7 | 15.4 | 14.6 | 13.7 |
| Gingin WA | 16.5 | 15.7 | 14.6 | 13 | 11.2 | 9.5 | 9.4 | 10.2 | 11.2 | 13.3 | 14.7 | 15.8 |
| Bunbury WA | 14.3 | 14.2 | 13.7 | 12.5 | 11.6 | 10.4 | 10.3 | 10.1 | 9.9 | 11.6 | 12.2 | 13.7 |
| Gosford NSW | 10.2 | 9.5 | 9.5 | 9.7 | 9.4 | 8.5 | 9.3 | 10.6 | 11.2 | 11.3 | 10.6 | 10.7 |
| Renmark SA | 17.3 | 16.4 | 16.0 | 15.6 | 13.5 | 12.2 | 12.5 | 14.3 | 15.4 | 16.4 | 16.6 | 16.9 |
| Mildura VIC | 15.6 | 15.1 | 14.5 | 13.5 | 11.7 | 10.8 | 11.1 | 12.1 | 13.1 | 14.2 | 15.1 | 15.4 |
| Griffith NSW | 16.0 | 14.7 | 14.4 | 13.8 | 12.0 | 11.0 | 11.0 | 12.8 | 14.1 | 15.0 | 15.4 | 15.7 |

Source: Commonwealth of Australia, Bureau of Meteorology (www.bom.gov.au).

Table 9. Long term average monthly rainfall for some of the main Australian citrus growing regions.

| Location | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Darwin NT | 427 | 375 | 319 | 102 | 21 | 2 | 1 | 5 | 15 | 70 | 142 | 249 | 1728 |
| Katherine NT | 235 | 217 | 161 | 33 | 5 | 2 | 1 | 1 | 6 | 28 | 88 | 200 | 977 |
| Emerald QLD | 88 | 81 | 57 | 34 | 21 | 29 | 14 | 22 | 30 | 38 | 57 | 90 | 561 |
| Carnarvon WA | 12 | 20 | 16 | 14 | 35 | 47 | 44 | 18 | 6 | 5 | 4 | 6 | 226 |
| Gayndah QLD | 113 | 106 | 73 | 38 | 41 | 40 | 38 | 29 | 35 | 66 | 80 | 104 | 762 |
| Gingin WA | 9 | 12 | 15 | 35 | 85 | 132 | 134 | 104 | 70 | 36 | 23 | 11 | 666 |
| Bunbury WA | 11 | 6 | 15 | 34 | 102 | 137 | 142 | 118 | 87 | 31 | 26 | 20 | 729 |
| Gosford NSW | 109 | 151 | 125 | 85 | 88 | 111 | 44 | 61 | 66 | 71 | 99 | 84 | 1093 |
| Renmark SA | 18 | 19 | 13 | 18 | 23 | 22 | 24 | 24 | 24 | 25 | 21 | 20 | 252 |
| Mildura VIC | 22 | 23 | 20 | 20 | 25 | 22 | 26 | 26 | 27 | 29 | 25 | 26 | 291 |
| Griffith NSW | 34 | 30 | 36 | 28 | 35 | 34 | 34 | 35 | 32 | 38 | 34 | 32 | 402 |

Source: Commonwealth of Australia, Bureau of Meteorology (www.bom.gov.au).

Table 10. Total annual growing degree days (GDD 365) of Australian citrus growing areas.

| Location | Latitude | Longitude | GDD 365 |
|---|---|---|---|
| Darwin NT | −12.37 | 130.80 | 5517 |
| Katherine NT | −14.45 | 132.29 | 5001 |
| Kununurra WA | −15.74 | 128.74 | 5360 |
| Emerald QLD | −23.50 | 148.15 | 3495 |
| Bundaberg QLD | −24.84 | 152.34 | 3440 |
| Carnarvon WA | −24.85 | 113.63 | 3572 |
| Gayndah QLD | −25.61 | 151.61 | 3017 |
| Bourke NSW | −30.09 | 145.91 | 2676 |
| Gingin WA | −31.35 | 115.92 | 2129 |
| Merbein VIC | −34.17 | 142.04 | 1828 |
| Narromine NSW | −32.22 | 148.24 | 2031 |
| Harvey WA | −33.08 | 115.90 | 1656 |
| Renmark SA | −34.17 | 140.72 | 1799 |
| Waikerie SA | −34.18 | 139.97 | 1758 |
| Mildura VIC | −34.20 | 142.16 | 1864 |
| Griffith NSW | −34.28 | 146.02 | 1794 |
| Red Cliffs VIC | −34.30 | 142.19 | 1797 |
| Loxton SA | −34.45 | 140.56 | 1667 |
| Swan Hill VIC | −35.34 | 143.54 | 1624 |
| Leeton NSW | −34.56 | 146.39 | 1698 |
| Darlington Point NSW | −34.57 | 146.00 | 1765 |
| Coleambally NSW | −34.78 | 145.85 | 1744 |
| Barham NSW | −35.61 | 144.09 | 1568 |
| Cobram VIC | −35.90 | 145.62 | 1534 |

Source: Hutton and Dunne 2001.

In Australia, accumulated heat units are often reported for the phenological (growth) period from bud break to harvest or annually from July to June to reflect the fruit growing season in the southern hemisphere. In areas where there is a pronounced drop in temperature during winter, the interval between mid-bloom and maturity is approximately 7–8 months for early varieties and 11–13 months for late varieties. In more tropical environments it is 6 months and 8–9 months, respectively. A difference of 2 months (59 days) in season start date exists between northern and southern Australia.

High early season temperatures and greater seasonal heat are directly related to fruit maturing early. Net heat accumulation for the year (GDD 365) is substantially higher in the lower latitudes, nearer the equator. The thermal environment experienced by citrus grown further south than latitude 23° is quite similar during the spring flush period (first 100 days), but there are large differences in heat sums experienced between northern and southern locations during early to mid-summer when developing fruit are going through Stages I and II fruit growth. The differences between heat sums are even stronger during the fruit maturation period (Stage III) of fruit development.

Table 11. Mean timing (Julian days*) of key growth stages in the annual phenological cycle of Imperial mandarins and length of growing season for different Australian citrus growing regions.

| Region | Start day of citrus growing season | Fruit set day (≈ petal fall ) | Harvest** | Number of days from set to harvest |
|---|---|---|---|---|
| | ------------------ Julian days* -------------- | | | |
| Emerald QLD | 191 | 256 | 92 | 201 |
| Gayndah QLD | 194 | 260 | 100 | 205 |
| Mundubbera QLD | 193 | 258 | 90 | 197 |
| Moree NSW | 211 | 280 | 120 | 205 |
| Bourke NSW | 203 | 272 | 145 | 238 |
| Harvey WA | 202 | 269 | 179 | 275 |
| Renmark SA | 224 | 298 | 190 | 257 |
| Waikerie SA | 222 | 293 | 136 | 208 |
| Mildura VIC | 227 | 302 | 172 | 235 |
| Griffith NSW | 242 | 325 | 200 | 240 |

*Day 1 = 1st January; so, for example, day 92 = 2nd April, day 179 = 29th June, day 191 =10th July, etc.
**Timing based on actual dates of flowering, petal fall and harvest for surveyed sites around Australia.
Source: Adapted from Hutton and Dunne 2001.

## A changing climate

The climate in Australia has changed over the last one hundred years, with research showing significant increases in accumulated heat units from the 1970s onwards. Records show that since the early 1900s Australia's climate has warmed by nearly 0.9 °C (mean global temperature has risen by 0.85 °C). Average rainfall has increased slightly in the north west and declined in the south west; that decline being most apparent in the amount of winter rainfall.

It is predicted that by 2030 the annual average temperature will be approximately 1 °C higher in coastal areas and 1–1.2 °C higher in inland areas than currently. There will be more extremely hot days (> 35 °C) over summer and fewer extremely cold days, with an accompanying decrease in frost frequency over the whole of Australia, particularly in the south. Average annual rainfall will be stable in the north and decrease by 2–5% in southern and eastern Australia, particularly in winter and spring. Droughts will become more frequent, especially in the south west. Heavy rainfall events will increase over most parts of Australia, mainly in summer and autumn. Average wind speed is likely to increase in most coastal areas by 2.5–7.5% by 2030 and by 10% over most of Australia by 2070. (Source: *'State of the Climate Report 2014'*, www.bom.gov.au/state-of-the-climate).

These predicted changes in climate may have a significant impact on citrus cultivation and management practices in some regions and need to be considered in future plantings. The frequency and duration of vegetative flushes by citrus trees is affected mainly by temperature (as long as water and nutrients are not limiting). Increased temperatures associated with climate change are predicted to result in earlier and faster shoot growth and a shortened period of leaf hardening. There is also likely to be a geographic expansion southward of areas suitable for citrus production (Aurambout et al. 2009).

Research in southern NSW and Queensland has shown that flowering is commencing about 2–3 weeks earlier and increasing the length of the growing season. For example observations made on the same navel orange trees since the early 1990s at the NSW DPI research station at Dareton in south western NSW suggest that, on average, full flowering is becoming earlier at a rate of 19 hours per year, so flowering is about 18 days earlier now than in the early 1990s (Figure 22). The number of cool days during autumn are decreasing. This means that fruit are maturing earlier and that the development of good peel colour in early maturing varieties may be more problematic in the future.

An examination of climate records for the subtropical mandarin growing region around Gayndah in Queensland (25.61°S, 151.61°E, altitude 106 m) showed that there had been a dramatic increase in accumulated heat units commencing around 1970 (Figure 23). Average annual heat units between 1950 and 1970 were around 2,800, whereas from 2000 and 2008, 3,100 heat units were accumulated on average, resulting in an annual growing season more than 10% longer with predicted harvesting dates becoming steadily earlier each year (Figure 24). Imperial mandarins now mature 10 days earlier making the fruit internally mature around the end of March. It was estimated that Murcott tangor requires at least 2,500 heat units from flowering to reach an acceptable eating quality, and that Murcotts grown in the region will mature two weeks earlier by 2030 (Smith et al. 2008).

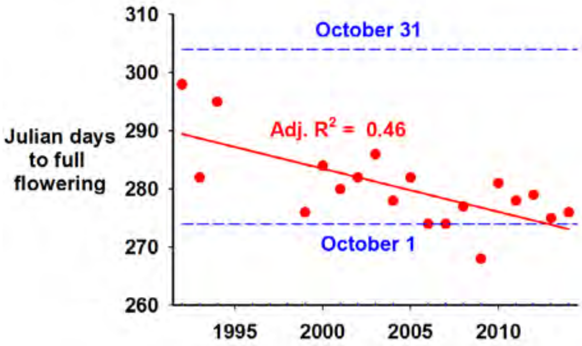


Figure 22. Change in the number of Julian days to reach full bloom for navel oranges at Dareton, NSW. Source: T Khurshid 2015, pers. comm.

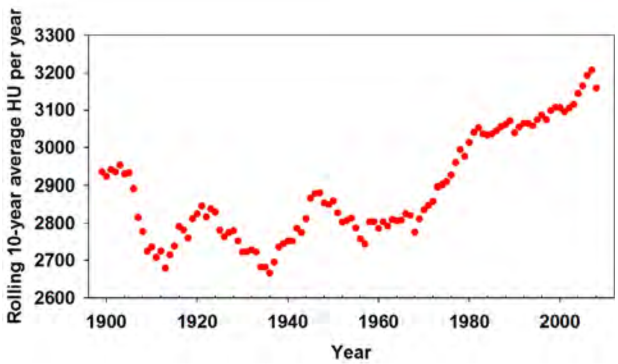


Figure 23. Rolling 10-year average annual heat unit (HU) accumulation at Gayndah. Source: Smith et al. 2008.

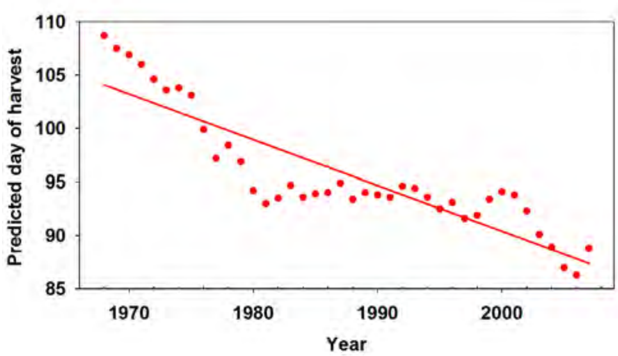


Figure 24. Predicted day of Imperial harvest at Gayndah assuming 2,300 heat units must accumulate from flowering, for the period 1960 to present (based on a 10 year rolling average). Source: Smith et al. 2008.

Mandarins require mean daily temperatures below 20 °C during the final fruit maturation period in order to achieve good peel colour. For early maturing varieties such as Imperial this means that cool conditions are needed during March and April. The number of days with mean daily temperatures below 20 °C in early autumn has been decreasing since about the 1950s (Figure 25). During the 1970s there was an average of six days with mean temperatures below 20 °C in the first two months of autumn, compared to an average of four since the early part of the new century. This combination of earlier maturity times and the reduced number of cool days in autumn mean that fruit will have less colour at harvest. Some of the possible effects of predicted changes in climate for Gayndah are outlined in Table 12. More general changes on citrus production likely to be observed as the climate changes are described in Table 13.

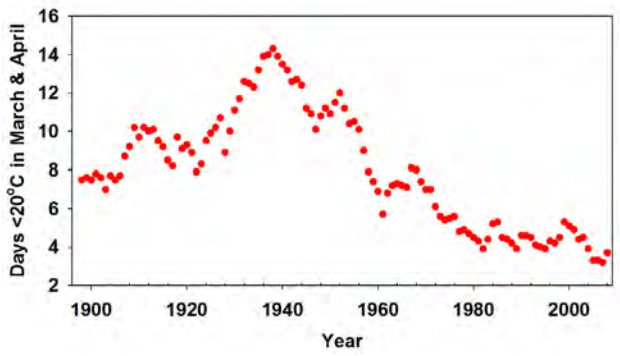


Figure 25. Number of days below 20°C mean temperature experienced at Gayndah during the first two months of autumn (10 year rolling average). Source: Smith et al. 2008.

Table 12. Climatic variables for Gayndah, averaged for 1999–2008 and predicted for 2019–2030.

| Climate variable | | 1999–2008 | Predicted 2019–2030 |
|---|---|---|---|
| Heat units | Summer | 1243 | 1285 |
| | Autumn | 830 | 878 |
| | Winter | 274 | 304 |
| | Spring | 844 | 885 |
| | Total annual | 3191 | 3352 |
| Days from flowering to 2300 heat units | | 191 | 181 |
| Days from flowering to 2500 heat units | | 212 | 193 |
| March and April days mean temp* < 20°C | | 3.7 | 2.5 |
| Autumn days mean temp < 20°C | | 25.2 | 21.3 |

* mean temp. = (max. + min.) ÷ 2. Source: Smith et al. 2008.

Table 13. Possible effects of predicted climate changes on citrus production.

| Higher temperatures and more extremely hot days | More heavy rainfall | Decline in average rainfall in southern Australia |
|---|---|---|
| • growing regions may expand in cooler regions and contract in hotter regions<br>• variety mix may change to more heat tolerant cultivars<br>• fruit peel colour development may be affected for early maturing varieties<br>• earlier flowering, flushing, fruit development and maturity<br>• increased fruitlet drop<br>• reduced fruit set<br>• increased evaporation<br>• increased water use and frequency of irrigation<br>• increased pressure on high security water supplies<br>• incidence and severity of some pests and diseases may change<br>• spread of QFF and increased chance of overwintering populations | • increased incidence of flooding and waterlogging episodes<br>• increased soil erosion and runoff<br>• increased incidence of Phytophthora root and collar rots<br>• incidence and severity of some pests and diseases may increase and others decline<br>• increased incidence of fruit splitting, rind disorders and postharvest breakdown | • educed tree growth, leaf flushing, yields and fruit size<br>• increased water stress<br>• use of more drought tolerant rootstocks<br>• need for more efficient irrigation systems and accurate irrigation scheduling<br>• growth of inter-row sods reduced<br>• increased wind erosion<br>• increased pressure on high security water supplies<br>• growing regions and production area may contract |

## Phenology

The following information is not entirely specific to mandarins, but provides a broad overview of some of the general effects of climate on citrus phenology and fruit quality characteristics.

Phenology is the study of the relationship between climate and plant growth and development. Timing of particular developmental milestones (e.g. flowering) is usually described in terms of calendar date, but the drivers are climate and the plant's internal programming. So, the precise timing of each developmental stage will vary with region and from year to year, mainly as a result of local climatic conditions. The length of the growing cycle and rate of fruit maturity also varies with variety.

Flowering and the cycles of vegetative and root growth are similar in most regions, except very tropical climates, where there can be more or less continuous growth cycling. Figure 26 outlines the main phenological stages and their approximate timing for citrus in southern Australia. The length of each stage can vary and even though they are diagrammatically represented as having definitive start and finish times, the transition from one stage to the next is more subtle and stages may overlap on the same tree. Table 14 outlines the timing of the main phenological stages for mandarins in Queensland and southern Australia.

Table 14. Key phenological stages of mandarins, outlining timing for Queensland and southern Australia.

| Development stage | Approximate timing for mandarins | |
|---|---|---|
| | Gayndah/ Mundubbera Queensland | Sunraysia, southern NSW and Victoria |
| Bud break (Figure 27) | Late July – August | August |
| Pre-bloom (Figure 28 ) | August | September |
| Full bloom (Figure 29) | Late August – September | October |
| End of petal fall (Figure 30) | September – early October | Late October – early November |
| Stage I fruit growth – cell division (Figure 31) | October – early December | November – December |
| Stage II fruit growth – cell expansion (Figure 32) | Mid December – March | Late January – April |
| Colour break (Figure 33) | Late March – May | Mid-April – June |
| Stage III fruit growth – maturation (Figure 34) | April – August | June – late August |
| Harvest | April – August | June – late September |

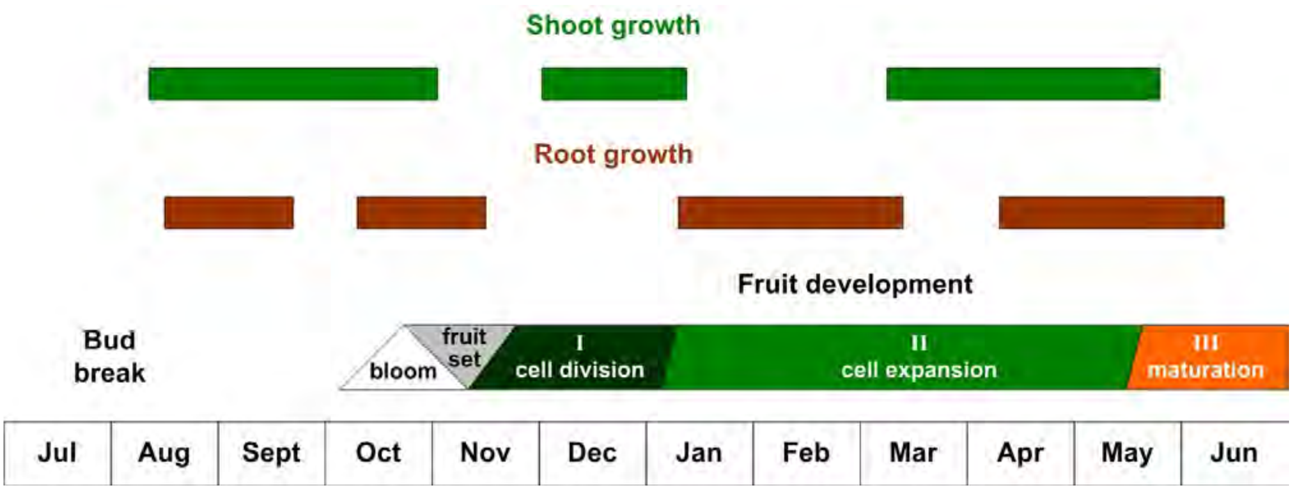


Figure 26. Diagrammatic representation of the citrus phenological cycle in southern Australia. Source: Michael Treeby.

Climate and phenology

## Pictorial representation of phenological stages

Figure 27. Bud break.

Figure 28. Pre-bloom.

Figure 29. Full bloom.

Figure 30. End of petal fall.

Figure 31. Stage I fruit growth – cell division.

Figure 32. Stage II cell growth – cell expansion.

Figure 33. Colour break.

Figure 34. Stage III fruit growth – maturation.

Citrus vegetative growth, fruit growth and fruit maturation rates correlate with temperature, and these relationships are reflected in the heat unit concept mentioned in the previous section. Fruit growth and maturation are spread over 3 to 10 months, depending on variety and climate (again, predominately temperature). Warmer (but not hot) temperatures, and hence high heat unit accumulation, result in faster growth and earlier maturity, whereas lower temperatures, and hence low heat unit accumulation, delay growth and maturity.

Differences in the maturation dates between 'early' and' late' cultivars are believed to reflect differences in heat unit requirements, with late cultivars requiring more heat units. When the monthly increment of heat units is small, even seemingly slight differences between cultivars in heat requirements may result in a considerable delay in maturation of one cultivar's fruit compared to another cultivar's fruit. Areas with low annual heat sums are better suited to early ripening cultivars (e.g. Clementines and Satsumas).

## Shoot and root growth

Shoot growth is important for canopy development, photosynthesis and to provide potential flowering sites. Trees in most regions have three main leaf flushes, in spring, summer and autumn. The spring shoot flush is the most intense and is initiated when temperatures rise above 12.5 °C, or in tropical regions after the alleviation of a period of water stress. Most citrus trees make little or no shoot growth below 12.5 °C or above 40 °C and maximum shoot growth occurs at temperatures between 25 °C and 31 °C (Girton 1927).

Shoots produced under cooler conditions (e.g. spring flush) tend to have shorter internodes and the leaves are more upright and lie closer to the stem. Shoots produced under warmer conditions (i.e. summer flush) tend to have longer internodes and larger leaves that are generally more perpendicular to the stem. In most regions the summer and autumn leaf flushes are not usually as intense as the spring flush and the seasonal pattern of these flushes is highly variable depending on local climatic conditions. The spring and summer leaf flushes are often in competition with the developing fruit for water, nutrients and carbohydrates.

Although citrus trees thrive in hot, dry environments, leaf photosynthesis has a relatively narrow optimum temperature range (Kriedemann 1968). Temperatures between 25 °C and 30 °C are optimal, and temperatures of 35 °C and above reduce photosynthetic activity. Extremely high light intensities, as those occurring in subtropical desert areas, cause leaf temperatures to rise considerably beyond ambient temperature, due to insufficient evaporative cooling (Syvertson & Lloyd 1994).

For young citrus trees, shoot flushes tend to inhibit root growth, so phases of shoot and root growth tend to alternate (Castle & Bevington 1985). There is probably considerable overlap in mature trees. Root growth takes place uninterruptedly as long as soil temperature, moisture and aeration are adequate, but intensity of root growth varies considerably (Spiegel-Roy & Goldschmidt 1996). Citrus root growth commences in spring when soil temperatures rise above 13 °C, and starts earlier in light sandy soils, which tend to warm up more quickly than heavy, clay soils. Water and nutrient uptake are positively correlated with soil temperature; low soil temperatures in spring can reduce uptake. Root growth is limited at soil temperatures below 18 °C and is the most intense at soil temperatures above 29 °C (Monselise 1947). Soil temperatures above 36 °C restrict root growth (Castle 1980). Root growth is also markedly affected by crop load, with heavy crops taking most of the carbohydrates produced by the leaves and inhibiting root growth as a result (Goldschmidt & Golomb 1982).

## Flowering

Two environmental stimuli play a major role in the natural control of citrus flowering: cold temperatures, especially in the cooler, subtropical growing areas, and water stress, mainly in tropical climates. Most citrus flowers (inflorescences) are produced on one-year-old wood. Floral bud induction is strongly correlated with the number of hours of low temperatures. As the hours of low temperature accumulate, bud differentiation in spring shoots shifts from predominantly vegetative (no flowers) to predominantly leafy inflorescences (leaves and flowers), to predominantly leafless inflorescences (also known as 'white blossom') [Figure 35]. The most effective temperature range for flower induction is 10 to 15 °C. As the number of hours between 10 °C and 15 °C increases, so does flowering intensity – partly explaining the variability in flowering intensity from year to year.

Flowering in most regions is induced by a period of low temperatures (<20 °C) for at least 30 days (moderate flowering), with periods of 45 days (<20 °C) resulting in a good flowering (Albrigo 2004). In tropical regions with high average temperatures all year, flowering is usually triggered by a period of water stress longer than

30 days, but economic levels of flowering require 45 to 60 days of water stress.

Temperature also affects the date and intensity of flowering. High temperatures during bud initiation and differentiation shorten development time and advance flowering, while cool conditions delay growth and development (Albrigo 2004). Low to moderate temperatures (<20 °C) usually result in a more protracted bloom period, whereas higher temperatures shorten the flowering period.

Apart from temperature, floral bud initiation, flowering and fruit set for the next season's crop can also be influenced by the current season's crop load and the timing of that crop's harvest, as well as the availability of suitably aged shoots. A heavy crop load and a crop left to hang late in the season can reduce floral bud initiation, flowering and fruit set. Fruit also have an inhibitory effect on bud sprouting, mainly due to the influence that fruit have on important phytohormones such as gibberellins and competition for carbohydrates. Poor vegetative growth in the previous season (especially the spring and summer flushes) can also reduce the number of potential flowering sites. Drought or water stress can trigger increased or 'out of season' flowering. The mechanism is not well understood, but phytohormones have been implicated (Kosita & Takahara 2004).

Figure 35. Left: White blossom (leafless inflorescence) – few leaves and many flowers which normally results in poor fruit set and smaller fruit.
Right: Green blossom (leafy inflorescence) – multiple leaves, few flowers which normally results in good fruit set and larger fruit.

## Fruit set

Fruit set is influenced by a range of factors including the number and type of inflorescences, competition with the spring leaf flush and other fruitlets for water and nutrient supply. Water stress can be particularly dangerous during fruit set, leading to a massive drop of fruitlets (Monselise 1986). There is a strong demand for nutrients during the spring flush, flowering and fruit set periods and it is critical that trees are well supplied leading into this stage. Low soil temperatures in spring can reduce nutrient and water uptake. Fruit set occurs over a very wide temperature range. For varieties that require pollination, temperature also affects the growth rate of the pollen tube.

The relative proportions of the various inflorescence types is an important influence on overall fruit set because leafy inflorescences tend to have a higher fruit set than leafless inflorescences (Krajewski & Rabe 1995). It is thought that leafy inflorescences are better able to supply carbohydrates, water and nutrients to the developing fruit, due to a more developed xylem cylinder and a higher number of vascular bundles (Erner & Shomer 1996).

All actively growing parts of the plant (sinks) compete for carbohydrates, as well as water and nutrients. Carbohydrates are transported to and stored in the roots and trunks mostly during late autumn and early winter, and this store is crucial to the developing fruitlets in early spring. If carbohydrate reserves are low due to heavy demand in the previous season (by, for example, a heavy late hanging crop) or other factors that have limited carbohydrate storage, fruit set can be reduced.

## Fruit growth and quality

Fruit growth is largely a function of temperature, but there are many other factors such as moisture availability and orchard management practices (e.g. nutrition) that also exert strong influences (Marsh 1973). Total heat units from bloom to maturity are strongly and positively correlated with fruit maturation rates and quality. Warmer climates are associated with faster growth and earlier maturity; whereas fruit growing in cooler climates have slower growth rates and later maturity. In warmer climates with faster maturation rates fruit also senesce more rapidly and do not hold well on trees.

Citrus fruit are berries with a thick removable peel that encases a soft pulp, comprised of about 80–90% water. Citrus fruit growth is generally linear or follows a single flattened 'S' shaped trajectory. There is a period of early slow growth followed by a rapid increase, after which growth slows down (Bain 1958). Imperial mandarin fruit growth in Queensland is linear, possibly due to warmer conditions (H Hofman pers. comm.).

Fruit go through three stages of development, Stage I – cell division, Stage II – cell expansion and Stage III – maturation (see Figure 36).

The first stage of fruit growth is cell division which lasts between 30–40 days. During this stage all the cells that make up the mature fruit are defined and potential final fruit size is determined. This is the period most sensitive to adverse climatic conditions such as high temperatures (>35 °C) and moisture stress. In warm humid climates fruit size is often larger, (even with a heavy crop load) because higher temperatures increase the rate of fruit growth, compared with regions with a cooler spring. The optimum temperature range for fruit growth is widely believed to be between 20–30 °C, but a range of other factors such as water availability and mineral nutrition can moderate the expected benefits of favourable temperatures on fruit growth.

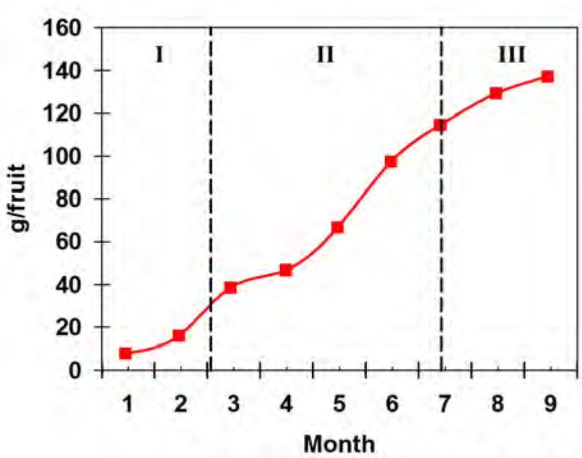


Figure 36. Fruit growth of mandarin fruit. Source: Adapted from Ladaniya 2008.

During Stage I there are two natural fruit drop periods, one soon after the start of fruit set and a second towards the end of this stage. The loss of fruitlets during Stage I is affected by temperature, humidity, soil moisture supply and competition between fruitlets for nutrients and carbohydrates. High temperatures, dry or windy conditions during early summer can cause excessive fruit shedding. Once fruit reach about 10–20 mm they are reasonably resistant to drop until close to harvest.

Stage II, the cell expansion or enlargement phase, typically lasts between three to four months, depending on variety and climatic conditions. During this stage the juice sacs in the pulp take up water and enlarge, and the cells of the albedo expand and stretch to accommodate the expanding pulp. Initially organic acid levels in the pulp are very high, and sugar levels very low, but as fruit mature the amount of sugar steadily increases and total acidity declines. The sugar and acid contents and their relative ratio contribute to fruit flavour and vary with citrus type. Very high or low temperatures and moisture stress during this stage can reduce fruit size and quality.

Fruit maturation, or Stage III, is characterised by the accumulation of sugars (measured as total soluble solids [TSS]), diminishing organic acids (measured as titratable acidity [TA]) and a change in rind colour. The length of the maturation period varies with variety and climate (predominately temperature). In warmer regions, fruit growth and maturation is faster and TSS accumulate more rapidly. Fruit growth and TSS accumulation are slower in cooler climates, and acidity levels at maturity are usually higher because organic acids are depleted more slowly. Large day/night (diurnal) temperature fluctuations also promote sugar accumulation and acid retention and enhance flavour development. Varieties that mature early usually have a lower heat unit requirement than later maturing varieties (Ferguson & Grafton-Cardwell 2014).

Fruit colour is affected by cool temperatures, particularly diurnal fluctuations during fruit ripening. When temperatures fall below 15 °C, the rind will begin to colour as the green pigment (chlorophyll) in the peel starts to degrade and orange pigments (carotenoids) accumulate. The decline in rind chlorophyll proceeds over several months and the onset of carotenoid accumulation almost coincides with the disappearance of chlorophyll (Iglesias et al. 2007). In tropical regions with high average temperatures all year, chlorophyll levels stay high and peel colour remains green, whereas in regions with cooler conditions during autumn and winter skin colour is much more acceptable to consumers. Excessive tree vigour, shading and high nitrogen levels can also result in poor fruit colour. The variety that will colour best in an area is the one that reaches maturity at the beginning of the dormant season. The decline in air and soil temperatures in autumn marks the onset of colour changes in subtropical regions (Young & Erickson 1961).

Citrus are non-climacteric fruit; this means that fruit ripen on the tree and once harvested will not continue to mature. Fruit taste is largely governed by the level of sugars and acids in the fruit and their relative ratios. In hot tropical climates where fruit maturation is faster, the fruit have less time to accumulate TSS and fruit flavour can be insipid as a result. The higher overnight temperatures in hot tropical climates also results in greater loss of acid, which also contributes to the insipid flavour. Fruit grown in cooler climates mature later, but have higher acid and TSS levels and good peel colour.

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# Varieties

## Introduction

In the last 25 years the demand for easy-to-peel citrus varieties such as mandarins, has increased around the world. As a result, mandarin plantings in Australia have more than doubled in the last 40 years, from 2,200 hectares in 1982/83 to 5,500 ha in 2014 and production has increased from 26,000 tonnes to 120,000 tonnes today (Forsyth & Ryall 1985; CAL 2015; CAL 2017).

In 1982/83 mandarins represented 7% of total citrus plantings, with around 533,000 mandarin trees, of which 43% were grown in Queensland. Overall Ellendale tangor and Imperial mandarin were the most widely grown varieties. New plantings in Queensland included Murcott tangor as the third most important variety followed by Ortanique (Forsyth & Ryall 1985; Forsyth 1987). The trend from 1982 to 1991 was a general decrease in bearing trees and a significant increase in non-bearing trees from 400,000 in 1981 to one million in 1992 (Revelant 1993).

In 1982/83 around 4,806 tonnes of mandarins were exported (18% of total production), valued at $13M. Fruit exports were mostly Ellendale tangor, mainly from Queensland (4,558 t) and sent to markets in North America (1,751 t), SE Asia (1,292 t), Europe (745 t) and the Middle East (712 t) [Forsyth et al. 1983 and Forsyth & Ryall 1985]. Australian mandarin exports today are around 49,000 tonnes, representing 40% of total citrus production and valued at $95M. The major export markets are China, the United Arab Emirates, Thailand, New Zealand and Indonesia (CAL 2017).

The most recent industry statistics indicate that up to 40 different mandarin varieties are currently grown in Australia. The most important varieties in terms of area planted are Afourer (W. Murcott), Murcott and Imperial, followed by Daisy, Hickson, Avana Tardivo and Nules clementine (Figure 37). Imperial and Murcott currently dominate plantings (59% of the total number of trees), but the trend is towards planting seedless or low-seeded varieties, such as Tang-Gold mandarin (a near-seedless selection of W. Murcott Afourer), and low-seeded selections of Murcott, such as IrM2.

While Queensland has traditionally been the largest production region for mandarins, this will change in coming years with the expansion in plantings of Afourer mandarin in southern Australia. Afourer mandarin is well suited to the climatic conditions in southern Australia, with warm summers, cool winters and low humidity.

Citrus breeders worldwide are working on developing varieties to meet a range of selection criteria that fulfil consumers' preferences. These criteria are based on the concept of 'convenience-style' fruit that are easily peeled and are sweet, seedless, highly coloured and of a size that fits in a lunchbox.

There are other market opportunities for varieties that do not necessarily meet all these criteria, but still have commercial importance due to characteristics such as low acidity, good eating quality or a distinctive appearance. For example, Dekopon is very sweet and has export potential into Asian markets, where it is eaten fresh, but is also used for jams, vinegars, teas and other beverages. Another variety, Gold Nugget has a distinctive pebbled rind, is seedless with a sweet and rich flavour. This variety is marketed domestically as a late-season, good-eating, seedless mandarin easily identified by its external appearance.

## History of mandarin varieties in Australia

The first mandarins were probably brought to Australia through trade with China. In a catalogue of fruits that were cultivated in the Sydney Botanic Gardens in 1828, four varieties were listed: the Common mandarin, Fang-Kau ('superior quality'), Tuan-Kat ('few or no seeds') and Chu-Cha Kud ('small, sweet and red-skinned') [Bowman 1955]. Shepherd (1851), in his book '*Practical Remarks on the Cultivation of the Orange and Olive*', was advocating the Canton mandarin ("as the best mandarin we have"), the Emperor of China mandarin ("large, flavoursome, no thorns but not so firm"), Emperor mandarin ("small, delicious, thin skinned, firm, and heavy, thornless") and Thorny mandarin ("similar to Emperor but with numerous spines"). By 1893, Crichton in the '*Australasian Fruit Culturist*' considered Emperor to be the 'largest and finest' mandarin, followed by Canton and then Thorny.

In 1936, nurseries in the Sydney region were selling a range of mandarin trees at £5/100, on sweet orange, rough lemon and trifoliate orange rootstock. Varieties included Beauty of Glen Retreat, Clementine, Early Imperial, Ellendale, Emperor, Fewtrell, Fagan, King, Muscio, Satsuma, Parker, Richard's Special, Scarlet and Thorny (Rosen 1936).

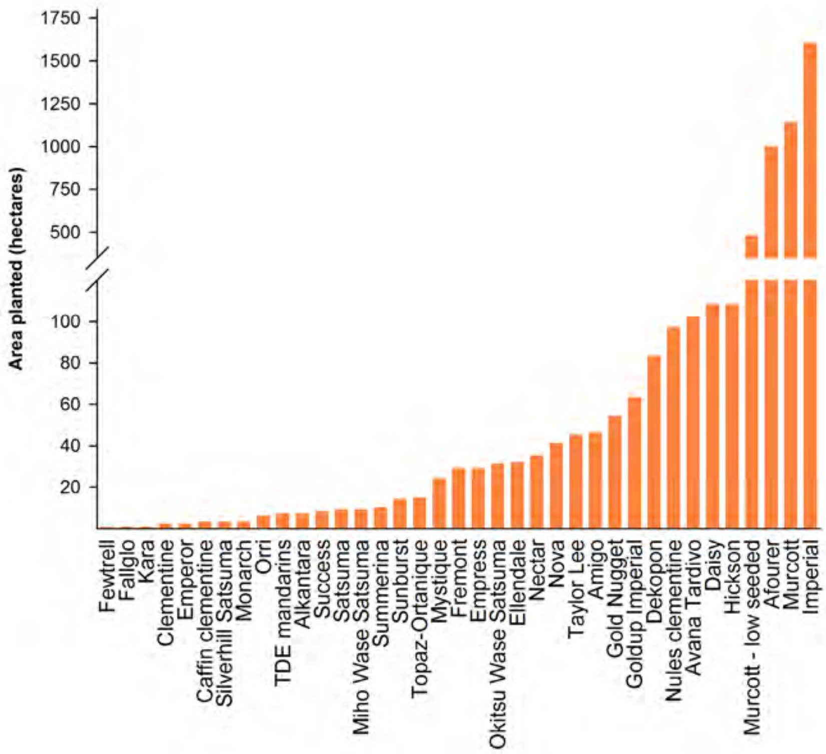



Figure 37. Australian mandarin plantings by variety in 2014. Source: CAL 2015.

While bud sports played an important role in developing better selections of oranges, it was the selection of naturally-occurring (i.e. resulting from cross-pollination) seedlings that had the greatest impact on what mandarin varieties were grown in Australia up until the mid-twentieth century. For example, Imperial mandarin was a seedling that grew at the back door of Jacob King's house on his orchard at Emu Plains near Sydney in the 1880s (McAlpin 1984) and was named by Richard Sheppard (Anon. 1936). Trees were supplied to a number of Emu Plains citrus growers before it was distributed more widely and introduced to Queensland in 1956 (Robinson 1999). Imperial remains the most important mandarin on the Australian domestic market, although it was not until 1956 that the first trees were planted in Queensland. Beauty of Glen Retreat (selected in 1888 at Enoggera, Brisbane) and Ellendale tangor (selected about 1878 at Burrum, Queensland) are two other seedling selections that were commercially important. Collectively, these varieties dominated Australian mandarin production throughout much of the twentieth century.

Bowman (1955) wrote that mandarins had been grown extensively in the Sydney region, but had declined due to competition with oranges. To be grown commercially, the varieties Emperor, Ellendale and Beauty of Glen Retreat, must have 'inherent size and quality as they do in Queensland'. He classified mandarins, tangors and tangelos on maturity and noted that "there is a distinct place for a good early variety". Early varieties included Imperial*, Unshiu, Fewtrell* and Clementine. Mid-season varieties were Beauty of Glen Retreat*, Emperor*, Scarlet*, Dancy, Parker*, Silverhill satsuma and Thorny or Willow Leaf. Late-season varieties were Burgess or Solid Scarlet*, Ellendale*, Wallent*, Umatilla and Kara. Varieties marked with an asterisk are Australian varieties derived from chance seedlings. A description of these varieties can be found in Cox (1975).

In the late 1960s a citrus nurseryman imported a number of mandarin varieties as budwood from California. Shortly after their establishment in post-entry quarantine (PEQ), authorities were informed that two of the budwood source trees were showing symptoms of stubborn (*Spiroplasma citri*), an exotic disease not present in Australia. Due to difficulties in testing for stubborn in PEQ, the imports were destroyed and quarantine officials placed a ban on citrus budwood importations which was not lifted until 1986.

From 1968 to 1980 the Queensland Department of Primary Industries (QDPI) imported some mandarin varieties as seed, mainly from California and Florida. Varieties included Fremont, Fairchild, Nova, Murcott, Sunburst, Malvasio, Ortanique, Osceola, Page and Sunburst. Nova, Fremont, Ortanique and Sunburst gained some commercial importance in Queensland. Minneola tangelo was also introduced as budwood from California in the early 1960s to replace an old selection of Minneola tangelo infected with *psorosis* virus. Minneola tangelo has proven to be suited to inland growing regions that are free of Alternaria brown spot.

When budwood imports resumed most mandarin introductions were public varieties from recognised citrus improvement schemes in Spain, California, Japan and Italy. New varieties were imported by state departments of agriculture through the Australian Citrus Improvement Program (Florissen et al. 2000). The Australian Citrus Improvement Program co-ordinated importation, local selection and breeding of new varieties, horticultural and market evaluation, and maintenance and multiplication of high health status material.

Between 1986 and 2001 there were twenty three mandarin introductions into Australia. These included Nules, Oroval, Fina, Marisol, Clementard, Hernandina, Arrufatina, Corsica 1, Corsica 2 and Caffin Clementines, Okitsu Wase, Miho Wase and Clausellina satsumas, W. Murcott, Avana Tardivo di Ciaculli, Avana Apireno, Pixie, Fallglo, Nova, Daisy, Fortune, Encore and Topaz mandarins. Of these, W. Murcott (Afourer), Daisy, Avana Tardivo di Ciaculli and Nules clementine have all become commercial varieties.

Since 2001 there has been a rapid increase in the number of new mandarin varieties and hybrids introduced into Australia for evaluation and potential commercialisation. The majority of these originated from breeding and selection programs in Italy, Israel, Spain, Morocco, South Africa and California. Most new citrus varieties are now imported as budwood by private variety managers or individuals and are protected by Plant Breeder's Rights (PBR).

Thirty two new varieties have been imported since 2001 and of these twenty seven have PBR, or some form of protection. The other five (Sidi Aissa, Orogrande and Nour clementines, Primosole and Etna mandarins) are public access varieties and were introduced by Auscitrus (Table 16).

In addition, several locally bred or selected mandarins are currently under evaluation in southern Australia. These include an Imperial × Clementine hybrid (91-03-04) bred by CSIRO, IrM1 and IrM2 low-seeded Murcott selections from QDPI, Royal Honey Murcott (progeny of Ellendale × Murcott), a low-seeded Afourer selection from Queensland and two early maturing Nova mandarins that are also from Queensland.

## Public versus private varieties

Public access varieties of mandarins such as Imperial, Murcott tangor, W. Murcott (Afourer), Daisy, Nules clementine, Okitsu Wase satsuma and Topaz are managed and supplied by Auscitrus as high health status budwood. Auscitrus also maintains mother (or foundation) and budwood source trees for the majority of privately owned varieties on behalf of variety managers. The mother trees are held as potted plants in an insect proof screen house. The budwood or rapid nursery multiplication trees are grown in a shade house or in the field. This is done on a fee for service basis and distribution of this budwood is at the discretion of the variety manager. Auscitrus also has a fee structure for the establishment, maintenance, management and virus indexing of mother and budwood source trees.

Managers of private varieties introduce budwood from overseas, or can act on behalf of local growers who have found or developed new varieties worthy of evaluation and possible commercialisation. The variety manager also administers PBR requirements or undertakes local data collection to obtain provisional or full PBR status.

Currently there are five main variety managers handling the development of new mandarin varieties in Australia. These include:

- **Advanced Production Methods (APM)** is an independent horticultural consulting firm managing Summerina.
- **Australian Nurserymen's Fruit Improvement Company (ANFIC)** is a member of the Associated International Group of Nurseries (AIGN). ANFIC has introduced varieties from Italy and Israel including Nouvelle, Cami, Alkantara, C1829, C1867, Tacle, Mandared, Mandalate, Nectar, Mor and Orri.
- **Favco and Carter and Spencer** is commercialising the QDPI low seeded Murcotts (IrM1 and IrM2) developed by irradiation.
- **Nuleaf IP Pty Ltd** has the rights to varieties from the University of California Riverside (UCR) breeding program, including Tang-Gold, Gold Nugget, Daisy SL, Kinnow SL and the three TDE varieties (Shasta Gold, Yosemite Gold, Tahoe Gold).

- **Variety Access Pty Ltd** has linkages to Biogold International, a variety and intellectual property management group with representatives in USA, Spain, Chile, China and South Africa. Variety Access has introduced varieties from California, Israel and South Africa including Kishu, USDA 88-2, Hadass, Orah and ARC Nadorcott SL. Variety Access has also been the most active in securing management rights to a range of Australian mandarin induced mutations and selections such as 2PH low-seeded Murcott, 2PH low-seeded Afourer, Goldup Imperial, Royal Honey Murcott (RHM), H2 mandarin and an early MJR Nova (all from Queensland).

Table 16. Imported mandarin varieties provided for independent evaluation since 2001.

| Variety | Origin | Ownership |
|---|---|---|
| Alkantara tangor | Italy | Private |
| ARC1519 | South Africa | Private |
| ARC1614 | South Africa | Private |
| ARC1848 | South Africa | Private |
| ARC Nadorcott SL | South Africa | Private |
| C1829 tangor | Italy | Private |
| C1867 tangor | Italy | Private |
| Cami | Italy | Private |
| Dekopon | Japan | Private |
| Etna | Italy | Public |
| Gold Nugget | California | Private |
| Hadass | Israel | Private |
| Kishu | California | Private |
| Mandalate | Italy | Private |
| Mandared tangor | Italy | Private |
| Mor Murcott | Israel | Private |
| Nectar | Israel | Private |
| Nour clementine | Morocco | Public |
| Nouvelle | South Africa | Private |
| Orah | Israel | Private |
| Orogrande clementine | Spain | Public |
| Orri (Or 4) (second introduction) | Israel | Private |
| Orri (Or 4) | Israel | Private |
| Primosole | Italy | Public |
| Shasta Gold (TDE 2) | California | Private |
| Sidi Aissa clementine | Morocco | Public |
| Tacle tangor | Italy | Private |
| Tahoe Gold (TDE 3) | California | Private |
| Tang-Gold | California | Private |
| USDA 88-2 | Florida | Private |
| Winola | Israel | Private |
| Yosemite Gold (TDE 4) | California | Private |

Varieties from QDPI breeding program will be commercialised under a joint government and industry arrangement. The trend in the future will be the continued introduction, evaluation and commercialisation of new mandarins as managed varieties with some form of PBR protection. Local mandarin selections or induced mutations thought to have commercial potential will also most probably be developed as protected varieties.

## Maturity periods

Mandarins are grown in many locations across Australia, including the Central Burnett and Emerald in Queensland, the Riverland and along the Murray Valley, the far south of Western Australia and the Riverina region in NSW. The distribution of growing regions across different climatic zones, from sub-tropical through temperate to Mediterranean-type climates, means fruit mature at different times. This results in an extended marketing period for most varieties. For example, Imperial mandarin can be available from April to August, depending on the growing region.

Table 17 shows the estimated peak maturity times for Imperial mandarins in different regions of Australia. For more information on the performance of varieties in different climates, refer to the Climate and phenology chapter.

Mandarins grown in the humid subtropical regions around the Central Burnett towns of Gayndah and Mundubbera can mature up to one month earlier than those grown in the Sunraysia/Riverland regions. The Riverina region in southern NSW with lower average minimum monthly temperatures during winter and early spring is about 2–3 weeks later than the Sunraysia/Riverland. Western Australia's growing regions north of Perth are closer to Sunraysia/Riverland in terms of fruit maturity, but the southern growing region of Harvey is cooler with clay soil types and has similar fruit maturity timings to the Riverina area of NSW.

Maturity times for the same variety can also vary within a region due to local micro-climatic effects and soil type, as well as the rootstock used. Generally trees grown in sandy soils on north facing slopes mature earlier than those grown on heavy clay soils.

Rootstocks also have a pronounced effect on maturity timing. Trees on some rootstocks tend to mature fruit earlier (fruit colour and internal maturity) while trees on other rootstocks can hold fruit in good condition on the tree for an extended period, allowing for late harvesting.

Troyer citrange is a vigorous rootstock and when used under Imperial, mandarin fruit tend to be larger, have higher sugar content and mature 7–10 days earlier than fruit on trees grafted onto other rootstocks (Owen-Turner 1995). Generally, trees on *C. macrophylla*, *C. volkameriana*, Troyer and Carrizo citrange rootstocks are considered early maturing and trees on *C. trifoliata* and Cleopatra mandarin rootstocks are late maturing. Table 18 shows juice quality results for Tang-Gold from small scale evaluation plantings at Dareton. The fruit from trees on *C. volkameriana* rootstock had the lowest juice content, soluble solids and acid levels of all the rootstocks tested with Tang-Gold. For more information on different rootstocks refer to the Rootstocks chapter.

Since 2014 CAL has used BrimA to help define the maturity standards for mandarins. Prior to this, fruit maturity standards were based on the °Brix:acid ratio. The Australian Citrus Standard (ACS) is based on the California Standard which is derived from BrimA. BrimA is a formula that shows the relationship between °Brix and acid and is a better predictor of consumer acceptability, compared with the older index based on the °Brix:acid ratio (Obenland et al. 2009). In 2013 consumer taste panel testing conducted in the Perth and Melbourne markets on Afourer mandarin helped validate the use of a minimum BrimA standard for Australian mandarins (Storer et al. 2014).

To calculate the ACS, the % acid of the sample is multiplied by 4 and then subtracted from the °Brix. A further multiplier of 16.5 is used to simply make the number bigger:

$$\mathbf{ACS = [°Brix - (acid \times 4)] \times 16.5}$$

The maturity standards for Imperial mandarin are a minimum juice content of 33% and an ACS of 110. For all other mandarins the minimum juice content is 35% and ACS is 110.

Table 19 shows juice quality results for Tang-Gold mandarin top-worked onto mature Valencia orange trees with a range of rootstocks. There were concerns initially that the yield and fruit quality characteristics of a variety could be influenced by the Valencia interstock on top-worked trees, but this was not the case. Trees on *C. trifoliata* tended to consistently produce fruit with higher °Brix levels across the range of mandarin varieties evaluated.

Table 20 shows sequential juice quality results, rind thickness and fruit diameter measurements for Tang-Gold mandarin in 2016. Full rind colour was developed by late June and fruit exceeded the ACS by early July. Fruit harvest was on the 11th August at a mid-point in its maturity period when the °Brix level exceeded 12.

Indicative maturity times for a range of varieties are outlined in Table 21. This maturity chart is based on long-term, fruit quality testing data collected at the main Australian citrus variety evaluation site, Dareton, southern NSW. It is a summary of sequential testing of fruit over 2–8 seasons and gives an indication of peak maturity timing under the weather and soil conditions (sandy loam) in the Sunraysia district around Mildura. The maturity window is typically based on when fruit reach 10 °Brix, juice content exceeds 35% and acid content is less than 1.2%. The maturity period finishes when fruit quality begins to deteriorate.

## What variety to plant – factors to consider

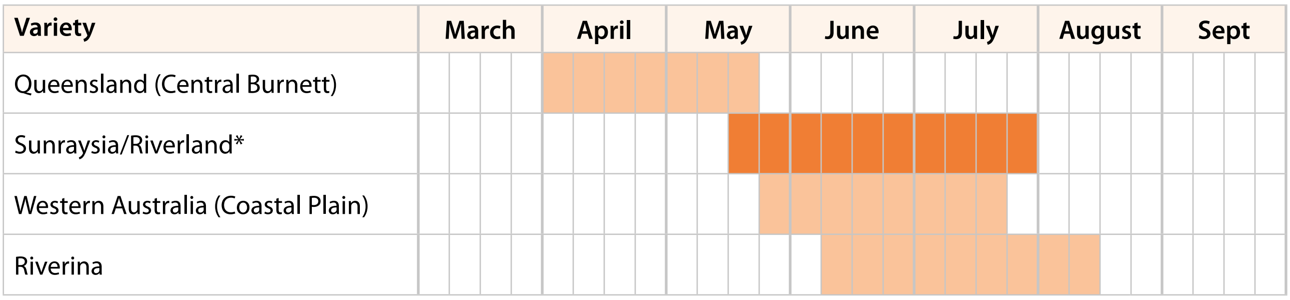
The development of any new citrus planting requires careful planning. From the time of ordering the trees, it may take up to seven years before a commercial crop is produced. The development of any perennial tree crop involves nursery tree production, field preparation, tree establishment and tree management to achieve maximum productivity and premium quality fruit. Preparation of a cost:benefit analysis and marketing strategy for a variety is essential prior to ordering any trees. Time spent on the planning stage will allow a critical assessment of the physical and financial aspects of the potential new investment.

### Production requirements for mandarins

The production of good quality mandarins requires a range of tree and crop management practices. These include:

- careful variety selection to match local climatic conditions and market requirements
- careful selection of rootstock to reduce the likelihood of incompatibility problems, to suit the soil type and to produce the required early or late maturing fruit
- protection from cross-pollination during flowering for self-infertile varieties that have the potential to be less seedy
- crop load monitoring and management to ensure trees produce good sized fruit and to reduce the likelihood of trees entering an alternate bearing pattern
- annual pruning to ensure good fruit production inside the canopy
- precise monitoring of irrigation – especially close to harvest
- nutrition practices specific to mandarins to produce premium quality fruit
- monitoring of fruit quality parameters for optimum maturity and marketing.

Table 17. Estimated maturity periods for Imperial mandarin in different growing regions in Australia.




*Maturity times based on sequential testing at the variety trial site at NSW DPI Dareton Research station.

Table 18. Fruit quality results at harvest (18/8/2016) for 6 year old Tang-Gold mandarin trees on a range of rootstocks.

| **Rootstock** | % juice | °Brix | % acid | °Brix:acid ratio | ACS |
|---|---|---|---|---|---|
| Swingle citrumelo | 46 | 14.5 | 1.05 | 13.8 | 170 |
| C. trifoliata | 46 | 14.1 | 0.99 | 14.2 | 167 |
| C-35 citrange | 43 | 14.0 | 0.87 | 16.1 | 174 |
| Troyer citrange | 46 | 13.4 | 0.81 | 16.5 | 168 |
| C. volkameriana | 35 | 12.7 | 0.71 | 17.9 | 163 |
| Australian Citrus Standard | 35 | – | – | – | 110 |

Table 19. Fruit quality results at harvest (11/8/2016) for 6 year old Tang-Gold mandarin trees top-worked onto Valencia orange grown on three rootstocks.

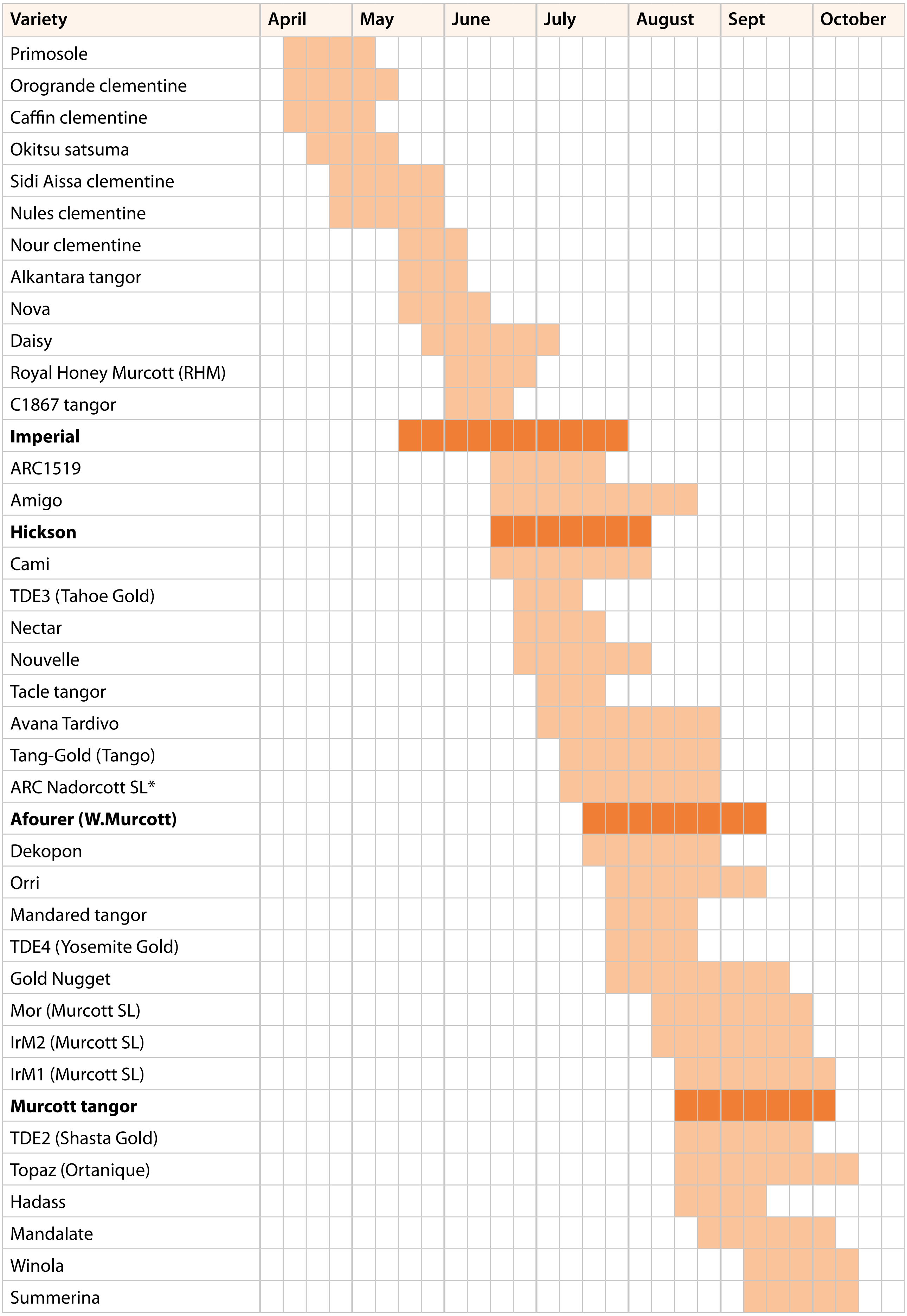
| **Rootstock** | **% juice** | **°Brix** | **% acid** | **°Brix:acid ratio** | **ACS** |
|---|---|---|---|---|---|
| *C. trifoliata* | 47 | 14.1 | 0.99 | 14.2 | 167 |
| Cleopatra mandarin | 46 | 13.4 | 1.09 | 12.2 | 149 |
| Troyer citrange | 49 | 12.6 | 0.91 | 13.9 | 148 |
| ACS | 35 | – | – | – | 110 |

Table 20. Sequential fruit quality data for 6 year old Tang-Gold mandarin trees top-worked onto Valencia orange grown on Carrizo citrange rootstock in 2016.

| **Date** | **% juice** | **°Brix** | **% acid** | **°Brix:acid ratio** | **ACS** | **Rind thickness (mm)** | **Fruit diameter (mm)** |
|---|---|---|---|---|---|---|---|
| 16 May | 53 | 10.1 | 1.41 | 7.2 | 74 | 2.6 | 64 |
| 27 May | 51 | 10.6 | 1.18 | 9.0 | 97 | 2.5 | 66 |
| 7 June | 46 | 10.5 | 1.13 | 9.3 | 99 | 2.8 | 69 |
| 21 June | 50 | 11.1 | 1.10 | 10.1 | 110 | 2.3 | 68 |
| 4 June | 50 | 11.9 | 1.14 | 10.4 | 121 | 2.7 | 64 |
| 18 June | 44 | 11.6 | 0.84 | 13.8 | 136 | 3.1 | 70 |
| 29 July | 46 | 11.6 | 0.82 | 14.2 | 137 | 2.4 | 67 |
| 11 August | 49 | 12.6 | 0.91 | 13.9 | 148 | 2.6 | 67 |
| ACS | 35 | – | – | – | 110 | – | – |

Varieties

Table 21. Maturity periods for a range of mandarin varieties in the Sunraysia region of Australia.




*SL – seedless.

## Key factors

### *Climate*

Climate is an important consideration in variety selection. Local weather conditions, especially temperature, humidity and rainfall can have major effects on fruit size, shape, maturity and quality (see the Climate and phenology chapter).

In a study on satsuma mandarins grown in four different locations in California, Nauer et al. (1974) found that fruit grown in warmer, drier locations were larger, rounder and had a coarser, thicker rind than fruit grown in cooler, coastal locations. The best quality satsuma mandarins are produced in regions with moderate day-time temperatures and cool night-time temperature two months prior to harvest (Kurihara 1973; Marsh et al. 1999).

Murcott tangor typically has larger fruit size and a smoother rind when grown in Queensland, compared to fruit grown in the hot and dry southern regions, such as Sunraysia and the Riverland.

Clementine mandarins probably have the most demanding climatic requirements. This is the main reason why most plantings are still restricted entirely to the coastal regions in many countries (Saunt 2000). The Gin Gin area on the coastal plain north of Perth in Western Australia has proven suitable for the production of good quality Nules clementine.

### *Market potential*

A variety's current and future market potential is one of the key selection criteria used to choose which variety to plant. The market trend is for seedless fruit, so the variety should be seedless or capable of producing seedless fruit (self-infertile) if isolated from pollen-fertile varieties. Other key criteria for mandarins include the variety being capable of achieving good fruit size, being easy to peel and having good eating quality. Smith and Campbell (2007) found that the three most important characteristics for mandarins exported to China were fruit size, a smooth skin texture and high juice content. A consumer study in the USA rated sweetness, fruit shape, acidity and flavour as the most important factors governing a willingness to buy a mandarin (House et al. 2011). For more information refer to the Crop management chapter.

### *Plant Breeder's Rights (PBR)*

The majority of new mandarin varieties will have some form of PBR and be controlled by a local variety manager. The decision making process is even more critical for these varieties as contractual arrangements and royalty payments are required in order to obtain, grow and market fruit from these varieties.

### *Variety performance information and technical support*

Information on how the variety grows and crops in its country of origin and under Australian conditions is important in understanding what special requirements may be needed to achieve maximum yield and premium fruit quality. Information on the growth habit, cropping pattern, harvest timing and other management issues, including the presence of thorns or susceptibility to fungal diseases, such as Alternaria brown spot, is critical. Observing the variety growing in its country of origin and visiting Australian evaluation sites, may be needed to obtain information.

### *Management*

Growing premium quality mandarins, especially for export, often requires a higher level of management than that needed for other citrus types. For example, when Afourer mandarin was initially grown in Queensland, fruit tended to become large and puffy. However, with a strict water and nutrient management program, fruit size and rind condition can be controlled.

Some new PBR varieties such as Gold Nugget and Orri mandarins, require even more specialised management strategies to overcome a low-fruiting, vigorous, upright growth habit. Limb girdling and removal of upright growth have been two strategies used in Israel to improve the fruit set of Orri. Canopy manipulation by bending upright growth to a horizontal plane has also been demonstrated to improve fruit production on Gold Nugget in southern Spain.

### *Postharvest management*

Mandarins require more careful handling than other citrus fruits and are more susceptible to rind damage and plugging during harvesting procedures. For example, Imperial mandarin is unsuitable for export due to its soft fruit and thin rind which is easily damaged during packing and transport. The fruit of most varieties such as Imperial, Murcott and Afourer are clipped from the tree. This increases harvesting costs, but is now the standard practice for market presentation.

Mandarins also tend to have a much shorter maturity period than other citrus and fruit left on the trees can quickly pass the stage of optimum maturity. Varieties such as satsuma mandarin have a very short shelf life compared to other citrus types, especially oranges.

Postharvest handling, including commercial wax application and storage conditions, can also influence the taste and aroma of mandarins. However, this may vary with the variety. For example, sensory evaluations in California found that Afourer (W. Murcott) could be stored for up to seven weeks at 8 °C without a significant loss of flavour, compared to storage at 0 °C and 4 °C (Oberland et al. 2011). For information see the Postharvest handling chapter.

### *Cost:benefit analysis*

When selecting a variety it is important to compare the advantages and disadvantages of planting a new variety based on the projected return on investment. Costs of production need to be balanced by projected dollar returns. Additional costs associated with mandarin production can be yearly pruning, fruit thinning, fruit clipping at harvest and multiple picks. For example, labour costs associated with clipping fruit are estimated to be up to three times more than snap-picking oranges.

### Checklist for variety selection

#### *Essential characteristics:*

- ☑ Seedless or potentially seedless.
- ☑ Premium fruit quality – good colour, smooth clean skins and acceptable sugar:acid ratio.
- ☑ Easy to peel.
- ☑ Suitable for domestic and export markets.
- ☑ Good postharvest handling characteristics.
- ☑ Suitable for local climate.
- ☑ Tree and crop management information available.
- ☑ PBR contractual arrangements and royalty costs satisfactory.
- ☑ Availability of high health status nursery trees.

#### *Desirable characteristics:*

- ☑ Information on performance in Australia.
- ☑ Proven record overseas (if applicable).
- ☑ Compatibility with rootstock suitable for soil conditions.
- ☑ Technical support available from variety manager for PBR material.

## Breeding

### Australian programs

Alan Ross initiated the first formal mandarin breeding program in Queensland in 1944 using Ellendale tangor as the female parent. His efforts led to the production of the variety Ellenor (thought to be an Ellendale × Thorny hybrid), and other high-quality selections (Chapman 1987). The next series of crosses were made in 1965/66 using Imperial mandarin as the female parent and pollen from a broad range of other varieties, including Wallent, Ellendale and Hickson mandarins and Jaffa and Joppa oranges as the male parent. Only two hybrids survived through to commercial exploitation – Aurora (Imperial × Wallent) and Monarch (Imperial × Hickson), but neither are grown to any extent today. More crosses were made in 1973 using Imperial × Wallent or Ellendale, but none were outstanding (Chapman 1987). Additional crosses were also made in 1981 between Ellendale or Imperial × Murcott.

Hybrids of Imperial × Ellendale were produced by the Victorian Department of Agriculture during the 1960s and, in collaboration with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), resulted in the release of Sunset mandarin. It was the first citrus variety to be granted PBR under Australia legislation in 1992, but it has poor fruit quality and is no longer grown.

In the 1980s CSIRO and Queensland Department of Agriculture and Fisheries (QDAF) independently began to increase their commitment to mandarin breeding. Both organisations recognised that the future of the Australian citrus industry was dependent on better germplasm and one way of getting this was to breed it locally for Australian conditions. Substantial mandarin breeding programs were established at Merbein in southern Australia, and at Bundaberg in Queensland, with additional biotechnology research by CSIRO in Adelaide, aimed at engineering the seedlessness trait. This expansion in breeding work was funded by the Federal and Queensland governments, national citrus industry levy funds and contributions from Queensland growers.

However, changing government and industry priorities as well as decreased availability of funds saw the biotechnology component terminated in 2004. In 2009, CSIRO closed down the breeding program at Merbein. This program had resulted in two commercial mandarin releases, Merbeingold 2336 and Merbeingold 2350, both of which have had only limited adoption by industry.

Today, aside from a small amount of private mutation breeding, the only Australian mandarin genetic improvement program is the QDAF breeding program at Bundaberg. The focus of this program is to meet consumer expectations in Asian markets. The program includes the development of new hybrids through conventional cross-pollination and the irradiation of budwood to reduce seed numbers. Three releases from the QDAF program have met with commercial success and are now being exported to markets such as China, Japan and Thailand. These include the low seeded Murcott selections IrM1 and IrM2. Another four selections are in the final stages of testing, and commercial quantities of fruit will be available for market evaluation in the next few years.

The QDAF program is continuing to produce new hybrids every flowering season, and is evaluating these as they come into production. Approximately 50,000 hybrids are currently in the field. Using multiple generations of hybridisation and selection, the breeding populations now display a greater percentage of hybrids with desirable characteristics. However, this advance is off-set by ever changing consumer expectations and market competition. There are also additional challenges in trying to counteract the negative impacts of warming climatic conditions on productivity and fruit colour development, as well as the looming threat of the exotic disease huanglongbing, HLB (citrus greening), which is devastating many citrus growing industries around the world.

## Overseas programs

There are active breeding programs in most of the major mandarin producing countries. Some of the better known programs include those in Japan, South Korea, China, California, Florida, Brazil, Uruguay, Chile, Spain, Italy, France, Israel and South Africa. Differences in market focus and climatic conditions are the two main drivers for the different approaches adopted in these breeding programs. For example, European programs are focused on their domestic markets where seedlessness is paramount, whereas countries producing for Asian markets place more emphasis on external appearance and lower acid levels. Breeding programs in countries like Japan, South Korea and Florida must contend with temperatures sometimes low enough to kill poorly suited germplasm.

Mandarins developed to suit particular climatic conditions and/or markets seldom do well when grown under different climatic conditions and/or sold to different markets; hence the need for local breeding programs. Whereas the development of new commercial orange varieties remains dominated by the selection of bud sports by astute orchardists, new mandarin varieties have arisen through the selection of naturally occurring seedlings (naturally occurring crosses that inherit genetic material from both parents) and are increasingly the result of breeding programs. Many of these programs are attempting to speed up the breeding process by developing new techniques such as DNA marker-based selection. To date, this has met with limited success. After almost 30 years since the first DNA markers became available, there is little evidence of their application or successful use in commercial breeding programs. Genetically complex parents, long generation intervals, and the requirement to improve a large number of complex traits simultaneously, will continue to reinforce the need for conventional breeding approaches that generate large hybrid populations.

## The breeding process

Breeding new varieties using cross-pollination is a long-term process involving the production of thousands of seedlings and years of evaluation, after which only a few may end up as commercially successful varieties. The steps involved in a typical breeding program are outlined in page 51. The major constraint to the release of a new variety from a hybridisation program is the long juvenility period of the seedlings, which may vary from 5 to 12 or more years. Effectively, it takes a minimum of 14 years from the initial cross being made through to a new variety being released. The steps involved in a typical mutation breeding program using irradiation are outlined in Table 23. Mutation breeding via bud irradiation uses mature tissue, so the long juvenility period of the hybrid seedling is avoided and variety release can be as early as 7 to 11 years after irradiation.

Female and male parents are chosen each season based on their likely ability to transmit the required traits to offspring. Conversely, great care is taken to exclude parents known to transmit undesirable traits (e.g. rough skins, prominent necks, high acidity). Experience has shown that some parents will produce no useful offspring regardless of how many hybrids are produced, and that parents can be useful in one environment, but are ill-suited to another. For example, Ellendale has been an excellent parent in the Australian and Uruguayan breeding programs, but was a complete failure when used by Japanese breeders. Careful selection of only high quality parents and the production of large hybrid families are two critical considerations.

During field evaluation, a range of criteria are used to select which hybrids have potential and should be included in future semi-commercial plantings. The selection criteria of the QDAF mandarin program include the fruit traits of size, external and internal colour, °Brix, sugar:acid balance, skin texture, flat shape, absence of neck, flavour/taste, juice content, peelability, rind oil offensiveness, skin thickness, rag, albedo retention, chewiness, granulation, firmness, seed number, presence of a navel, ability to colour under warm conditions, postharvest life, and on-tree storage life. Tree traits include resistance to Alternaria brown spot and citrus scab, yield, seasonal cropping consistency and maturity time. These selection criteria are based on key consumer trends in addition to production constraints, such as climate warming and increasing market competition from oher international citrus producing regions.

Table 22. Timeline for a hybridisation program, from cross-pollination to variety naming and release.

| Operation | Year | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Controlled pollination | ■ | | | | | | | | | | | | | | | | |
| Germinate seeds* | | ■ | | | | | | | | | | | | | | | |
| Plant-out seedlings | | | ■ | | | | | | | | | | | | | | |
| Seedling growth through to flowering | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | |
| 1st phase evaluation of fruit | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| Select potential candidates and propagate | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | | | |
| 2nd phase evaluation of multiplied selections | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | |
| Variety release | | | | | | | | | | | | | | ■ | ■ | ■ | ■ |

* This may involve embryo rescue and hybrid identification where female parents are polyembryonic.

Table 23. Timeline for a mutation program, from irradiation to variety naming and release.

| Operation | Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Irradiate buds from mature fruiting shoot | ■ | | | | | | | | | | | |
| Propagate and bud $vM_1$ trees | ■ | | | | | | | | | | | |
| Bud shoots from $vM_1$ trees to create $vM_2$ trees | | ■ | ■ | | | | | | | | | |
| Plant-out $vM_2$ trees | | | ■ | | | | | | | | | |
| Evaluate fruit from $vM_2$ trees | | | | ■ | ■ | ■ | ■ | ■ | | | | |
| Buds from selected $vM_2$ trees to create $vM_3$ trees | | | | | ■ | ■ | ■ | ■ | | | | |
| Evaluate fruit from $vM_3$ trees | | | | | | ■ | ■ | ■ | ■ | | | |
| Variety release | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ |

$vM_1$ indicates the first generation of vegetative propagation following mutation treatment.
$vM_2$ indicates the second generation of vegetative propagation following mutation treatment.
$vM_3$ indicates the third generation of vegetative propagation following mutation treatment.

## Mandarin breeding stages

Figure 38. Breeding – pollination: the flowers of the female parent have the male parts removed (emasculated) and pollen from the male parent is applied to the stigma. The tags are used to identify the different male (pollen) parents.

Figure 39. Breeding – pollination: the fruit produced from hand pollinations is bagged to prevent loss as they approach maturity.

Figure 40. Breeding – seed germination: the hybrid seed is extracted from the bagged fruit and sown in potting mix, ready for transfer to the nursery.

Figure 41. Breeding – disease testing: during the nursery phase ($\approx$12 months) seedlings are inoculated with pathogens that cause the fungal diseases Alternaria brown spot and citrus scab. These two diseases are major problems in warm wet tropical, sub-tropical and temperate regions of Australia. Any new varieties developed for humid areas need to be tolerant so any trees showing symptoms in the nursery are discarded prior to field planting.

Figure 42. Breeding – seedling establishment: the hybrid seedlings are planted in the field at high densities ($>$10,000 tree/ha) and managed to maximise vegetative growth.

Figure 43. Breeding – seedling evaluation: hybrid seedlings start to flower about five years after field planting and will remain in the field for another five years to enable most hybrids to commence fruiting.

## Evaluation

### Introduction

The developmet of any new mandarin planting is a long-term and expensive undertaking. Before selecting a new variety to plant it is critical to have information on the variety's performance under local growing conditions. The decision to plant a new variety can be made based on early assessment of its cropping and fruit quality characteristics, plus the level of management that will be required to successfully grow the variety.

The majority of new mandarin varieties now available in Australia have been introduced from other citrus producing countries. To determine how a new variety will perform in an environment different from where it was bred or selected requires local horticultural evaluation. An evaluation program aims to produce a bearing tree grown to a commercial standard in the shortest possible time frame and make performance data available to industry.

Historically, citrus variety evaluation trials were conducted by the states' departments of agriculture on research stations or on grower properties, in fully replicated trials, demonstration blocks or in arboreta. Occasionally, growers have imported budwood through post-entry quarantine (PEQ) and grown a new variety on their own properties (e.g. the first importation of Afourer (W. Murcott) into Australia).

With the first release of mandarin varieties from PEQ after 1986, a number of trials of Spanish selections of Clementine mandarins were established, including a replicated field trial at NSW DPI's research station at Somersby in 1990 and a commercial district demonstration trial at Hillston in 1992. The Clementine selections included Marisol, Fina, Oroval and Nules. These were compared against two older Clementine selections, Algerian tangerine and Clementine 813. Additionally, plantings of two trees of various imported or selected mandarins were made at NSW DPI citrus arboreta at Gosford, Dareton and Griffith. Varieties included Imperial (standard), Fairchild, Fremont, Nova, Osceola, Page, Sunburst, Burndale, Ellenor, Malvasio, IE-73-1-25, IH-66-5-15, Kinnow, Sunset and Marisol, Fina, Oroval and Nules Clementines.

Fruit quality data were collected over two years and varieties were also assessed for their market potential by a panel consisting of mandarin growers, packers, nurserymen and NSW DPI staff. In the Sunraysia region the new varieties identified as having possible market potential were Nova, Page, Fremont, Sunset and Nules clementine (Sanderson & Sarooshi 1994).

Since the early 2000s the focus of variety evaluation shifted from long-term replicated field trials and arboreta trials to a more rapid evaluation program, at more sites in climatically distinct areas. Fully replicated, larger scale plantings with data collected over an extended period were viewed as being too costly and not providing information quickly enough for growers to make reasonably informed planting decisions about newly imported varieties.

Today, mandarin evaluation trials are predominantly conducted by primary industry agencies in NSW, QLD and WA. The main Australian citrus variety evaluation site is located at Dareton in southern NSW. Funding support in NSW is provided by the state government, Hort Innovation (HI) and the Australian Centre for International Agricultural Research (ACIAR); in Queensland by the state government, local citrus growers and HIA (for the evaluation of Queensland bred hybrids); and in Western Australia by the state government.

A major component of the evaluation work is to showcase new varieties to industry, highlight their preliminary performance in Australia and evaluate management techniques if production issues are reported overseas or identified locally. Formal presentations and fruit displays of new varieties are conducted at regional, state and national levels, often in association with the national industry organisation, Citrus Australia Limited (CAL). Variety information sheets are also developed once there is sufficient data to be confident of the variety's characteristics and field performance.

For varieties with PBR protection and/or variety management protocols, field inspection of trees at trial sites can only occur with approval from the variety owners. Some PBR varieties are also supplied to co-operating farmers for small scale testing.

### Evaluation methodology at Dareton

The aim of this evaluation program is to produce and evaluate fruit of a commercial standard in the shortest possible time-frame. The minimum time-frame from the introduction of the variety into Australian Post-Entry Quarantine to the development of a fully bearing, mature tree is approximately 10 years. Table 24 and outlines the main steps in the evaluation program.

Ten to fifteen buds of each new variety are supplied to the evaluation program at Dareton from the Australian Citrus Propagation Association Inc. (Auscitrus) budwood scheme to propagate nursery trees in a heated greenhouse. These nursery trees are then used to supply the grafting wood for top-working onto 4–6 mature Keenan Valencia orange trees (planted in 1987) and grown on *C. trifoliata*, Carrizo citrange or Cleopatra mandarin rootstocks. Seven nursery propagated trees of each variety were also planted on a range of rootstocks, predominantly for fruit quality testing and early assessment of rootstock:scion compatibility. The rootstocks used include Troyer and Carrizo citranges, *C. trifoliata*, Cleopatra mandarin, Swingle citrumelo, C-35 citrange and several new rootstocks from the USA, including C-146 and C-22.

Sometimes varieties are only tested for 2–3 seasons. For example Primosole mandarin and Orogrande clementine were only tested for 3 seasons due to their poor internal fruit quality, a tendency to granulate under the warm climate of Dareton and lack of commercial interest.

The sequential fruit quality testing is typically done over four seasons and can extend to at least eight if the variety has commercial potential. Some varieties, such as Tang-Gold mandarin, produced sufficient fruit for sequential quality testing at Year 3 from top working. This was one year earlier than the majority of other mandarin types under evaluation.

Table 24. Timeline for new variety entry and evaluation program at Dareton.

| Operation | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| **Variety introduction and multiplication phase** | | | | | | | | | | | |
| Budwood enters Australian PEQ for propagation and pathogen testing. | ■ | ■ | ■ | | | | | | | | |
| Variety released to Auscitrus[1] for mother tree* establishment at screen house repositories at EMAI[2] and Dareton and supply to variety managers/owners. | | | ■ | | | | | | | | |
| Auscitrus supplies buds to NSW DPI Dareton for nursery tree production and budwood multiplication for re-working. | | | ■ | | | | | | | | |
| Nursery trees assessed for trueness-to-type. Multiplication trees established at Auscitrus nursery at Dareton for provision of high-health status budwood supply to industry. | | | | ■ | ■ | | | | | | |
| Budwood available from Auscitrus to approved nurseries and growers. | | | | | | ■ | | | | | |
| **Evaluation phase** | | | | | | | | | | | |
| Nursery trees planted and buds grafted onto mature Valencia trees at NSW DPI Dareton evaluation site. | | | | | ■ | ■ | | | | | |
| Small numbers of fruit produced for showcasing to variety managers and industry. | | | | | | | ■ | | | | |
| Sufficient fruit produced for horticultural evaluation and sequential harvesting for maturity testing. | | | | | | | | ■ | | | |
| Top-worked trees producing 30–40 kg fruit; available for industry variety field days. | | | | | | | | | ■ | | |
| Preliminary evaluation results available. | | | | | | | | | ■ | | |
| Top-worked trees near full production (50–70 kg/tree) and field trees 20–30 kg fruit. | | | | | | | | | | ■ | |
| Top-worked trees full bearing (80–100 kg) and field trees producing 30–40 kg. | | | | | | | | | | | ■ |
| Final results of variety evaluation published. | | | | | | | | | | | ■ |

[1] Auscitrus is the trading name of the Australian Citrus Propagation Association Incorporated, a national industry organisation responsible for maintaining mother trees and providing propagation material of the highest health status.
* Mother (or foundation) trees are the original source trees for high-health status budwood.
[2] EMAI = Elizabeth Macarthur Agricultural Institute, Camden Sydney.

### *Criteria for assessment*

- Trueness-to-type

The nursery trees are managed to promote early flowering and fruit set to determine trueness-to-type, which is based on information and images from the country of origin supplied by the variety manager. Fruit produced on young potted trees and field trees are also inspected by variety managers and others familiar with the variety.

- Fruit quality

Fruit are tested on a 10–14 day schedule over the likely maturity period for each variety. Fruit testing starts before the variety is mature and continues until internal fruit quality begins to deteriorate. On each sampling date 10 fruit are collected from the 4 quadrants of the tree, including within the canopy. The fruit quality characteristics analysed include: % juice, °Brix, % acid, °Brix to acid ratio, BrimA index (see the section on Mandarin maturity periods and the Harvesting chapter for more information), seed number, rind thickness, fruit diameter and fruit weight. Other quality characteristics such as granulation, rind texture, rind puffiness, albedo breakdown, peelability and oil release when peeling, are also recorded.

- Maturity period

Sequential fruit quality testing over several seasons is required to determine the best potential 'marketing window' for each variety. The harvesting/marketing maturity period is considered to begin when the variety exceeds a minimum internal maturity that would be suitable for marketing. Citrus Australia Ltd (CAL) has recommended minimum standards of 35% juice content and an Australian Citrus Standard (ACS) of 110 for all mandarins except Imperial, which has a minimum juice content of 33%. The end of the maturity period is when the internal and external fruit quality parameters begin to decline. The peak 'marketing window' would occur within this maturity period. For example, with varieties such as Gold Nugget, peak marketability occurs when the °Brix content is high, which is towards the end of the harvest window. Comparative maturity charts are produced as data become available.

- Yield and fruit size

Individual fruit yields for each rootstock are collected from top-worked trees and the field planted nursery trees for a minimum of four seasons. Data collected include fruit thinning rates, fruit number at harvest and total yield. Fruit from varieties with PBR is also supplied to variety managers/marketers for commercial grading, packing and market testing.

- Phenology

The key growth stages in the yearly production cycle are also recorded. The main stages monitored include budbreak, start of bloom, full bloom, end of petal fall, end of fruit drop, cell division/cell expansion, colour change, fruit maturity and harvest. Accurate phenological information assists in the timing of management activities to maximise tree and crop performance.

- **Tree growth rate**

Trunk girth and canopy height are measured annually on field planted trees grown on a range of rootstocks. Trunk measurements are more reliable in determining tree growth rate as the canopy height can be affected by tree pruning or a heavy crop load weighing down branches. Trunk circumference, tree height and spread measurements are also used to determine cropping efficiency.

- Postharvest assessments

Some varieties with export potential undergo various postharvest storage treatments. For example, Tang-Gold and Orri mandarins have been held in storage at 4 °C for 4–8 weeks for fruit displays and to determine if quality can be maintained under prolonged cool storage conditions. Tarocco blood orange × Clementine mandarin hybrids (C1829, C1867, Tacle and Alkantara) have been in cool storage to determine if the development of anthocyanin pigment was enhanced.

Production issues

Small-scale testing of various management techniques is also implemented if production issues are reported overseas or identified locally. For example, to improve fruit set of Orri mandarin, various crop management strategies used overseas have been trialled, such as girdling, application of gibberellic acid (GA) at flowering, pruning and branch manipulation to reduce vigour. The application of GA at late petal fall has been used in Israel, South Africa and Spain to improve fruit set in Orri mandarins. Initial testing at the variety evaluation site at Dareton has also demonstrated positive effects on fruit retention (please note that the use of

GA at flowering is currently not registered on product labels in Australia). Use of GA and 2-4,D (Stop Drop®) to improve rind condition and retain fruit on the trees has also been implemented on Gold Nugget mandarin to extend its harvest period.

### Other evaluation trials

Managers of varieties with PBR may also supply varieties (under a confidential contract) to selected citrus producers for field evaluation. For example, Orri mandarin is currently established on a semi-commercial scale on private evaluation sites in South Australia and NSW.

The evaluation of local selections or bud sports identified by growers can also be included in the national variety evaluation program at Dareton. Although such discoveries are relatively rare, more are appearing as the potential commercial value is realised by growers. For example, Royal Honey Murcott (RHM) and early Nova mandarin selections are planted commercially by the variety owners in Queensland. These selections are being developed for Australian and possible international distribution by a variety manager.

Trees bred or selected in Australia are pathogen tested and mother trees established by Auscitrus for the supply of high health status budwood. Please note that due to the presence of severe orange stem pitting strains of *citrus tristeza virus* (CTV) in Queensland, the movement of budwood or trees from Queensland to other states is illegal. Varieties originating in Queensland have to undergo pathogen elimination before distribution to other states.

There are also a few multi-variety evaluation plantings established on co-operating growers' properties. State governments, with the support of industry, undertake most of the formal variety evaluation, but some are outside these formal schemes and managed by the grower. The Department of Agriculture and Food West Australia (DAFWA) have small regional evaluation sites on growers' properties in West Gin Gin, Harvey and Bindoon. Variety managers supply budwood and two trees are top-worked to provide fruit for quality testing, determination of maturity period and showcasing to local farmers.

## Variety evaluation stages

Figure 44. Mother (foundation) trees of citrus varieties kept in the Auscitrus insect-proof screen house at Dareton, NSW.

Figure 45. Eighteen month old top-worked tree with Valencia orange 'nurse limb' due for removal.

Figure 46. Three year old top-worked tree with its first fruit.

Figure 47. Four year old Orri mandarin top-worked to Valencia orange on *C. trifoliata* rootstock.

Figure 48. Fruit quality testing is undertaken on a 10–14 day schedule over the likely maturity period for each variety. Fruit are analysed for juice, sugar and acid content, °Brix to acid ratio and the BrimA index.

Figure 49. A major component of the evaluation work is to showcase new varieties to industry at regional, state or national events.

## Major varieties

### Afourer (syn. W. Murcott and Nadorcott)

Afourer is a tangor of unknown parentage imported into California by WW Bitters from Mr El Bachir Nador in Morocco in 1985. It was assumed the variety arose as an open pollinated seedling of Murcott tangor from Florida. The name 'W. Murcott, Afourer,' was given by Mr Nador based on the coordinates of the experimental plot, 'INRA W' and the name of the town nearby, 'Afourer'. 'Afourer' became the local name for this variety, but it is also known as Nadorcott (after Mr. Nador) and marketed in California and sometimes in Australia as Delite™ and Cuties™. There have been both private and public introductions of Afourer into Australia; the first in the 1990s and a second release to selected nurserymen in 2000. Typically Afourer is late maturing, has deep orange coloured skin and flesh and is seedy if cross-pollinated with around 10–12 seeds/fruit (Figure 50).

Figure 50. Afourer is a late maturing tangor with an attractive deep orange flesh and skin colour.

Gamma irradiation of Afourer has led to the development of near-seedless selections that are protected by PBR. Tango is one such selection and was developed at the University of California Riverside (UCR). Tango fruit are similar to Afourer fruit in appearance, quality and production characteristics, but are seedless and mature slightly earlier. UC Riverside was granted PBR protection under the name Tang-Gold in Australia (Figure 51), and Nuleaf IP Pty Ltd is the exclusive licensee in Australia.

ARC Nadorcott LS tangor is an induced mutation of Nadorcott mandarin produced by the Agricultural Research Council (ARC), Addo, South Africa, jointly owned by Nador Cott Protection Company France and the ARC. It is managed in South Africa by Citrogold Pty Ltd and marketed under the trade name ClemenGold®. In Australia, ARC Nadorcott LS is controlled by Variety Access Pty Ltd. Both

Tang-Gold and ARC Nadorcott LS have low seed numbers (average <1 seed/fruit) even in mixed, pollen-rich plantings. These near-seedless selections have planting 'caps' on tree numbers in Australia and a controlled marketing system.

Figure 51. Tang-Gold – a seedless selection of Afourer with PBR protection in Australia.

Large areas of low-seeded Afourer are being established in China and most other citrus producing countries and it can now be considered the most popular new mandarin variety in the world. The development of low-seeded selections of Afourer has made this variety an attractive option for Australian growers.

At the time of the 2014 census of Australian citrus plantings there were around 1000 hectares of Afourer, of which 740 hectares were bearing trees (CAL 2016). The non-bearing plantings include Tang-Gold, but not ARC Nadorcott LS, which will soon be released to industry.

Afourer tangor grows best in southern Australian regions with warm summers and cool winters. Plantings in Queensland need strict irrigation management to improve internal fruit quality and maintain smaller fruit sizes to reduce the chance of fruit becoming 'puffy'. Harvesting in Queensland begins in early June and in the Murray Valley harvesting typically begins in mid to late July and can extend to early September. On the heavy clay soils in the Riverina region, trees on *C. trifoliata* can hold their fruit into October, but these fruit may have lower juice content and the rinds can re-green.

Trees are medium sized, with moderate vigour and an upright growing habit (Figure 52). Fruit set and yields are very high, with crop thinning required in heavy crop years to reduce the development of an alternate bearing habit. In well managed plantings, mature trees can produce yields of 60–80 tonnes/hectare. Trees benefit from a regular pruning program to remove vigorous upright shoots and improve light penetration into the canopy.

The main rootstocks used are the citranges, *C. trifoliata*, and more recently *C. macrophylla* in the Riverina region of NSW. However *C. macrophylla* is susceptible to stem pitting strains of *citrus tristeza virus* (CTV) and is not recommended in Australia. There have been reports from Corsica of incompatibility with *C. trifoliata* rootstock, but in California *C. trifoliata* is a preferred rootstock for late maturity. Observations of a long term rootstock trial in South Australia indicate that Cleopatra mandarin, Troyer, Carrizo, C-32 and Benton citranges are suitable rootstocks for Afourer tangor. There have been concerns with the use of C-35 citrange as a rootstock in Australia due to bud union creasing and reduced tree size, but it is used for ARC Nadorcott LS in South Africa.

Figure 52. Afourer fruit on tree.

Afourer tangor is a mid to late variety which is self-infertile and seedy if cross-pollinated. Several large plantings in southern Australia use netting to exclude bees during flowering and reduce seed numbers. Another method to reduce seediness is to isolate plantings from pollen viable citrus varieties, such as other mandarins, lemons and Valencia oranges. For more information on techniques to reduce seediness see the Crop management and Orchard basics chapters.

Fruit are moderately firm, easy to peel, slightly flattened, with an attractive deep orange flesh and skin colour. The central core of the fruit tends to be open and the segments separate easily. Fruit have a rich flavour with high °Brix (12–14) and acid levels (0.8–1.0%) at peak maturity. Juice content is generally high (45%), but fruit held late may dry out and suffer from granulation. Afourer tangor is suitable for export and fruit grown in the Sunraysia region have been shipped as far as the United Kingdom.

## Avana

Avana mandarins are classified in the Mediterranean or 'Willowleaf' group of mandarins. This group has narrow leaves, aromatic rind oil, dense foliage, and initial upright growth, followed by a drooping habit when branches carry a heavy crop load.

Two Avana selections originating in Italy were introduced into Australia in 1999. Avana Apireno is an early maturing selection, and testing in the Sunraysia region showed it matured about the same time as Imperial mandarin. There has been little commercial interest as a result. The other selection, Avana Tardivo di Ciaculli, is later maturing (Figure 53) and was seen as an option to extend the Imperial mandarin marketing season. Around 100 hectares have been planted in Queensland and South Australia (CAL 2016).

Figure 53. Avana Tardivo di Ciaculli fruit – a late, but seedy variety of Italian origin similar to Imperial mandarin.

Avana Tardivo di Ciaculli has tree and fruit characteristics similar to Imperial mandarin (Figure 54). Fruit achieve internal maturity by mid-July in southern Australia and approximately one month earlier in Queensland. Fruit can retain high levels of acid for a prolonged period and need to be held on the tree until the acidity decreases. Fruit tend to be small to medium sized (depending on crop load), seedy (average 12–15 seeds/fruit), have an orange rind colour when fully mature and are relatively easy to peel. Avana Tardivo di Ciaculli is self-fertile, so isolation from other pollen sources will not decrease seed numbers. The rind is slightly pebbled, but is more robust than Imperial mandarin and less likely to suffer harvest damage. The fruit segment walls are 'chewy', but the flesh is pleasant to consume if the acid content is not too high.

Crop load management is a priority. Avana Tardivo trees can be strongly alternate bearing due to heavy fruit set in some years, as well as the practice of holding fruit late on the tree to decrease acidity. Heavy crop loads often weigh down the branches exposing the fruit to sunburn. Fruit can be snap-picked from the tree and are less likely to plug compared with Imperial mandarin. Despite its similarity to the Imperial mandarin, the seedy nature of the Avana Tardivo fruit will most likely see it displaced on the domestic market by newer, low seeded varieties.

Figure 54. Avana Tardivo di Ciaculli fruit on tree.

## Clementines

Clementine mandarins are one of the most popular varieties in the world. The original Clementine mandarin (also known as Algerian tangerine) is believed to have been a chance seedling (likely a Willowleaf mandarin × sweet orange hybrid, [Wu et al. 2014]) selected just over a century ago in Algeria.

Clementine mandarins tend to produce high yields of small fruit. They require cross-pollination for good fruit set, but this also makes the fruit very seedy. Growth regulators can be applied at flowering to improve seedless fruit set where cross-pollination is prevented. Clementines are more suited to Mediterranean type climates rather than humid subtropical or tropical climates. Important Clementine mandarin varieties include Caffin, Clemenules, Fina, Marisol, Nour, Nules and Oroval.

Australia has introduced 13 Clementine selections from Spain and New Zealand since the late 1980s, these being Marisol, Fina, Oroval, Nules, Hernandina, Arrufatina, Clementard, Corsica 1, Corsica 2, Caffin, Sidi Aissa, Orogrande and Nour. Sidi Aissa has a similar maturity period to Nules, while Orogande has been less productive and with lower fruit quality. Nour is later maturing, but has small fruit size and can retain a green tinge at the base of the fruit when mature. Nules clementine is the only selection to achieve significant commercial status.

### Nules clementine

Nules clementine, also known as Clemenules, deNules or simply Nules, is a bud mutation of Fina clementine, discovered in 1953 near the township of Nules in the Castellon province of Spain. Nules clementine was imported into Australia in 1987 and released to selected nurseries in 1989. It is the most widely planted clementine selection in Spain, Australia, South Africa, California and the South American countries of Chile, Uruguay and Argentina.

At the time of the 2014 census of Australian citrus plantings there were 97 hectares of mostly bearing trees planted in southern Australia (CAL 2016). Approximately 70% of the planted area was in the Riverland and 30% in Western Australia.

In southern Australia fruit mature by late April/ May, and under favourable climatic conditions can be held on the tree longer than other Clementine varieties. Fruit are internally mature before full skin colour development, so de-greening is required for early harvested fruit (Figure 55). Nules is considered one of the best Clementines for sweetness and flavour. Fruit are easy to peel with a bright orange skin colour at full maturity and a slightly pebbled rind texture. Nules is self -incompatible and fruit will be low-seeded if grown in isolation from other fertile citrus varieties (Figure 56). Seed counts can be as high as 25 seeds/fruit when fruit are cross-pollinated (Figure 57). For more information on seediness, see the Crop management chapter.

The main rootstocks used for Nules clementine in Australia are Carrizo and Troyer citranges. Most plantings are on sandy soil types. Trees are vigorous and can grow into large trees, with the potential to produce large yields of good sized fruit. A high level of tree management is required to consistently produce good crops. Nules clementine can have a prolonged flowering period in some seasons and this can result in multiple crops on the tree at the same time, with a range of fruit sizes, rind textures and maturities – making a single harvest difficult. Fruit should be clipped from the tree to avoid plugging.

Nules clementine has done well in the coastal growing regions of Western Australia with a Mediterranean-like climate, producing good yields and fruit quality over many years. Trees in these areas are less likely to suffer temperature extremes experienced in the hot, dry inland growing regions of southern Australia. Clementines have not become a major mandarin category in Australia due to a range of factors including competition with Imperial mandarin, the need for a high level of management and inconsistent production and fruit quality, partly due to weather conditions.

Figure 55. Nules clementine is internally mature before full skin colour development is achieved and early-season fruit need to be de-greened.

Figure 56. Nules clementine is an early to mid-season variety that is seedless if cross-pollination is prevented.

Figure 57. Nules clementine fruit under cross-pollination conditions can be very seedy.

## Daisy

Daisy is a public variety developed by the United States Department of Agriculture and imported by QDPI on behalf of the Australian Citrus Improvement Association (ACIA) [Florissen, Sanderson & Broadbent 2000]. It was released to industry in 1995. Daisy is a hybrid of Fremont mandarin (Clementine × Ponkan mandarin) and Fortune mandarin (Clementine × Dancy mandarin). Daisy is self-fertile and will readily cross-pollinate with other mandarin varieties.

At the time of the 2014 census of Australian citrus plantings there were around 108 hectares of Daisy mandarin, all of which were bearing trees (CAL 2016). Approximately 60% of the planted area is in the Riverland/Sunraysia area and 26% in Queensland. Daisy is very seedy (about 15 seeds/fruit) and local market resistance to seeded mandarins has meant that no new plantings have been established in recent years. The recent development of low-seeded selections through gamma irradiation will lead to new plantings of the variety with the aim of exporting to Asian markets. There are currently two Australian low-seeded Daisy mandarin selections being tested on a semi-commercial basis (Figure 58). A third selection developed at the University of California (with PBR) will be released from quarantine in 2017.

Daisy is a medium sized tree with a spreading habit and can develop an alternate bearing pattern if crop load is not managed (Figure 59). In heavy-crop years selective pruning and fruit thinning are recommended to improve fruit size and reduce alternate bearing. Fruit can also set in dense clusters which should be thinned to about two fruits to improve fruit size.

Daisy is a mid-season variety, harvested in May in Queensland and June in southern Australia. Fruit for export is usually harvested slightly earlier than that for the domestic market. Fruit are medium to large, round, often with a small neck at the stem end and can be snap-picked. Internal fruit quality is high with good juice (50%), °Brix (12) and acid (0.9%) levels. The rind is smooth to slightly pebbled, with a glossy, deep orange skin colour and a fine textured, pale orange flesh. Fruit are moderately easy to peel and can be held on the tree for an extended period, however internal quality begins to deteriorate by mid-July in the Riverland/Sunraysia region. In some seasons fruit are susceptible to splitting and albedo breakdown, particularly on *C. trifoliata* rootstock. Large fruit may be susceptible to granulation. For more information on these disorders, refer to the Disorders chapter.

Figure 58. Daisy mandarin is a seedy mid-season variety. Low-seeded selections are currently being commercially tested in Australia.

Figure 59. Daisy is a medium sized tree with a spreading habit. It can develop an alternate bearing pattern if crop load is not managed.

Delayed incompatibility has been seen on Troyer citrange rootstock with declining vigour and benching in older plantings. Incompatibility is also a problem with Swingle citrumelo, with tree decline beginning at around 8–10 years of age. This incompatibility problem can be overcome using a sweet orange inter-stock. See the Rootstocks chapter for more information.

Daisy mandarin is very susceptible to the fungal disease brown spot (*Alternaria alternata*), especially when grown in wet and/or humid locations, such as coastal NSW and Queensland. The bark of young trees with open wounds (such as those caused by sucker removal) can be invaded by the wood-rotting fungus, *Diplodia*. See the Diseases chapter for more information.

Daisy mandarin has shown good heat tolerance. Trees in an evaluation site at Dareton have endured temperatures as high as 45 °C with minimal fruit damage in comparison to heat and sunburn effects on a large range of other mandarin varieties.

## Dekopon™

Dekopon, also known as shiranuhi or shiranui and hallabong, is a hybrid of Kiyomi and Ponkan mandarins, and was bred in Japan. Dekopon was a brand name used for shiranui in Japan, but has since become a generic marketing name. In the US and Australia Dekopon is sold under the name Sumo Citrus™. It is grown commercially in Japan, Korea (where it is eaten fresh, but also used for jams, marmalades, vinegars, teas and other beverages) and in Brazil and California.

Although a public variety, it was first imported in to Australia in 2003 by Pacific Fresh at Leeton, NSW. The company also managed its commercial release and marketing. Budwood for propagation is supplied by Pacific Fresh with a mother tree source held by Auscitrus. A limit on tree numbers for Australia (175,000) has been set by Pacific Fresh. There are currently no other sources for this variety in Australia. Selections of earlier maturing shiranui (Figure 60) originating from Japan and South Korea are not yet available in Australia.

At the time of the 2014 CAL census, there were around 80 hectares of Dekopon with more than half non-bearing trees (CAL 2016). Most plantings are in the Sunraysia/Riverland and Riverina areas of southern Australia. The main rootstocks used are Carrizo citrange and *C. trifoliata*.

Figure 60. Early (left) and normal (right) shiranui selections.

Dekopon is a mid to late season mandarin; maturing between late July and August in the Sunraysia region and about two weeks later in the Riverina. Dekopon is a large fruited, easy peel variety, with a rough rind, yellow-orange peel colour and a very prominent neck ('knob') at the stem end (Figure 61). It is not an attractive fruit, but is juicy and sweet with a Brix:acid ratio of 14, and few seeds.

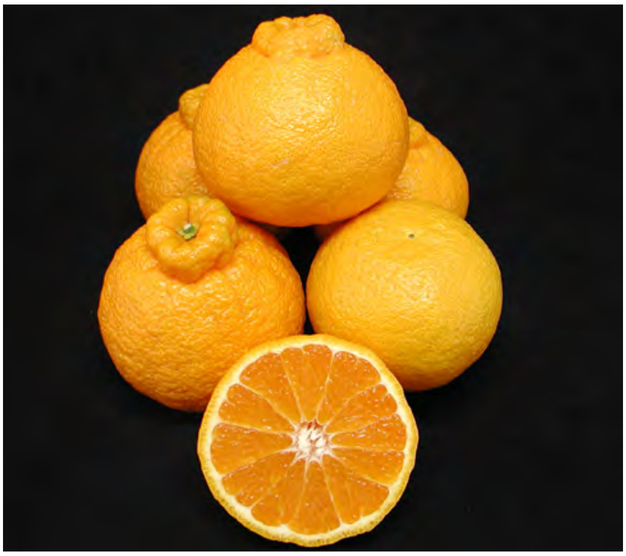


Figure 61. Dekopon is a mid to late maturing mandarin hybrid with a characteristic neck.

The tree has a bushy habit with the majority of the fruit produced on the ends of shoots (Figure 62), making any exposed fruit prone to sunburn in hot conditions. Over-cropping can occur, so fruit are thinned to reduce the risk of trees developing an alternate bearing pattern. The weight of the fruit can pull the lower branches down, so pruning is required to keep fruit off the ground. Dekopon is potentially high yielding with some 5 year old top-worked trees producing 50–60 kg of fruit. Fruit should be held on trees to develop a high sugar content. However, this strategy has to be managed carefully to ensure fruit maintain a high juice content and prevent segments from drying out at the ends. Growers have reported that Dekopon trees near pollen-fertile varieties, such as Murcott tangor and Imperial mandarin, have higher seed counts.

Figure 62. Dekopon fruit on the tree.

During wet weather, water may accumulate around the neck causing fruit rot. Fruit must be handled carefully during harvest to avoid skin damage, particularly to the neck. Clip fruit to avoid plugging. Specialised packing line equipment is needed to reduce damage during packing. A successful marketing campaign has been used to improve consumer acceptance of this variety's unusual shape. This variety may have export potential.

## Hickson

Hickson mandarin is an Australian selection reported by Jorgensen (1972) to have originated as a limb sport from an Ellendale tangor tree at Roma, Queensland. An alternative theory is that Hickson mandarin originated as a seedling of Beauty of Glen Retreat mandarin on the property of Mr Joe Stemp at Palmwoods, Queensland, some time prior to 1950. Data by Ashari, Aspinall & Sedgley (1989) are consistent with Hickson being a Beauty of Glen Retreat seedling and not a limb sport or a seedling of Ellendale tangor. Hickson has been known under other names such as Stemp and Success.

The 2014 census of Australian citrus plantings recorded 115 hectares of Hickson mandarin under cultivation in Queensland and Western Australia, with <5% of trees non-bearing. The principal rootstock used is Troyer citrange. Like Ellendale tangor, Hickson trees grow well for the first 10 years on rough lemon before declining.

General tree appearance is similar to Ellendale with leaf shape a little rounder and the leaf edges more serrated (Jorgensen 1972).

Hickson (Figure 63) is a mid-season, self-fertile variety maturing in June in Queensland, a couple of weeks earlier than Ellendale tangor. Hickson trees naturally set large crops of fruit which size well, are easy to peel, with good eating quality. Fruit are seedy (10–15 seeds/fruit), medium to large, often with a flattened shape and a thin yellow-orange skin. The fruit are less prone to wind-rub than many other mandarin varieties, and combined with its resistance to brown spot (*Alternaria alternata*) is a relatively low-cost mandarin to grow.

In Queensland, fruit have a small neck, often with a rough rind, but in southern Australia the rind is nearly always rough. The presence of a neck and the rough skin texture limit the potential to export this variety, particularly to Asian markets. In variety evaluation trials in the Sunraysia region, exposed fruit of Hickson mandarin has been shown to suffer severe sunburn.

Heavy crop loads also cause trees to split at the fork or suffer limb breakages. Hickson mandarin is susceptible to crotch rot, where wood rotting fungi (e.g. *Phomopsis* and *Diplodia*) invade the split forks, often causing tree death. Trees are also susceptible to the disorder 'winter yellows'. This disorder most commonly affects younger trees (2–5 years) with little or no crop, that have had vigorous shoot growth in late summer–early autumn. The disorder results in the roots being starved of carbohydrates (starch), leading to root death. Young trees with substantial root loss may not recover. See the Diseases and the Disorders chapters for more information.

Figure 63. Hickson mandarin is a mid-season variety which is seedy.

## Imperial

Imperial mandarin was a chance seedling found in an orchard at Emu Plains near Sydney around 1890. It was thought to be a hybrid of Willowleaf × Emperor mandarins, but isozyme genotyping by Ashari et al. (1989) indicated that this is probably incorrect. Imperial mandarin (also known as Early Imperial), although popular in Australia, is not grown commercially elsewhere. Goldup Imperial is an early maturing selection of Imperial found in the Sunraysia region and now predominantly planted in Queensland.

At the time of the 2014 census of Australian citrus plantings there were 1600 hectares of Imperial mandarins under cultivation, of which the majority were bearing trees (CAL 2016). There is also Goldup Imperial (an early maturing selection of Imperial mandarin) found in the Sunraysia region and now predominantly planted in Queensland. Until recently Imperial mandarin had long been the most widely planted variety in Australia, but it is now second to Murcott tangor. The majority of plantings are in Queensland, with the remainder in the Murray Valley, Riverland and Riverina regions.

Rootstocks used include Troyer citrange and Cleopatra mandarin. Incompatibility problems with *Citrus trifoliata* and its hybrids reduce the productive life of plantings, with trees on Troyer and Carrizo citranges declining at 12–15 years.

Recent trials in Queensland have shown Benton citrange to be a better performing rootstock for Imperial mandarin. A newly selected Yuzu hybrid (named 'Barkley', and originally from China) has also shown promise in a rootstock trial for Imperial mandarin at Gayndah, Queensland. It has a smooth bud union and produces good yields and fruit quality.

Imperial mandarin matures early and is usually the first mandarin of the season (Figure 64). The harvest period can run from late March to August, with late-held fruit from the southern growing regions (Murray Valley and Riverina). The fruit has a soft, thin, fine textured skin that is easily removed and the rind oil produces a distinctive aroma. Segments separate readily and the flavour is sweet if marketed at full maturity. Skin colour is yellow-orange with early season fruit from Queensland typically de-greened with ethylene gas. The peel is prone to plugging and fruit must be clipped. Fruit have a relatively short storage life of 2–4 weeks, depending on harvest maturity, and are generally unsuitable for export. The fruit are low-seeded (usually <5 seeds/fruit) in most plantings.

Figure 64. Imperial is the earliest mandarin variety and one of the most important on the Australian domestic market.

In some years Imperial mandarins are affected by a disorder known as granulation or internal dryness. Fruit show no obvious external symptoms, but when cut the fruit segments appear to be dry, white or colourless and are relatively tasteless. Fruit have lower extractable juice, soluble solids, sugar and acid levels. Research has yet to identify a single definitive cause, and it remains a problem of major commercial significance. For more information on granulation see the Disorders chapter.

Imperial is vigorous, upright and grows into a medium sized tree. Leaf shape is narrow, long and typical of a Mediterranean mandarin. Branches are thornless and regular pruning is practiced to open the centre of the tree to improve light penetration and reduce the upright nature of the growth. Imperial mandarin has a strong tendency to alternate bearing, which can be managed by fruit thinning and pruning in heavy crop years (Figure 65). For more information see the Crop management chapter.

Figure 65. Imperial mandarin has a strong tendency to alternate bearing which can be managed by fruit thinning and pruning in heavy crop years.

There have been many attempts at finding an alternative to Imperial mandarin through breeding programs and importations. Most of this effort has been by the QDAF citrus breeding program. The aim of this program is to develop mandarin varieties to fit the early marketing window that have domestic and export market potential, but without the typical production issues of Imperial mandarin such as small fruit size, alternate bearing, granulation and rootstock incompatibility. QDAF has developed a range of Ellendale × Murcott hybrids that are in the evaluation phase with the aim of releasing high quality, low seeded new varieties. None of the initial hybrids are as early-maturing as Imperial mandarin. In 1999 two Avana selections of Willowleaf mandarin, similar to Imperial, were introduced into Australia from Italy. For more information see the section on Avana.

## Murcott

Murcott tangor (also known as Honey Murcott) is a mandarin × sweet orange hybrid of obscure origin resulting from a breeding program in the USA. There have been multiple introductions of Murcott into Australia starting in the 1970s. Murcott is typically very seedy, but new low-seeded selections have been developed by irradiation in the last 15 years. These include: IrM1 (Figure 66) and IrM2 (Figure 67), developed by the QDAF and distributed by FAVCO and Carter & Spencer; Mor (Moria) developed in Israel and distributed by the Australian Nurserymen's Fruit Improvement Company Limited (ANFIC) and a low-seeded Murcott developed in Queensland by 2PH Farms. All these low-seeded selections are protected varieties.

Figure 66. IrM1 fruit ready for harvest.

Most interest in Queensland has been in IrM2 due to its earlier fruit maturity and skin colour development. IrM2 matures about 2 weeks earlier than IrM1, but tends to have a higher fruit set in southern Australia which can lead to smaller fruit size. Ironbark Citrus has a patented variety known as Royal Honey Murcott (Figure 68) or RHM (see the section on New varieties with commercial potential).

There were 1,618 hectares of Murcott tangor, predominantly in Queensland, at the time of the 2014 CAL census of Australian citrus plantings. It is the most important mandarin variety in Australia grown for both domestic and export markets (predominantly in south-east Asia). Around 30% of plantings are low-seeded selections.

A range of rootstocks is used, but rough lemon is unsuitable. The long-term compatibility of Murcott tangor on Swingle citrumelo is also questionable (see the Rootstock chapter for more information).

Murcott tangor is a late maturing variety harvested between July and September, depending on location. Trees have an upright habit with moderate vigour and become bushy with age. Murcott tangor requires good crop management to balance canopy size with crop load as it has a strong tendency to develop an alternate bearing pattern if crop load is not managed. Trees can suddenly collapse under a heavy crop load in an 'on' year, as a result of carbohydrate starvation of the tree roots due to the strong demand by the heavy crop (see the Disorders chapter for more information). Fruit thinning and tree mineral nutrition are key elements to achieving marketable fruit size, good rind quality and consistent cropping.

Figure 67. Fruit of IrM2, a low-seeded Murcott.

Figure 68. Royal Honey Murcott (RMH) mandarin.

Fruit are firm, can be held on the tree for an extended harvest period and have good postharvest storage characteristics. Fruit produced on the outer part of the canopy are sensitive to sunburn and wind blemish. Fruit are medium to large, depending on the level of fruit thinning. The skin is thin, ranging from smooth to slightly pebbly with shallow ribs. The thin skin can be difficult to peel, but the segments leave the albedo freely. Internal fruit quality is good with high °Brix levels and juice content, and the flesh is orange-coloured, with a rich flavour.

A major problem with the original Murcott tangor is the high seed number (10–20 seeds/fruit; Figure 69), even if trees are isolated from cross-pollinating varieties or grown as a single variety in large blocks. The development of low-seeded Murcotts with seed counts of 0–5 seeds/fruit, even in cross-pollination situations, has seen their rapid commercial adoption in Australia. However, these low seeded selections can be more sensitive to skin blemish, particularly 'tear-staining', which is thought to be a result of multiple fungicide applications, possibly under unfavourable weather conditions.

Figure 69. Murcott tangor.

## Satsumas

Satsuma mandarins, or Unshiu mikan, originated in Japan and are the most cold tolerant of all citrus fruit, especially when grown on *C. trifoliata* rootstock. A large range of selections have been developed in Japan and are grouped according to their time of fruit maturity. Satsuma mandarins are grown in countries such as Spain, China, Korea, South Africa, the USA, Uruguay, Argentina and New Zealand.

At the time of the 2014 CAL census of Australian citrus plantings, there were around 52 hectares of Satsuma mandarins under cultivation, of which approximately a quarter were non-bearing trees (CAL 2016). Satsumas are more suited to southern Australian growing conditions and most plantings are in the Riverland area. The main rootstock used has been Carrizo citrange.

The Silverhill Owari satsuma was an early introduction with limited commercial adoption. Okitsu and Miho Wase — both early maturing, seedless selections — were introduced in 1991 and released to nurserymen in 1996. A late maturing variety from Spain called Clausellina is also available, but has not been widely planted, largely as a result of poor fruit quality.

Okitsu Wase is the main Satsuma variety grown in Australia (Figure 70) and has a short maturity window of 3–4 weeks from early April to early May in southern Australia. Miho Wase satsuma matures approximately one week earlier than Okitsu Wase, but often does not have the same intensity of skin colour. Fruit are easy to peel, moderately smooth, seedless and slightly necked with a thin skin. Segments are readily separable, with a rich sub-acid flavour. Fruit of both varieties can be internally mature before full skin colour development, and ethylene de-greening is sometimes used for early marketing as a result. Fruit held on the tree for a prolonged period deteriorate rapidly and develop 'off flavours' and puffy rinds.

Figure 70. Okitsu Wase satsuma is an early seedless cold tolerant variety grown mainly in southern Australia.

Nursery trees of Satsuma mandarin are often slow to establish but grow into almost thornless, medium-sized trees with a spreading and drooping habit. Selective pruning and limb removal to open-up the tree and allow good light penetration will assist in fruit colour development. Satsuma mandarins tend to produce and retain high numbers of fruitlets, requiring fruit thinning to balance crop load.

Sunburn can be a major issue on exposed fruit, particularly on the western sides of trees. Damage is obvious with yellow and brown marking as well as misshapen fruit and internal dryness extending well into the fruit segments. Sunburnt fruit should be removed during thinning and harvest operations. Fruit must be clipped from the tree and handled carefully because they are susceptible to compression damage, splitting and stem end plugging by rough handling during harvest. Yields of 80–110 kg per tree have been achieved on 7 year old top-worked trees of Okitsu Wase satsuma in the Sunraysia area of southern Australia.

Satsuma mandarins are often in direct market competition with early season Imperial mandarins from Queensland. One common consumer complaint has been that Satsumas lack flavour and a sweet taste. A period of controlled water stress prior to harvest can be used to increase sugar content and maintain acid levels in fruit (Sanderson, 2003). For more information refer to the Irrigation chapter.

## Minor varieties

### Amigo

Amigo is a nucellar seedling found near an Ellendale tangor tree at Merbein, Victoria, in the Sunraysia region. It may be a natural hybrid of Imperial mandarin × Ellendale tangor. Budwood of Amigo is supplied as a public access variety by Auscitrus.

Trees have a similar upright growth habit to Imperial mandarin. Bud union overgrowth as a result of incompatibility can occur with *C. trifoliata* and its hybrids, but the effect is more delayed than with Imperial mandarin. Amigo on citrange rootstock has reached 18 years of age before decline was apparent.

Amigo fruit (Figure 71) are seedy, but this can vary from zero to >10 seeds/fruit. The fruit are easy to peel and do not have the unpleasant aroma that can occur with Ellendale hybrids. Fruit have a sweet flavour and high juice content (40–45%) at the beginning of its marketing period. The distinguishing feature of Amigo is its bright orange rind colour and a tendency to have a raised stem-end or 'neck'. Amigo overlaps the Imperial mandarin season, but matures several weeks later than Imperial. The harvest period can extend to the end of August in southern Australia. Fruit do not granulate, but do become puffy late in the season.

Figure 71. Amigo fruit.

### Fremont

Fremont is a public variety from California, imported into Australia as seed in 1968 by QDAF. It is a cross between a Clementine and Ponkan mandarin. QDAF has developed a low-seeded Fremont by gamma irradiation. This selection is currently being evaluated on a commercial scale and additional plantings are likely. The variety is predominantly grown in Queensland where it can achieve larger fruit size than in the hotter drier regions in southern Australia.

Trees are moderately vigorous with small to medium sized fruit. Trees can over-crop leading to very small fruit size. Fremont has an intense orange-red skin colour which is a distinctive characteristic of the variety (Figure 72). Fruit are sweet but 'chewy' due to the firm segment walls. In the NSW DPI arboretum at Dareton Fremont has shown some sensitivity to sunburn because fruit are borne at the ends of branches. Fruit of this older selection are also seedy with counts as high as 15 seeds/fruit recorded in desert areas of California. Fruit has been exported to the Middle East and there are marketing opportunities in the Philippines, Thailand and Malaysia.

Figure 72. Fremont fruit.

### Gold Nugget

Gold Nugget is a hybrid of Wilking (King tangor × Willowleaf mandarin) × Kincy (King tangor × Dancy mandarin). It has PBR protection and was developed by the University of California at Riverside. The variety manager in Australia is Nuleaf IP Pty Ltd. Tree growth is vigorous and tends to be upright and thorny when trees are young.

Management of tree growth is critical for good fruit production. Removal of upright vigorous branches is one strategy used in the USA. Bending branches until there is an audible 'crack' is another technique used in Spain to position shoots and limbs in a more horizontal plane to encourage fruiting. Top-worked evaluation trees have tended to become more consistent in productivity as they aged, but nursery grown trees have shown a stronger alternate bearing pattern, probably related to ineffective tree canopy management. There is a need to set a heavy crop load on Gold Nugget trees as this helps reduce the pebbled, bumpy rind texture of fruit. Large fruit can have very coarse rinds which could make fruit unmarketable.

Rind colour is yellow to orange with full colour developed by late July in the Sunraysia region. The basal (stylar) end of fruit can also crack and be penetrated by the *Alternaria* fungus, leading to black core rot (see Postharvest diseases and disorders chapter).

Fruit eating quality is good, with a sweet, rich flavour at maturity. Juice content is usually high (40%) and sugar to acid ratios of 18:1 can be reached at peak maturity in mid–late August in the Sunraysia region. Seed counts at evaluation sites with pollen-fertile varieties nearby have been as low as 0.03 seeds/fruit. Fruit will hold on the tree in good condition for an extended period, allowing a long harvesting window, which can extend into September in southern Australia.

Fruit peeled at picking release a substantial amount of oil from the peel. Harvested fruit should be allowed to 'rest' for several days prior to packing to reduce oil release and oleocellosis. Specialist grading and packing equipment is needed to reduce rind damage from oil release during postharvest handling operations. The difficulty in handling fruit after harvest has resulted in the removal of one large planting in South Australia.

Figure 73. Gold nugget fruit.

## Nectar

Nectar is an Israeli variety with PBR that resulted from a controlled pollination of Wilking mandarin (King tangor × Willowleaf mandarin). It is not a commercial variety in Israel due to its strong alternate bearing tendency. The variety was released by the Australian Nurseryman's Fruit Improvement Company (ANFIC) for commercial development in Queensland as an alternative to mid-season varieties, such as Hickson and Ellendale tangor.

Nectar tends to set fruit within a bushy canopy which makes it difficult to estimate how much fruit to thin. Because of the dense foliage fruit tend to be abraded and blemished. Heavy pruning is necessary to maintain an open canopy. Heavy crop loads of small fruit may result from inadequate tree management and lead to a pattern of strong alternate bearing. Trees have medium vigour, lack thorns and heavy fruit loads may cause limbs to bend and sometimes break.

The fruit (Figure 73) is slightly flattened, has a smooth to pebbled rind texture, an orange-yellow rind colour, is relatively easy to peel, has orange flesh and a seed count of <1 seeds/fruit, even in mixed blocks. Fruit have a good juice content and the flavour is rich and sweet. Maturity is late June to the end of July in Sunraysia and approximately 3 weeks earlier in Queensland. The marketing window for Nectar in Queensland can overlap with the end of the Imperial mandarin season and this has caused problems with fruit sales. Some Nectar trees have been removed in Queensland, and this trend may continue.

## Nova

Nova (also known as Suntina and Clemenvilla) is a hybrid of Fina Clementine × Orlando tangelo and is predominantly grown in Queensland. There are two sources of Nova in Australia: a seed import into Queensland and a more recent budwood introduction from Spain by QDPI. There are also two early Nova selections (MJR11 and MJR12) from Queensland that could lead to the expansion of plantings in Australia.

Trees are vigorous with some thorns and can produce good quality fruit. The rind colour is red-orange and can be initially difficult to peel due to the firmness of the fruit. Flesh is orange and segments separate easily. Juice content at maturity is typically >40%. Fruit are low-seeded if isolated from other pollen fertile varieties, but fruit numbers are often lower when trees are not cross-pollinated.

The maturity period for the early Nova selections is mid March to mid–April in Queensland, with de-greening needed for the initial marketing period. The harvest season is relatively short as granulation can develop if fruit are held on the tree for prolonged periods. Basal splitting of the fruit and black core rot (*Alternaria*) has also been an issue in southern Australia. The variety is susceptible to Alternaria brown spot under humid conditions.

Figure 74. Nova fruit.

### Taylor-Lee

Taylor-Lee is a privately owned variety from 2PH orchards at Emerald and was grown from seed with one parent being Murcott tangor. 2PH has also developed a low-seeded selection of Taylor-Lee through gamma irradiation, which is under variety management by Variety Access Pty Ltd.

Trees are large and can hold heavy crop loads, but if over-cropped can develop alternate bearing. Fruit are large, orange coloured (Figure 75), with a high juice content and good flavour. The rind thickness is between 3–4 mm and considered easier to peel than Murcott tangor. Seed numbers can be as high as 30–40 seeds/fruit in the original variety.

Figure 75. Taylor-Lee fruit.

### Topaz

Topaz is an Israeli selection of Ortanique tangor, which is a natural hybrid of an orange and a mandarin. It was introduced into Australia as a public access variety by the South Australian Department of Agriculture. There is also a seedling selection of Ortanique from Western Australia called Mystique.

Trees are large and capable of setting heavy crops which can be held on the tree for an extended period without deterioration. Vigorous shoot growth can be thorny and may need to be pruned out. Fruit tend to be large, orange coloured with a coarse rind that is not easy to peel and releases a lot of oil in the process. Juice content is high and eating quality good. Fruit are seeded in mixed plantings and often marketed at the end of the Murcott season. Mystique has similar fruit and tree characteristic to Topaz and is marketed from September to early November in Western Australia. Plantings have also been established to provide mandarin juice for blending with orange juice for the fresh juice market.

Figure 76. Topaz fruit.

## Promising new varieties

### Orri

Orri (the marketing name of Or 4) is a PBR protected variety from Israel and is an induced mutation of Orah (a hybrid of Temple tangor × Dancy mandarin). Although fruit have been produced from evaluation trees since 2009, commercial release of this variety in Australia is still under negotiation.

Orri fruit (Figure 77) are firm, with a slightly pebbled to smooth, orange-yellow rind that is relatively easy to peel. There is moderate oil release when peeling. Full skin colour is usually reached by early July in southern Australia, but acceptable eating quality can be achieved by mid-June. Orri is considered one of the highest quality eating mandarins available worldwide. Seed number averages 2 seeds/fruit in a mixed variety evaluation planting in the Sunraysia region. The fruit have a distinctive sweet and juicy flavour and segments separate easily. High °Brix levels (14) can be achieved without the loss of acid content, giving a balanced flavour.

Figure 77. Orri mandarin.

The major problem with Orri in Australian evaluation plantings has been its erratic cropping habit. The tree is very vigorous and this vigour has affected the fruiting potential of the variety. Strategies to control excessive vigour have included limb girdling at flowering, heavy pruning and gibberellic acid (GA) application at the end of petal fall to assist fruit set. The current strategy is to tie down limbs soon after tree establishment to encourage flowering and early fruit set to weigh down limbs and develop a more open canopy structure. Another option may be the use of a much lower vigour rootstock, such as Flying Dragon, to reduce scion growth.

The commercial adoption of Orri in Australia will be dependent on an economic assessment of the establishment, management and royalty costs against potential export and domestic market returns.

## Royal Honey Murcott (RHM)

RHM originated as a chance seedling discovered in 2001 in a commercial citrus planting at Eidsvold, Queensland. It is believed to be the progeny of Ellendale tangor (female parent) × Murcott tangor. RHM is PBR protected and owned by Ironbark Citrus, Mundubbera Queensland and is under variety management by Variety Access Pty Ltd. There are currently trial plantings of RHM in South Africa, Chile, USA and Spain.

The tree is vigorous and upright and requires canopy management for good fruit production. Trials to improve fruit set on top-worked evaluation trees have included limb girdling, pruning and a GA application at the end of flowering.

RHM fruit (Figure 78) are easy to peel, smooth, orange coloured and maintain good external quality with prolonged storage on the tree. The acid content of the fruit is low and continues to decline with on-tree storage. The flavour can be bland to an Australian palate, but has received favourable comment from Asian buyers and markets. RHM is currently grown in Queensland and is early maturing and harvested from late May to late June. RHM could be established in southern Australia to extend the marketing period into July. The variety can have seed counts of 12 seeds/ fruit when planted close to other pollen fertile varieties, but is low-seeded in solid plantings. Average seed counts of <1 seed/fruit have been recorded over two seasons at the Dareton evaluation site, even in a mixed citrus planting.

Figure 78. Royal Honey Murcott.

## Summerina

Summerina is thought to be a bud mutation from a commercial citrus planting in the Riverland region of South Australia. It is under variety management by Advanced Production Methods Pty Ltd (APM) at Mildura.

Top worked trees can be slow to come into production due to strong vigour and an upright growth habit. Fruit are easy to peel, coarse and bumpy with a ‘nipple’ at the base of some fruit (Figure 79). Fruit colour is yellow-orange and the flavour is sweet, but becomes bland at the end of the season, due to a low acid content. Fruit are seedless in a mixed variety planting. The harvest period is late season from early-September to mid-October. Internal fruit maturity can be achieved early, but fruit can be held on the tree for late marketing. Juice content is variable with young evaluation trees averaging 35–40%, whereas mature trees in South Australia have had higher juice levels (50%) in mid-September.

Figure 79. Summerina fruit.

## Other varieties

The lack of commercial interest in some new varieties can be due to a range of factors such as seediness, rough skin texture, poor or erratic cropping, thorniness, fruit granulation, inferior fruit quality or low market potential.

A major role of the Australian evaluation program is to identify varieties that have little or no commercial potential for the Australian citrus industry. This role is becoming increasingly important as most new varieties are under variety management schemes and require contractual agreements being entered into prior to tree establishment. To obtain a commercial advantage some growers are willing to take a risk and establish plantings based only on overseas performance information.

### Clementine mandarin × Tarocco blood orange – seedless triploid mandarins

Triploids are the result of crossing a tetraploid variety (4N) that has double the number of chromosomes with a variety that has a 'normal' number of chromosomes (2N). This can result in a triploid (3N) hybrid which is usually seedless, but can also be very thorny. Four such triploids have been imported and evaluated at Dareton:

1. **Tacle tangor** (Italy – PBR) a hybrid of Clementine Monreal × tetraploid Tarocco orange. Fruit are large and have smooth orange skin which is easy to remove. Fruit have high eating quality with good sugar to acid balance, but an erratic cropping habit and extreme thorniness makes it difficult to harvest.
2. **C1829 tangor** (Italy – PBR) a hybrid of Oroval Clementine × tetraploid Tarocco orange. Evaluation trees have been very slow to crop and sensitive to high fertiliser rates which have caused defoliation. Trees are thorny and exhibit an alternate bearing habit. There has been no anthocyanin pigment development in the flesh under southern inland conditions.
3. **C1867 tangor** (Italy – PBR) a hybrid of Oroval clementine × tetraploid Tarocco orange. It is the best performing of these hybrids (Tacle, C1829, 1867 and Alkantara) from Italy. Trees are thorny and exhibit an alternate bearing habit. Fruit size is smaller than the other hybrids, but still acceptable. There has been no anthocyanin pigment development in the flesh under southern inland conditions, but some pigmentation was achieved with fruit stored at <5 °C for at least 3 weeks. The expression of pigment was also enhanced when the fruit received some pre-chilling on the tree prior to harvest.
4. **Alkantara tangor C2191** (Italy – PBR) an early maturing hybrid of Oroval Clementine × tetraploid Tarocco orange and patented as 'Alkantara'. It produces large fruit that quickly become puffy if held on the tree past optimum maturity. Fruit can retain a green tinge, even when mature. The tree has an alternate bearing habit. There is no anthocyanin pigment development in the flesh in the field or with cool storage. The initial commercial interest in this variety was related to its early maturity (May), seedlessness and large fruit size.

### Mandalate (Italy –PBR)

Triploid hybrid (D8811) from Fortune mandarin × tetraploid Avana mandarin. Mandalate was imported as a potential variety to extend the Imperial marketing season, with 'Imperial like' fruit that are seedless and have good fruit quality. Tree growth habit and fruit appearance is very similar to its Avana parent. It has an aromatic smell released during peeling. However, fruit have a high acid content and have to be held on the tree for a prolonged period before becoming palatable. Stop-Drop® sprays and GA application are required to hold fruit and maintain rind condition. An alternate bearing habit and small fruit size were also issues, along with the recommendation not to use *C. trifoliata* rootstock due to its tendency to elevate the acid content of fruit.

## Primosole mandarin (Italy – public)

Primosole mandarin is also known as Clemensole in Spain. It is an Italian hybrid of Carvalhais mandarin × Miho Wase satsuma. Fruit granulated at all Australian evaluation sites due to its poor tolerance of warm weather conditions. Internal fruit quality is poor, with low sugar and acid content causing a bland flavour. One of the poorest performing mandarin varieties tested in Australia.

## TDE 2 (Shasta Gold), TDE 3 (Tahoe Gold) and TDE 4 (Yosemite Gold) (California – PBR)

Triploid hybrid selections of (Temple tangor × tetraploid Dancy mandarin) × Encore mandarin. Initial interest in this group of varieties diminished once trees were viewed at Australian evaluation sites. Positive characteristics include the sequential maturity period of all 3 hybrids, orange-red rind colour, low seed number and large fruit size. However, the main negative characteristic is the thorny nature of the trees which makes harvest operations difficult and potentially dangerous for pickers. Another issue is the coarse skin of fruit. In addition some test marketing comments suggested the fruit can be too large. TDE 4 (Yosemite Gold) was the preferred selection for commercialisation in Australia as it has less thorns and a slightly smoother skin, but it also has the lowest yield.

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# Rootstocks

## Introduction

Mandarin trees are propagated by budding on to seedling rootstocks (Figure 80). Rootstocks are used because grafted trees produce fruit from about their third year, whereas citrus grown on their own roots have a long juvenile period and may not bear fruit until anywhere between 7 and 15 years of age. Rootstocks are selected for their ability to enhance cultivar yield and quality and tolerance to various soil conditions and pest and disease problems. Rootstocks also vary in their tolerance to cold, drought, flooding, soil type and salinity, pH and fertility.

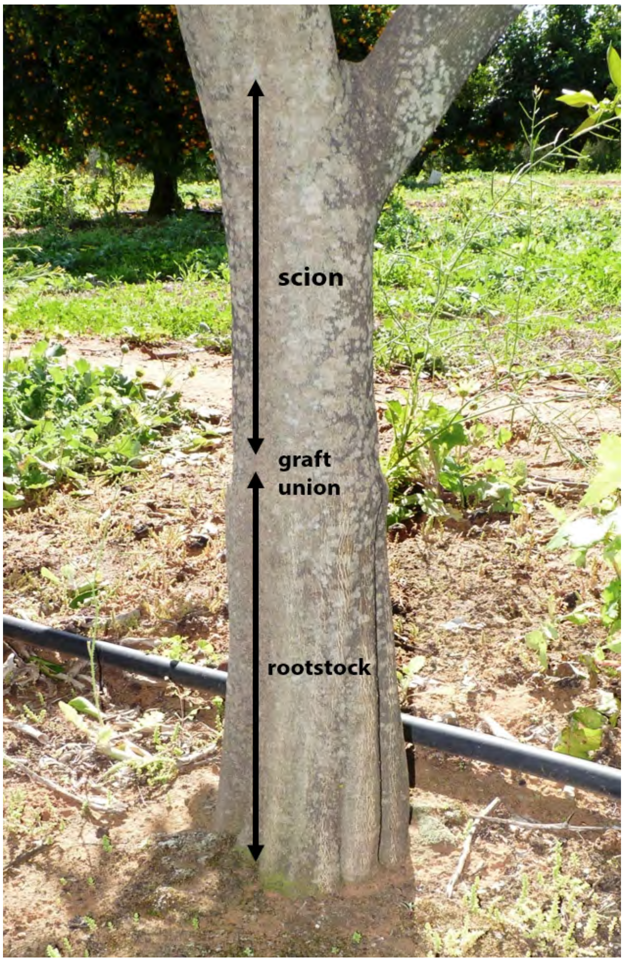


Figure 80. Citrus trees are grown on selected rootstocks. This photo is young Daisy mandarin grafted on Carrizo citrange rootstock, showing a smooth graft union.

Careful selection of a suitable rootstock is important for the long-term health and productivity of any orchard. There is no ideal rootstock for all sites and for all varieties. Final rootstock choice will be a compromise. The choice depends on a large number of important factors, including scion variety, compatibility and local environmental and site conditions. Soil type and drainage are critical factors and are often the basis for rootstock decisions.

The most important issues that affect citrus tree performance in Australia and that need to be considered when choosing a rootstock include tolerance to Phytophthora root and collar rots, *citrus tristeza virus* (CTV), citrus nematodes, lime and salt. Rootstocks also differ in their ability to thrive in soils that have previously been used to grow citrus (i.e. replant sites).

Rootstocks have pronounced effects on scion vigour and tree size, fruit size and yield, fruit quality characteristics such as juice, sugar and acid content, skin texture and thickness and maturity timing. These are usually evaluated in breeding and rootstock trials, along with susceptibility to key pests and diseases. Sometimes a rootstock is bred or evaluated for a specific purpose, such as tree size control, Phytophthora resistance, tolerance to conditions such as high salinity, high pH or calcareous soils.

Traditionally, rootstock evaluation trials were designed to be long-term; at least 12–15 years of data were collected to fully assess scion:rootstock combinations and to identify any incompatibility problems. Today, given the number of new mandarin varieties being bred and/or introduced into Australia, as well as the cost of conducting such long term research trials, many newer mandarin varieties may not have been fully tested on a broad range of rootstocks or under Australian conditions.

Rootstock evaluation normally relies on common measures of horticultural performance, but rootstock selection decisions based only on those traits do not take into account differences in the relative value or contribution of each rootstock attribute. For a more comprehensive assessment of rootstock choice an alternative approach is to integrate the horticultural performance data with an economic analysis. For example, for juicing varieties such as Valencia orange, Castle et al. (2010) showed that even though trees on *Citrus volkameriana* produced fruit with poor juice quality and high losses to blight disease, they were precocious bearers, relatively high-yielding and had one of the highest cash flows and rates of return. In contrast, for mandarins grown predominately for the fresh fruit market, consideration of fruit quality characteristics is critically important when choosing a rootstock.

When selecting a rootstock the key steps involved include:

- eliminating incompatible combinations
- assessing the soil conditions at the site (including whether it is a virgin or replant soil)
- choosing the horticultural characteristics that best meet the requirements of the markets you seek to supply.

### Factors to consider before choosing a rootstock:

- **Soil conditions:** A full soil survey of the site by a soil scientist is recommended. A soil survey involves digging soil pits or soil cores in a grid pattern across the site. Soil pits allow visual assessment of soil texture, depth and structure down the entire profile and are particularly useful for identifying the presence of any impermeable or other layers that may impede root growth and drainage and cause temporary waterlogging. Samples of the soil in the different layers should also be analysed for their chemical and physical properties to identify any potential problems related to pH (especially alkalinity), fertility, salinity and drainage. For more detailed information on soils and their properties refer to the Orchard basics and Irrigation chapters.

  Soil survey data (soil profiles and descriptions, reports and maps) are also available on the following websites: *Australian Soil Resource Information System* (ASRIS) database; *Queensland Spatial Catalogue – QSpatial; NSW Office of Environment & Heritage eSPADE* and the *Victorian Soil Information System* (VSIS).
- **Scion variety**: important for rootstock compatibility.
- **Maturity timing**: early, mid or late rootstocks can affect the timing of fruit maturity, but this effect is only up to about 10 days.
- **Water supply**: source, quality and reliability of supply. Rootstocks vary in their ability to use soil water, to withstand water shortages and in their tolerance to salinity.
- **Management practices**: irrigation system and practices; nutrition practices such as fertigation and open hydroponics (OHS).

  Currently only a small number of rootstocks are recommended for mandarins and all have some limitations. The main rootstocks currently used in Australia for mandarins are *Citrus trifoliata* (syn. *P. trifoliata*, trifoliate orange), Cleopatra mandarin and Troyer and Carrizo citrange. Troyer citrange is preferred in Queensland and Carrizo citrange is preferred in the southern states; however, there is little difference in performance between the two. Other rootstocks used include Benton citrange, rough lemon, sweet orange and Swingle citrumelo. The advantages and disadvantages of some of the main citrus rootstocks are summarised in Table 25.

There are several mandarin rootstock trials currently underway in Australia – the details of which are also summarised in this chapter.

### Rootstock characteristics for Australian conditions should include (Broadbent 1988):

***Essential***

- ☑ Good horticultural performance – such as yield and yield efficiency of stock/scion combination.
- ☑ Good scion fruit quality.
- ☑ Suitability to soil conditions.
- ☑ Tolerance to *citrus tristeza virus* (CTV).
- ☑ Tolerance to Phytophthora root and collar rots.

***Desirable***

- ☑ Salt tolerance.
- ☑ Lime tolerance.
- ☑ Citrus nematode resistance.
- ☑ Tolerance to waterlogging.
- ☑ Dwarfing.
- ☑ Seediness and nucellar embryony of rootstock to produce true to type seedlings.

***Minor***

- ☑ Drought tolerance.
- ☑ Cold tolerance.

## Compatibility

Of all the citrus types grown on rootstocks, mandarin and their hybrids are the most susceptible to incompatibility problems and there are a number of important combinations that are particularly problematic. The basis of the incompatibility can be physiological and/or anatomical, but can also be related to a viral or viroid infection. Poor cropping, poor tree appearance and size can be symptoms of incompatibility.

Webber (1948) suggested compatibility is usually indicated by a straight, smooth bud union (Figure 80). Progressively greater size differences between the rootstock and the scion indicates decreasing degrees of compatibility. The bud union is usually easily identifiable by the difference in size between the rootstock and scion, but this is not always the case. Different bark textures and colours of the rootstock and the scion can also help in locating the union. Mandarin type rootstocks can have a slate-brown colour readily distinguishable from the scion.

The rootstock is generally round and smooth as with sweet orange and rough lemon. However, with trifoliate orange and many of its hybrids the rootstock may be deeply ridged and convoluted (sometimes referred to as benching or fluting) with the bark folds extending inwards. These large ridges usually represent the extension of large lateral roots.

Incompatibility problems typically occur at the bud union, resulting in either the scion overgrowing the rootstock or more commonly the rootstock overgrowing the scion. However, a swelling at the bud union is not necessarily an indication of incompatibility. Depending on the degree of overgrowth, tree growth and production will decline and in some instances can be so severe as to cause tree death. The age at which trees start to decline varies and sometimes compatibility problems do not become evident for many years.

Graft union abnormalities that occur as a result of incompatibility are usually associated with external symptoms, such as:

- an overgrowth at, above, or below the graft union
- gumming at the graft union
- abnormal suckering above or below the union
- dryness of the bark, usually both above and below the union
- external cracking or rupturing of the bark at the bud union
- bud union crease.

Bud union crease is an indented ring at the bud union causing a cincturing effect and is often in association with gum production (Figure 81). It causes the food transport vessels (phloem) to degenerate and can be recognized by the development of a brown line or necrotic area under the bark. The crease restricts the movement of carbohydrates down to the roots, with starch accumulation above the bud union and a reduction below, resulting in the roots starving. Bud union crease may result in a mechanically weak union causing trees to break at the union.

The appearance of the rootstock may be influenced by the presence of other diseases. For example, in Figure 82 *C. trifoliata* is infected with citrus exocortis viroid (CEV) showing bark scaling. Figure 83 shows a healthy bud union with the typical convoluted bark folds associated with C. trifoliata.

With bud union crease caused by *citrus tatter leaf* or *citrus leaf blotch viruses*, it is common to find suckers on the rootstock, particularly with *C. trifoliata* stock and its hybrids.

When C. macrophylla rootstock is infected with stem pitting strains of CTV carried in the scion, the trunk becomes 'ropey' with large pits visible externally or numerous small pits when the bark is removed. C. macrophylla can also react to cachexia (xyloporosis or hop stunt virus [HSV]) carried in an infected scion, by showing inverse pitting and gumming.

Most mandarins grown on C. trifoliata and its hybrids with sweet orange, namely Troyer and Carrizo citranges and Swingle citrumelo, show some degree of incompatibility. It shows up as the rootstock overgrowing the scion, commonly referred to as benching (Figure 84). With some combinations this overgrowth does not appear to have a significant effect on tree performance (e.g. Ellendale tangor on C. trifoliata, Murcott on Cleopatra mandarin), but for other varieties this incompatibility can eventually cause tree decline or even death (e.g. Imperial on Troyer citrange; Figure 85).

A strong trend for rootstocks to differ in the extent to which they influenced benching in four mandarin varieties (Imperial, Fallglo, Nova and Nules), and for rootstocks to have a consistent effect across different scions, has been noted in Queensland (Smith 2007). Benching tended to be more severe on Swingle citrumelo and least on sweet orange and Cleopatra mandarin.

Imperial mandarin has a tendency to bench more severely than other varieties. Imperial grown on Troyer citrange can start to decline from about 5–7 years but more commonly at between 13 to 15 years (Figure 86). Stress (such as over-cropping) or poor management practices can exacerbate the problem.

Other examples of incompatibilities include Silverhill Satsuma mandarin on Troyer citrange, and Imperial, Hickson and Satsuma mandarins and Ellendale tangor showing delayed incompatibility with rough lemon after 12–15 years (Sarooshi et al. 2000). The long-term compatibility of Murcott tangor on Swingle citrumelo is also questionable. In Florida, this combination shows symptoms of canopy decline when trees are about 6–8 years old. A bud union crease, commonly with a brownish-yellow stain, can be seen when a strip of bark is removed at the bud union (Castle & Stover 2000). Table 26 outlines some known incompatibilities for various scion rootstock combinations.

Figure 81. Bud union crease of a navel orange on *C. trifoliata* rootstock, caused by citrus tatter leaf virus infection.

Figure 82. *C. trifoliata* rootstock with an orange scion showing bark scaling due to infection by citrus exocortis viroid (CEV).

Figure 83. *C. trifoliata* rootstock with an orange scion showing a healthy bud union with typical fluting of the rootstock.

Figure 84. Imperial mandarin on C. trifoliata – note sprouting and severe benching/fluting of rootstock due to incompatibility.

Figure 85. Imperial mandarin on Troyer citrange showing rootstock overgrowth.

Figure 86. A 13-year old Imperial mandarin on Cleopatra mandarin rootstock. Photo: Malcolm Smith.


Figure 87. Imperial mandarin grown on Troyer citrange using a Valencia orange interstock.

Figure 88. Ellendale tangor on Cleopatra mandarin rootstock showing a smooth bud union.

Figure 89. Ellendale tangor on Carrizo citrange, showing slight overgrowth of rootstock.

Figure 90. Murcott tangor on C. trifoliata.

Figure 91. Decline due to incompatibility of Imperial mandarin on Carrizo citrange after 15 years.

Figure 92. Imperial on Nelspruit ×639 showing severe benching on 4 year old trees. Photo: Malcolm Smith.

Rootstocks

Table 25. The advantages and disadvantages of some of the main citrus rootstocks. (Summarised from various publications listed in the references section of this chapter).

| Rootstock | Advantages | Disadvantages |
|---|---|---|
| **Benton citrange** | • Suitable for both virgin and replant sites<br>• Moderate yields and good yield efficiency<br>• Suitable for high density planting<br>• Good fruit quality<br>• Tolerant of Phytophthora, cachexia and citrus nematode and resistant to CTV | • Intolerant of highly alkaline soils<br>• Poor salt tolerance<br>• Susceptible to exocortis, but symptom expression unknown |
| **C-35 citrange** | • Suitable for both virgin and replant sites<br>• Moderate yields of good quality fruit<br>• Tolerant of Phytophthora root rot, cachexia, CTV and citrus nematode | • Not suitable for heavy or high pH soils<br>• Poor salt tolerance<br>• Susceptible to exocortis but symptom expression unknown |
| **Carrizo and Troyer citrange** | • Suitable for both virgin and replant sites<br>• Grows well on a range of soil types but not heavy clays<br>• Moderate salt tolerance<br>• Highly productive with good fruit quality<br>• Tolerant of Phytophthora and cachexia and resistant to CTV | • Intolerant of highly alkaline soils<br>• Not suitable for heavy clay soils<br>• Intolerant of exocortis<br>• Susceptible to sudden death and citrus blight<br>• Most mandarin varieties show some symptoms of incompatibility (i.e. benching). |
| ***Citrus macrophylla*** | • Suitable for virgin sites only<br>• Vigorous trees with good yields of early maturing fruit<br>• Good tolerance of high pH soils and salinity | • Not suitable for replant sites<br>• Poor fruit quality, fruit dry out early<br>• Susceptible to CTV and may show severe stem pitting with some strains, resulting in decline<br>• Susceptible to cachexia, will show gumming and pitting<br>• Susceptible to citrus nematode |
| ***Citrus trifoliata*** | • Preferred stock for heavy soils and replant sites<br>• Shallow rooting, but good fibrous root production<br>• Tree size small to medium with very good fruit quality and yield efficiency<br>• Suitable for high density planting<br>• Resistant to Phytophthora, CTV and citrus nematode and tolerant of cachexia | • Intolerant of highly acid and alkaline soils<br>• Poor performance on deep sands if irrigation management is poor<br>• Poor drought tolerance<br>• Low tolerance to salt<br>• Intolerant of exocortis and sudden death<br>• Susceptible to citrus blight<br>• Some symptoms of incompatibility, e.g. benching with most mandarin varieties |
| ***Citrus volkameriana*** | • Suitable for virgin sites only<br>• Good tolerance of high pH soils<br>• Moderate salinity tolerance<br>• Large productive trees producing large fruit with early maturity<br>• Tolerant of cachexia, CTV and exocortis | • Not suitable for replant sites<br>• Poor fruit quality and fruit do not hold well on trees<br>• Susceptible to Phytophthora root and collar rots and citrus nematode |

| Rootstock | Advantages | Disadvantages |
| --- | --- | --- |
| **Cleopatra mandarin** | • Suitable for virgin sites only<br>• Long lived trees producing good quality fruit<br>• Tolerant of high pH and saline soils<br>• Tolerant to CTV, cachexia, exocortis and citrus blight<br>• Fruit able to be held on trees due to delayed skin colouring | • Unsuitable for replant sites unless well drained and well managed<br>• Slow to crop in early years<br>• Susceptible to Phytophthora root and collar rots and citrus nematode |
| **Emperor mandarin** | • Suitable for virgin sites only<br>• Large trees with moderate yields and medium fruit quality<br>• Tolerant of CTV, cachexia, exocortis and citrus blight | • Unsuitable for replant sites<br>• Slow to crop in early years<br>• Low juice and TSS levels<br>• Susceptible to Phytophthora root and collar rots and citrus nematode |
| **Rangpur lime** | • Suitable for virgin sites only<br>• Very good salinity tolerance<br>• Suitable for high pH soils<br>• Very good drought tolerance<br>• Large vigorous trees with moderate yields.<br>• Early fruit maturity<br>• Tolerant of CTV and cachexia | • Not suitable for replant sites<br>• Poor fruit quality<br>• Susceptible to Phytophthora root and collar rots, citrus blight and citrus nematode<br>• Intolerant of exocortis |
| **Rough lemon** | • Suitable for virgin sites only<br>• Deep rooted and good drought tolerance, best on deep sands<br>• Large vigorous trees with good yields of large fruit that are early maturing<br>• Tolerant of CTV, exocortis and cachexia | • Unsuitable for replant sites<br>• Unsuitable for heavy clays or poorly drained sites<br>• Poor salt tolerance, accumulates chloride causing leaf drop<br>• Poor fruit quality, fruit dry out early and do not hold well<br>• Susceptible to Phytophthora root and collar rots, citrus blight and citrus nematode<br>• Unsuitable for some mandarins (e.g. Satsuma mandarin and Ellendale tangor) due to delayed incompatibility with tree deterioration at 12–15 years |
| **Sweet orange** | • Suitable for virgin sites only<br>• Good salt tolerance<br>• Large trees with good yields of medium quality fruit which holds well<br>• Tolerant of CTV, cachexia, exocortis and citrus blight | • Unsuitable for replant sites<br>• Poor tolerance to high pH soils, drought and waterlogging<br>• Susceptible to Phytophthora root and collar rots and citrus nematode |
| **Swingle citrumelo** | • Suitable for virgin and replant sites<br>• More salt tolerant than the citranges<br>• Moderately high yields of good quality medium to large fruit<br>• Tolerant of Phytophthora root and collar rots, cachexia, CTV, exocortis, citrus blight and citrus nematode | • Unsuited to some heavy clay soils<br>• Unsuited to some alkaline soils<br>• Late maturing<br>• Incompatible with some varieties, e.g. benching observed with some mandarin varieties such as Imperial, Fallglo, Nova and Nules Clementine (Smith, in Khurshid et al. 2007). Long-term compatibility with Murcott tangor questionable – delayed incompatibility reported in Florida (Castle & Stover, 2000) |

Table 26. Recommendations and scion compatibility with various rootstocks. (Summarised from various publications listed in reference section of this chapter).

| Mandarin variety or group | Rootstock | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Benton citrange | Carrizo/ Troyer citrange | *Citrus trifoliata* | *Citrus volkameriana* | Cleopatra mandarin | Emperor mandarin | Rough lemon | Sweet orange* | Swingle citrumelo |
| Afourer | ? | ✓ C | ✓ C | ✗ C | ✓ C | ? | ✗ C | A C | ? |
| Clementine mandarins | ✓L C | ✓ SI | A SI | ✗ C | ✓ C | A C | ✗ C | A C | A SI |
| Ellendale tangor | ✓ C | ✓ C | ✓ C | ✗ C | A C | A C | A C | A C | ✓ C |
| Imperial mandarin | ✓ C | ✓ SI | A SI | C | ✓ C | ✗ C | A C | A C | ✗ SI |
| Hickson mandarin | ? | ✓ SI | ✓ SI | ✗ C | ✓ C | ✗ C | A C | A C | ? |
| Minneola tangelo | ? | ✓ C | ✓ C | ✗ C | ✓ C | ✗ NC | ✗ C | A C | ✓ C |
| Murcott tangor | ? | ✓ C | ✓ SI | ✗ C | ✓ C | ✗ C | A C | A C | ?? SI |
| Satsuma mandarin | A L C | ✓ C | ✓ C | ✗ C | A C | A C | ✗ C | A C | A C |
| Tang-Gold | ? | ✓ C | ✓ C | ✗ C | ✓ C | ? | ✗ C | A C | ? |

Legend:
ü= recommended. ✗ = not recommended. A = acceptable, but better choices may exist. C = compatible. NC = not compatible. L = limited evaluation. SI = some incompatibility – may be delayed or may not cause major issues if well managed. ? = unknown. ?? = long-term compatibility questionable – trees in Florida show symptoms of decline at 6–8 years (Castle & Stover 2000). Sweet orange* = In Queensland the severe sweet orange strain of tristeza virus could reduce tree life and productivity.

## Horticultural characteristics

Almost all horticultural attributes, ranging from vegetative growth through to yield, fruit quality and tree longevity, are influenced by rootstock. Rootstock effects are variable and depend to a large extent on site and soil conditions and climate.

### Tree size and vigour

Tree size refers to the size of the canopy of a mature tree under good growing conditions. Rough lemon, *C. volkameriana*, *C. macrophylla*, Rangpur lime, sweet orange, Cleopatra and Emperor mandarins tend to produce large trees while *C. trifoliata* and its hybrids with sweet orange, namely Benton, Troyer and Carrizo citrange, and Swingle citrumelo produce smaller trees. See Table 27 for rootstock ratings. Kusaba et al. (2004) categorised rough lemon as a vigorous rootstock and *C. trifoliata* as intermediate. Tree spacing is partly dictated by expected tree vigour and final tree size. Larger trees will need to be spaced further apart, whereas small to medium sized trees allow for closer plantings.

### Yield and yield efficiency

Yield is the weight or number of fruit produced by a mature tree; larger trees usually produce more fruit, but planting density and therefore yields per hectare should also be considered. Yield is also assessed in terms of kg/unit of canopy volume, an index known as yield efficiency. See Table 28 for rootstock ratings. Trees on *C. trifoliata* and Benton citrange have high yield efficiencies and are suitable for higher density plantings. Yield is also dependent on many other factors such as local climatic and site conditions as well as cultural practices including crop management strategies, pruning, irrigation and nutrition.

The effect of rootstock on biennial (alternate) bearing is unclear with conflicting results from different trials. In a long-term trial, fruit yields of Ellendale tangor on seven different rootstocks increased sharply for the first 10 years then plateaued out for the most productive rootstocks (Smith et al. 2004). The same authors found there were no significant rootstock effects on biennial bearing until trees reached about 15 years of age and that the intensity of biennial bearing increased as trees aged. Georgiou (2002), in a trial evaluating 12 rootstocks for Clementine mandarin trees, found that all rootstocks exhibited a strong alternate bearing index (ABI) in the early years of fruit production.

### Fruit size and quality

Rootstocks in conjunction with other management practices, such as crop regulation, irrigation and nutrition, can have a significant influence on fruit size, maturity and quality parameters including total soluble solids (TSS), titratable acidity (TA), percent juice, rind thickness and texture. Table 28 gives a broad overview of the fruit quality characteristics for different rootstocks.

Trees on the slower growing rootstocks *C. trifoliata* and Benton citrange produce mid to late season fruit that have good TSS, TA, juice content and rind quality, although fruit size can be smaller. Trees on Carrizo and Troyer citrange also produce high yields of good quality fruit with an early to mid- season maturity, whereas trees on Cleopatra mandarin and sweet orange produce fruit of good quality that matures mid to late season. In a trial of four mandarin varieties on six rootstocks, El-Zeftawi and Thornton (1978) found that Symons sweet orange and Emperor mandarin were the most suitable rootstocks for mandarins in terms of quality, yield and productivity in virgin, well drained sandy loam soils. The citrange rootstocks gave the largest juice volume and lowest acidity while Emperor mandarin had the opposite effect.

Vigorous rootstocks (e.g. rough lemon, *C. macrophylla* and *C. volkameriana*) tend to produce good yields of larger fruit with early fruit maturity, but the fruit do not hold well on the tree and fruit have thick coarse rinds and lower TSS and TA. These rootstocks are not recommended for use with mandarins in Australia because of the poor quality of fruit produced by trees growing on them.

Small fruit size can be a problem with some mandarin varieties (e.g. Imperial and Clementine mandarins) and market returns are often directly linked to fruit size. There is an inverse relationship between fruit size and juice TSS and TA, with larger fruit tending to have lower levels of each. It is not known how rootstocks exert their influence, but it is thought to be related to the tree's plumbing from the roots to the shoots and to the fruit, to phytohormones and to mineral nutrient uptake and transport (Barry, Castle & Davies 2004).

Rootstocks also appear to have some effect on fruit granulation in mandarins. Queensland work (Hofmann 2011) supports previous research that suggests that fruit produced on more vigorous early fruiting rootstocks (such as rough lemon and *C. volkameriana*) are more prone to granulation. Assessments of Imperial mandarin fruit between 2001 and 2006 showed that granulation was highest on trees on *C. volkameriana*, followed by trees on Troyer and Carrizo citrange, sweet orange and C-32. Granulation was consistently lower on trees on Cleopatra mandarin, Benton citrange and especially Swingle citrumelo (Smith 2006).

The influence of rootstock on granulation has been attributed to effects on both the internal quality of fruit especially TSS content and their role in plant water status. However, these effects can be variable from season to season and across growing regions because a rootstock's influence can be modulated by both climate and other site-specific factors such as soil type, irrigation and nutrient management. For more information on granulation refer to the chapter on Disorders.

## Site and soil conditions

The soil type and its characteristics, such as texture, depth, pH, fertility and drainage, as well as whether the site is replant or virgin ground, will have a major effect on rootstock performance. This is evidenced in Table 29, which provides a summary of various rootstock trial results with Ellendale tangor on different sites around Australia.

### Root systems, structure and water use

The root system of a citrus tree is composed of varying amounts of fibrous roots, laterals and tap roots. Site conditions and tree management affect root development. In sandy loam soils *C. trifoliata* tends to have a relatively shallow root system with an abundance of fibrous roots and not many deep laterals. Most of the citranges have a poorly developed tap root, but have many laterals which may penetrate deeper than the tap root. Fibrous roots are also less extensive in the surface layers than for *C. trifoliata*. Cleopatra mandarin has a deep root system with extensive lateral roots and a moderate amount of fibrous roots. Sweet orange is moderately shallow rooted with an abundance of feeder and lateral roots, but not a well-developed tap root. With rough lemon a strong tap root is produced, along with abundant lateral roots that extend a considerable distance from the main trunk (Bitters 1986). In sandy soils rough lemon can have a vigorous and extensive root system and has been described as having 'superior adaptability' in sandy soils (Lawrence & Bridges 1974). The amount and depth of fibrous roots of rough lemon vary with soil conditions.

Rootstocks can also be classified according to the volume of soil penetrated by the roots: those with an extensive root system (e.g. rough lemon) and those with a more intensive system (e.g. *C. trifoliata* selections). Rough lemon has extensive lateral and vertical root development and is well adapted to deep sandy soils. *C. trifoliata* selections tend to have the majority of their feeder roots in the top 76 cm of the soil (Castle & Krezdorn 1975). However, rooting depth and spread can also be dependent on soil type and *C. trifoliata* has a much larger root system when grown on soils that have good water holding capacity, such as loams and clay loams.

Depth of rooting has been positively correlated to tree height, with the tallest trees usually having the deepest roots. Castle and Krezdorn (1975) categorised rootstocks into three groups based on tree height: the tallest trees were on rough lemon and Cleopatra mandarin, followed by trees on Troyer and Carrizo citrange and sweet orange (intermediate) with trees on *C. trifoliata* the smallest.

Root regeneration from injury due to waterlogging or Phytophthora root rot has also been assessed for some rootstocks. Roots of rough lemon and Troyer citrange recover better than those of sweet orange and Cleopatra mandarin (Broadbent 1996).

Rootstocks have a pronounced effect on tree water status which becomes more pronounced when soil water is limiting. Genetically determined rootstock characteristics such as root distribution, density and quantity, water and nutrient uptake efficiency, xylem (water conducting) vessel anatomy and root hydraulic conductivity all affect plant water relations (Castle & Krezdorn 1977; Syvertsen 1981; Romero et al. 2006).

The hydraulic conductivity of roots is the dominant factor controlling water movement in trees. Syvertsen et al. (1985) found that vigorous seedling rootstocks, such as rough lemon and Carrizo citrange, tended to have higher conductivities than the less vigorous Cleopatra mandarin.

Rootstocks with better drought tolerance include Rangpur lime, rough lemon and Swingle citrumelo, while Carrizo and Troyer citrange have moderate tolerance. Shallow rooted stocks such as *C. trifoliata*, Cleopatra mandarin and sweet orange have relatively poor drought tolerance. Rough lemon had high drought tolerance due to an extensive root system with higher stem conductivity and transpiration rates and larger xylem vessels allowing better water extraction in sandy soils (Syvertsen 1981). Carrizo citrange had intermediate root conductivity and Cleopatra mandarin, with the smallest root system, had low root conductivity. However, Romero et al. (2006) found that Clemenules mandarins on Cleopatra mandarin to be more efficient at extracting soil water during low soil water conditions than trees on Carrizo citrange, allowing trees to better withstand and recover from moderate water stress.

Mesejo et al. (2016), in a study with Chislett navel, Nova and Clementine mandarins, found a significant correlation between rootstock and the incidence of fruit splitting. Rootstocks with larger xylem vessels caused greater instability in tree-water status. This causes greater daily fluctuations in shrinkage and expansion of fruits, contributing to higher rates of fruit splitting. Rootstocks such as Carrizo citrange and C-35 with larger xylem vessels had higher rates of fruit splitting compared to Cleopatra mandarin or *C. trifoliata*. See the chapter on Disorders for more information on fruit splitting.

### Salt tolerance

Citrus trees are among the most salt sensitive horticultural crops (Maas 1990). High leaf chloride levels lead to physiological and visible leaf damage (Cooper & Shull 1953). High leaf sodium levels have detrimental effects on photosynthesis and transpiration (Behboudian et al. 1986). Both may lead to growth and yield reductions before visual symptoms are evident. The ability of citrus trees to tolerate root zone salinity is mostly dependent on rootstock (Maas 1993).

Table 27. Rootstock tree characteristics and tolerance to soil and site conditions. (Summarised from various publications listed in the reference section of this chapter).

| Rootstock | Tree size | Tree vigour | Root system | Virgin ground | Replant ground | Heavy soils | Tolerance to high salinity | Tolerance to calcareous soils/high pH | Drought tolerance | Cold tolerance |
|---|---|---|---|---|---|---|---|---|---|---|
| **Benton citrange** | Medium | Moderate | Intermediate | ✓ | ✓ | Poor? | Poor | Poor on most calcareous soils | Moderate | Moderate |
| **C-35 citrange** | Medium | Moderate | ? | ✓ | ✓ | Poor | Poor | Poor | ? | Moderate ? |
| **Carrizo and Troyer citrange** | Medium to large | Moderate | Intermediate | ✓ | ✓ | Poor | Poor to moderate | Poor | Moderate | Moderate |
| ***Citrus macrophylla*** | Medium to large | High | Deep and wide | ✓ | ✗ | Poor? | Good; boron tolerant | Good; prone to magnesium deficiency | Moderate | Poor |
| ***Citrus trifoliata*** | Medium | Low to moderate | Shallow | ✓ | ✓ | Good if well drained | Poor; takes up chloride | Very poor | Poor | Good |
| ***Citrus volkameriana*** | Large | High | Deep and wide | ✓ | ✗ | Moderate | Moderate | Good | Moderate to good | Poor |
| **Cleopatra mandarin** | Medium to large | Moderate | Intermediate | ✓ | ✗ Used on well managed replant sites in Queensland | Moderate | Very good; excludes chloride | Very good | Moderate | Good |
| **Emperor mandarin** | Large | Moderate | Deep and wide | ✓ | ✗ | Moderate | ? | ? | Good | Moderate |
| **Rangpur lime** | Large | High | Deep and wide | ✓ | ✗ | ? | Very good | Good | Very good | Poor |
| **Rough lemon** | Large | High | Deep and wide | ✓ | ✗ | Poor | Poor | Moderate | Good | Poor |
| **Sweet orange** | Large | Moderate to high | Intermediate | ✓ | ✗ | Poor | Moderate | Moderate to good | Poor | Moderate to good |
| **Swingle citrumelo** | Medium to large | Moderate | Intermediate | ✓ | ✓ | Poor | Moderate | Poor | Moderate | Moderate to good |

✓ Suitable ✗ Not advisable ? Unknown

Table 28. Rootstock effects on citrus (not specifically mandarins) fruit yield and quality characteristics. (Summarised from various publications listed in the reference section of this chapter).

| Rootstock | Yield/tree | Maturity | Fruit size | Fruit quality | Juice content | TSS | Acidity | Rind texture | Rind thickness |
|---|---|---|---|---|---|---|---|---|---|
| **Benton citrange** | Medium; good yield efficiency | Mid | Medium | Good | High | High | High | Smooth | Medium |
| **C-35 citrange** | Medium | Mid | Medium | Good | High | High | Medium to high | Smooth | Thin |
| **Carrizo and Troyer citrange** | High | Mid | Medium | Good | High | High | Medium | Smooth | Thin |
| ***Citrus macrophylla*** | Very high | Early | Large | Poor; dry out early | Low | Low | Low | Coarse | Thick |
| ***Citrus trifoliata*** | Medium; good yield efficiency | Mid to late; holds well | Medium | Very good | High | High | High | Smooth | Thin |
| ***Citrus volkameriana*** | Medium to high | Early; does not hold well | Large | Poor | Low | Low | Low | Coarse | Thick |
| **Cleopatra mandarin** | Variable; medium but slow to crop in early years | Mid | Small to medium | Medium | High | Medium | Medium to high | Medium | Thin |
| **Emperor mandarin** | Medium; slow to crop | Mid | Medium | Medium | Low | Low | Medium | Medium | Medium |
| **Rangpur lime** | High | Early | Large | Medium | Medium | Medium | Medium | Medium | Medium |
| **Rough lemon** | High | Early; does not hold well | Large | Poor | Low | Low | Low | Coarse | Thick |
| **Sweet orange** | High | Mid to late; holds well | Medium | Medium | Medium | Medium | Medium | Medium | Medium |
| **Swingle citrumelo** | Medium to high | Mid to late | Medium to large | Good | High | High | Medium | Smooth | Thin |

Table 29. Summary of Australian rootstock trials for Ellendale tangor showing recommended rootstocks will vary according to soil conditions.

| Trial location | Soil type | Scion | Rootstock | Recommended rootstock |
|---|---|---|---|---|
| Yanco, NSW (Bevington & Duncan 1978) | Replant ground, clay loam, prone to waterlogging | Ellendale tangor | *C. trifoliata*<br>Emperor mandarin<br>Sweet orange | *C. trifoliata* |
| Yanco, NSW (Bevington & Duncan 1978) | Virgin ground, sandy loam | Ellendale tangor | Carrizo citrange<br>*C. trifoliata*<br>Emperor mandarin<br>Sweet orange | Carrizo citrange<br>*C. trifoliata* |
| Dareton, NSW (Bevington & Duncan 1978) | Well drained, sandy soil | Ellendale tangor | Carrizo & Troyer citrange<br>*C. trifoliata*<br>Cleopatra mandarin<br>Emperor mandarin<br>Sweet orange | Cleopatra or Emperor mandarin, sweet orange |
| Mildura, Vic (El-Zeflawi & Thornton 1978, Thornton 1977) | Virgin soil, well drained, sandy/ sandy loam alkaline | Dancy, Emperor, Imperial mandarins and Ellendale tangor | Carrizo & Troyer citrange<br>*C. trifoliata*<br>Cleopatra mandarin<br>Emperor mandarin<br>Sweet orange | Emperor mandarin or sweet orange |
| Mundaberra, Qld (Smith et al. 2004) | Virgin soil, alluvial loam/fine sand | Ellendale tangor | Carrizo & Troyer citrange<br>Emperor mandarin<br>Rough lemon<br>Sweet orange | Troyer citrange |

Cleopatra mandarin and Rangpur lime are the most salt tolerant, while Swingle citrumelo, sweet orange, and Troyer and Carrizo citrange have moderate salt tolerance. Benton citrange, *C. trifoliata* and rough lemon have poor tolerance. The basis of the differences in salt tolerance between rootstocks is their ability to restrict the accumulation of sodium and chloride ions, or both, from either their own shoot or that of the scion (Sykes 2011b). *C. trifoliata* tends to accumulate chloride ions, whereas Rangpur lime and Cleopatra mandarin exclude chloride very effectively.

## Soil pH

Soils vary widely in their pH levels depending on locality. Naturally acid soils with a low pH (< 5.5) are common in coastal areas, but have also developed in inland areas following heavy dressings or prolonged use of acidifying fertilisers. Alkaline or calcareous soils (pH > 7.5) are far more common in the drier inland areas (such as in the growing regions of southern Australia and the Northern Territory) because of low rainfall, significant amounts of calcium carbonate in the soil or irrigation water high in calcium bicarbonate. Both pH extremes are undesirable and can cause nutritional problems with some rootstocks. The best rootstocks for high pH soils include Cleopatra mandarin, Rangpur lime, sweet orange and *C. volkameriana*. Those with poor tolerance of high pH soils include *C. trifoliata* and some of its hybrids.

## Nutrient absorption

'*Roots have a strong influence on plant composition, but the differential ability to absorb nutrients is only one factor affecting the mineral concentration in plant tissues. Most reports on rootstock effects are based on leaf analysis. Variations in distribution pattern, capability of nutrients to move across bud unions, environmental and soil factors, fruit load and above all the genetic makeup of stock and scion are intimately involved*', Wutscher 1989.

'*Rootstock-induced nutritional differences will be different for young and mature trees and some diseases including viral infection can also have an impact, but in healthy trees with an adequate supply of nutrients, the amount of nutrients in the scion will depend on nutrient uptake and translocation by the rootstock*', Wutscher 1989.

In 1989, Wutscher published a table (Table 30) summarising the general effects of rootstocks on mineral element levels in citrus leaves. This summary was a synthesis of the results from many pot experiments, field studies and the author's experience. Although more work has been published on the effects of rootstocks on the mineral nutrition of citrus trees in the years since Wutscher produced this summary in 1989, those results are not included in his table.

For example rough lemon, Cleopatra mandarin and Troyer citrange were found to be more efficient in the uptake of nitrogen than *C. trifoliata*, Swingle citrumelo and Rangpur lime (Keshava Murthy & Iyengar 1992). These differences were possibly attributable to root radius, length, surface area and density. Smith (2004) found rootstock effects on leaf nutrient levels for phosphorus, calcium, magnesium, manganese and boron in Ellendale tangor. The latter observations have some implications for the suitability of some rootstocks and the management of trees on these rootstocks, due to their notable inability to supply sufficient mineral nutrients to the scion.

### Cold tolerance

Rootstocks can affect the cold tolerance of trees. However, this tolerance can also be further modified by the amount of 'cold conditioning' trees receive before damaging temperatures occur. Daytime temperatures below 15.6 °C and night time temperatures below 4.4 °C will harden trees, but this tolerance of cold temperatures is lost following a few days of warmer weather (O'Connell et al. 2011). The most frost hardy rootstocks include *C. trifoliata* and Cleopatra mandarin. See Table 31 for rootstock ratings.

Critical freeze damage temperatures for citrus are related not only to scion variety and rootstock, but also to the maturity of foliage and fruit. Fruit that are more mature and higher in TSS will withstand lower temperatures, as will larger fruit and fruit with thicker peels (O'Connell et al. 2011). As a consequence of their effect on fruit size and quality, rootstocks also influence the tolerance of fruit to freezing. High TSS in fruit at the time of a frost event can help reduce dehydration and subsequent freeze damage. For more information on frost damage and frost mitigation strategies refer to the chapters on Disorders, and Orchard basics.

Table 30. Some rootstock effects on mineral element levels in citrus leaves (Wutscher 1989). Note: This table does not include any new published work since that time.

| Element | Induce high levels | Induce low levels |
|---|---|---|
| **Nitrogen (N)** | Rangpur lime, rough lemon, sweet orange | Cleopatra mandarin, *C. trifoliata*, sour orange |
| **Phosphorus (P)** | *C. trifoliata*, rough lemon, sweet orange, Swingle citrumelo | Cleopatra mandarin, Troyer citrange, sour orange |
| **Potassium (K)** | Swingle citrumelo | Cleopatra mandarin, rough lemon, Troyer citrange |
| **Calcium (Ca)** | Cleopatra mandarin, rough lemon, Troyer citrange, sour orange | Sweet orange |
| **Magnesium (Mg)** | *C. trifoliata*, Cleopatra mandarin, Carrizo citrange | Rangpur lime, sour orange |
| **Sulfur (S)** | Rough lemon | *C. trifoliata*, Cleopatra mandarin |
| **Sodium (Na)** | Rough lemon | Sour orange, sweet orange |
| **Chloride (Cl)** | *C. trifoliata*, Carrizo and Troyer citrange | Cleopatra mandarin, sour orange |
| **Iron (Fe)** | Rough lemon, sour orange | *C. trifoliata*, Swingle citrumelo |
| **Manganese (Mn)** | Rough lemon | Sour orange, sweet orange, Swingle citrumelo |
| **Zinc (Zn)** | Cleopatra mandarin, rough lemon | Carrizo citrange, *C. trifoliata*, sour orange, sweet orange |
| **Copper (Cu)** | Swingle citrumelo, sweet orange | Cleopatra mandarin, rough lemon, sour orange, Troyer citrange |
| **Boron (B)** | *C. trifoliata*, Cleopatra mandarin | Carrizo citrange, sour orange |

### Mycorrhizal dependency

Some soil fungi (*Glomus* spp., mycorrhizae) develop symbiotic associations with the roots of many plant species. Mycorrhizae are widely distributed and the roots of every citrus tree are probably infected by mycorrhizal fungi at some stage. Increased uptake of phosphorus is the primary beneficial effect, but copper and zinc uptake may also be increased.

Mycorrhizal dependency is defined by Gerdemann (1975) as the degree to which a plant is dependent on the mycorrhizal condition in order to produce its maximum growth or yield at a given level of soil fertility. However, on average, rootstocks exhibited the greatest mycorrhizal dependency with the least fertilization (Menge, Johnson, & Platt 1978). So, in well managed orchards mycorrhizal dependency may be less important. While the plant growth response varies with soil fertility (this is especially the case with phosphorus), mycorrhizal dependency is also affected by soil type, species of mycorrhizal fungus and rootstock type.

In a low phosphorus sandy soil, mycorrhizal dependency is highest for Cleopatra mandarin and rough lemon, followed by Swingle citrumelo, then the less dependent Carrizo and Troyer citrange, and *C. trifoliata* is the least dependent (Menge, Johnson & Platt 1978, Graham & Syvertsen 1985).

## Disease and pest tolerance

Disease tolerance is defined as the ability of a host plant to limit the impact of a pathogen on its health and performance. Resistance is an extreme point on the tolerance scale and involves the prevention of infection or a reduction in the level of infection within the host. Table 31 presents a summary of the pest and disease tolerances for the most common rootstocks. See the chapters on Diseases, and Pests for more detailed information.

### Phytophthora root and collar rots

*Phytophthora* is a fungal-like disease organism common in Australian soils. *P. citrophthora* and *P. nicotianae* (syn. *P. parasitica*) cause collar and root rots in citrus. *Phytophthora* is active in wet conditions and is a problem in poorly drained soils. Citrus rootstocks have varying tolerances to root rot. *C. trifoliata* is highly resistant, the citrange rootstocks (Troyer, Carrizo and Benton) and Swingle citrumelo have good tolerance, Cleopatra mandarin has intermediate tolerance, while Rangpur lime, rough lemon, *C. volkameriana,* and especially sweet orange, are very susceptible to infection.

### Citrus blight

Citrus blight can be a problem in orchards in Queensland, but has also been found on two orchards in the Riverina region of NSW. The exact cause of citrus blight is unknown, but it can be transmitted from tree to tree through natural root grafting. Citrus blight causes tree decline as a result of blockages in the water conducting tissue (xylem). There is no cure and trees must be removed and replaced, using more tolerant rootstocks. See the chapter on Diseases for more information.

Rootstocks including *C. trifoliata* and the citranges, rough lemon, *C. volkameriana* and Rangpur lime are highly susceptible to citrus blight. Sweet orange is highly resistant, while Cleopatra and Emperor mandarins and Swingle citrumelo are regarded as tolerant. However, most of the resistant or tolerant rootstocks are unsuitable for replant situations. Significant losses of 12–15 year old trees on Cleopatra mandarin planted in old citrus soil have been observed in the USA (Castle et al. 2006).

### Citrus tristeza virus (CTV)

CTV exists as mild and severe strains in nearly every citrus tree in Australia. Different strains of the virus cause various diseases, including grapefruit stem pitting, orange stem pitting and quick decline of orange and mandarin varieties grown on sour orange and smooth Seville rootstocks. Young trees may wilt and die in a few months after infection (quick decline) when infected budwood is used, or will linger for a number of years, making very poor growth before death.

CTV is the reason why sour orange and smooth Seville are not used as rootstocks for oranges or mandarins in Australia. No quick decline symptoms are seen on mandarin and orange trees growing on their own roots, or on rough lemon, mandarin, the citranges, *C. trifoliata* and sweet orange rootstocks. Australian *C. trifoliata* clones and most citranges are resistant to CTV. *C. macrophylla* rootstock is very susceptible to stem pitting, however for mandarin scions grown on this rootstock the pitting is only seen on the rootstock. For this reason *C. macrophylla* is not recommended for use in Australia as a rootstock.

### Cachexia (xyloporosis)

*Citrus cachexia viroid* (CVd-IIb, also known as hop stunt viroid or HSV) is latent in some old citrus varieties, including Ellendale tangor. It is carried in the plant sap. It can be transmitted from tree to tree by budding or grafting, natural root grafting and mechanically by hedging and pruning. Cachexia is not seed transmitted.

Cachexia affects some mandarin varieties (Clementine mandarin and Ellendale tangor), tangelos and *C. macrophylla* rootstock. The disease is characterised by inverse pitting of the bark with associated gumming. Affected trees are stunted with yellowing of the canopy and general tree decline. Rootstock sprouting at the bud union is also common. Cachexia is rarely seen in Australia, especially with the availability of 'viroid-free' budwood from Australian Citrus Propagation Association Incorporated (Auscitrus).

### Exocortis

*Citrus exocortis viroid* (CEV-d) can infect all citrus types but its presence is symptomless in most. The viroid is carried in plant tissue and can be spread from tree to tree by budding or grafting, and mechanically by pruning and hedging activities. Natural grafting of tree roots can also transmit the viroid between trees. CEV is not seed transmitted in citrus.

Symptoms (e.g. reduced tree size and/or bark scaling) develop when infected budwood is grown on intolerant rootstocks such as *C. trifoliata* and its hybrids (i.e. Benton, Carrizo and Troyer citrange) and Rangpur lime. The viroid produces bark-scaling of *C. trifoliata* rootstock at between two to four years and infected trees are stunted (Figure 93). Bark scaling symptoms are rarely seen in the citranges in Australia. No symptoms are seen on rough lemon, sweet orange and mandarin rootstocks. Exocortis is rarely seen in new plantings in Australia due to the availability of healthy budwood free of the viroid from Auscitrus.

Figure 93. Stunting of an orange tree on *C. trifoliata* rootstock infected with citrus exocortis viroid.

### Other viruses

As discussed previously, two other viruses, *citrus* tatter leaf virus (CTLV) and citrus leaf blotch virus (CLBV), can also cause bud union crease. CTLV affects trees on *C. trifoliata,* the citranges and Swingle citrumelo. CLBV affects trees on the citranges and Swingle citrumelo and there is a very small chance of it being transmitted through seed.

### Citrus nematode

Nematodes are small microscopic worms, some of which are parasites of citrus roots. The most important is the citrus nematode (*Tylenchulus semipenetrans*) which affects citrus, grapes and olives. Productivity declines in the range of 10–30%, depending on the level of infection, have been reported (Verdejo-Lucas & McKenry 2004). Nematodes can survive in the soil on old infested roots for long periods of time and nematode populations can be especially high in soils that have previously been planted with citrus, grapes or olives.

Rootstocks are classified as being resistant if they greatly inhibit nematode reproduction. One identified source of genetic resistance against citrus nematode comes from *C. trifoliata* (Verdejo-Lucas & McKenry 2004). Swingle citrumelo is also resistant, whilst Troyer and Carrizo citrange have moderate resistance. Most other rootstocks are susceptible, especially Cleopatra mandarin and Rangpur lime.

There are also several new biotypes of citrus nematodes that have been identified overseas, which can infect normally resistant rootstocks, but their presence in Australia has not been reported. Refer to the chapter on Pests for more information on nematodes and their management.

## Rootstocks characteristics

The information presented here has been sourced from a range of publications on citrus rootstocks as listed in the reference section of this chapter.

### Benton citrange

Benton citrange is a hybrid of Ruby Blood sweet orange and *C. trifoliata* that was bred in NSW by FT Bowman in 1945. It was initially selected as a rootstock for Eureka lemon and was released to industry in 1984. Benton citrange can be used in virgin and replant soils because it has good tolerance to Phytophthora root and collar rots and citrus nematode. It is resistant to CTV, does not show symptoms of cachexia, but reacts to exocortis. It does well on most soil types but is not suitable for most calcareous or saline soils. It is moderately drought and cold tolerant.

Table 31. Comparative ratings of citrus (not specifically mandarins) rootstocks to selected diseases and citrus nematode.

| Rootstock | Phytophthora | *Citrus tristeza virus (CTV)* | Exocortis | Cachexia | Citrus blight | Citrus nematode |
|---|---|---|---|---|---|---|
| **Benton citrange** | 2 | 1 | 4? | T | ? | T – ? |
| **C-35 citrange** | 2 | 1? | 4 | T | ? | T – ? |
| **Carrizo and Troyer citrange** | 2 | 1 | 4 | T | S | R – 3 |
| ***Citrus macrophylla*** | 3 | 4 | 1 | S | S | S – 4 |
| ***Citrus trifoliata*** | 1 | 1 | 5 | T | S | R – 1 |
| ***Citrus volkameriana*** | 4 | 2 | 1 | T | S | S – 4 |
| **Cleopatra mandarin** | 3 | 1 | 1 | T | T** | S – 4 |
| **Emperor mandarin** | 3 | 1 | 1 | T | T | S – ? |
| **Rangpur lime** | 4 | 2 | 4 | T | S | S – 4 |
| **Rough lemon** | 4 | 2 | 1 | T | S | S – 4 |
| **Sweet orange** | 5 | 2* | 1 | T | T | S – 4 |
| **Swingle citrumelo** | 2 | 1 | 2? | T | T | R – 1 |

1 = Best 5 = Worst T = Tolerant S = Susceptible R = Resistant ? = Probable rating.
* Queensland has orange stem pitting strains of CTV, therefore the rating in Queensland would be 4.
** Although the incidence of citrus blight is low in young trees, substantial losses have been recorded in the USA when trees reach 12–15 years of age (Castle et al. 2006).

Trees on Benton citrange are moderately vigorous, medium sized and producing good yields of high quality fruit. It has a high yield efficiency and is suitable for high density plantings. Both Emperor mandarin and Ellendale tangor on Benton citrange performed satisfactorily in a trial on sandy soil at Yanco in NSW (Long et al. 1977).

A recent rootstock trial in Queensland with four early mandarin varieties (Fallglo, Imperial, Nova and Nules) on ten rootstocks showed Benton citrange to be an outstanding rootstock in the early years. Trees on this rootstock had a very smooth union and produced good sized fruit in heavy-crop seasons. The fruit had low levels of granulation and early yields were very encouraging. However, results in the later stages of the trial have been less consistent and suggest caution before wide-scale adoption (Smith in Khurshid et al. 2007).

## C-35 citrange

C-35 citrange is a hybrid of Ruby Blood orange and *C. trifoliata*, bred in California and released to industry in 1987. C-35 can be used in both virgin and replant sites and has moderate tolerance to Phytophthora root rot, CTV and citrus nematode, does not show symptoms of cachexia but reacts to exocortis. C-35 does best in well drained soils and is not suitable for heavy clays, poorly drained sites, calcareous soils or saline conditions.

Trees on C-35 produce moderate yields of good quality fruit. It is not widely used as a rootstock in Australia. In a mandarin rootstock trial in Queensland C-35 offered no real advantage over existing recommended rootstocks. It causes benching at the graft union with Imperial mandarin, but this has not led to tree decline (Smith 2007). In New Zealand Clementine mandarins on C-35 are high yielding trees with good fruit quality (Currie et al. 2000).

### Carrizo and Troyer citrange

Carrizo and Troyer citrange are hybrids of *C. trifoliata* and Washington navel orange developed in the USA. There appears to be little difference between the two in their performance. Troyer citrange is preferred in Queensland, while Carrizo is used in the southern states. Both do well on most soil types, apart from heavy clays and high pH soils. They have moderate tolerance to saline conditions, but do not tolerate over-watering. They are suitable for virgin and replant soils, are tolerant of Phytophthora root rot and do not show symptoms of cachexia. They are resistant to CTV, but react to exocortis viroid and are susceptible to citrus blight.

Trees on these rootstocks are medium to large with young trees being quite vigorous, producing good crops of high quality fruit. Fruit maturity is slightly earlier than that for fruit growing on trees on *C. trifoliata*, Swingle citrumelo and Cleopatra mandarin.

Troyer citrange is widely used as a rootstock for mandarins in Queensland especially on replant soils. Imperial mandarins on Troyer citrange can decline at 5–7 years, but more commonly at 13–15 years, with symptoms of rootstock overgrowth at the bud union causing a cincturing effect. In Queensland tree replacement is recommended at 15 years. Alternatively an interstock such as sweet orange can be used to alleviate incompatibility. Poor tree management, such as water or nutrient stress and excessive early cropping, may exacerbate the decline. In a study of Imperial mandarin producers in the Sunraysia region of southern Australia, Bevington (2001) found that three of the four sites affected by this decline were heavy producers. Bevington suggested that the onset of decline may be triggered by the stress of carrying excessive crop loads and so careful crop management strategies need to be employed to reduce over-cropping.

In California, Satsuma mandarins on citranges developed creasing at the bud union at 16 to 18 years of age (Ferguson & Grafton-Cardwell 2014).

Smith et al. (2004) found that Troyer citrange was the best choice for Ellendale tangor in a long-term rootstock trial in Queensland. Chapman (1984) recommended Troyer citrange as a rootstock for Ellendale tangor in replant and sites with shallow soils. Another rootstock trial in Queensland with four early mandarin varieties (Fallglo, Imperial, Nova and Nules) on ten rootstocks showed the performance of Carrizo and Troyer citrange to be nearly identical. However, benching with Troyer resulted in tree decline at around 15 years.

### ***Citrus trifoliata*** (syn. ***Poncirus trifoliata***, also known as trifoliate orange)

*C. trifoliata* originated in China and is widely used as a rootstock for many citrus varieties in Australia and many countries worldwide. It can be used on virgin and replant soils and is highly resistant to Phytophthora root rot, CTV and citrus nematode, but is susceptible to exocortis and citrus blight. It does well on most soil types including heavy clay soils, but is unsuitable for highly acid, highly calcareous or saline soils. It performs poorly on deep sands if not well irrigated. In sandy loam soils *C. trifoliata* tends to have a relatively shallow root system with an abundance of fibrous roots, and not so many deep laterals. Such shallow rooted stocks have relatively poor drought tolerance.

Trees on *C. trifoliata* are small to medium sized and have low to moderate vigour and are suitable for higher density plantings. Fruit matures mid-season, are of excellent quality and hold well on trees. *C. trifoliata* is widely used as a rootstock for mandarins especially in replant soils. There is some incompatibility with Imperial mandarin; a bud union crease with cincturing being evident. An inter-stock of sweet orange is sometimes used to overcome this incompatibility.

In a study of Imperial mandarin producers in the Sunraysia region Bevington (2001) suggested that *C. trifoliata* would be the preferred rootstock for heavier soils under Sunraysia conditions. Under Queensland conditions most mandarin trees on *C. trifoliata* lack vigour (excluding Ellendale tangor) with poor yields especially on sandy and sandy loam soils (Chapman, 1984). However, Ellendale tangor on *C. trifoliata* performs well especially in replant sites.

### ***Citrus volkameriana*** (also known as Volkamer lemon)

*C. volkameriana* is thought to have originated in Italy as a natural hybrid of a lemon and sour orange. *C. volkameriana* is only suitable for virgin soils because of its susceptibility to Phytophthora root rot and citrus nematode. It is tolerant to CTV, exocortis and cachexia, but susceptible to citrus blight. It does best on well drained sandy soils, has good tolerance to high pH/calcareous soils and has moderate salinity tolerance.

*C. volkameriana* is more commonly used as a rootstock for lemons and is not widely used for mandarins. It is similar to rough lemon but more cold tolerant. It is a very vigorous rootstock producing large trees with heavy crop loads, but fruit quality is poor. It produces good sized fruit early in the season, but fruit do not store well on trees. A recent rootstock trial in Queensland with four early mandarin varieties (Fallglo, Imperial, Nova and Nules) showed that all varieties on this rootstock produced fruit with low juice content, low TSS and TA, poor external colour and high granulation. It is without merit and cannot be recommended (Smith 2007).

### Cleopatra mandarin

Cleopatra mandarin originated in India and is compatible with most mandarins and as a result is widely used in Florida, Spain and Australia as a rootstock for mandarins, especially in shallow, alkaline soils. Cleopatra mandarin does best in well drained virgin soils. It is highly susceptible to Phytophthora root rot and citrus nematode and so its use in most replant situations should be avoided. Cleopatra mandarin is tolerant to citrus blight, but in the USA tree losses have been recorded at 12–15 years of age (Castle et al. 2006). Cleopatra mandarin is used in replant soils in Queensland, but only if soils are well drained and irrigation management is good. Cleopatra mandarin can tolerate high pH soils and high salinity due to its ability to exclude chloride. It is tolerant of CTV, exocortis and cachexia.

Trees on Cleopatra mandarin are medium to large and long lived. However they are shy bearing in the early years and produce only moderate yields for the first 10–15 years. Fruit quality is good. Fruit tend to be small with a mid-season maturity. Trials in Queensland have suggested that fruit from trees on Cleopatra mandarin have delayed skin colouration rather than being late maturing (Smith 2007). Cleopatra mandarin is often used to extend the harvest period, especially for Imperial mandarins.

Chapman (1984) recommended Cleopatra mandarin as the best rootstock for high yields of mandarin fruit (excluding Ellendale tangor) in virgin soils in Queensland. In a study of Imperial mandarin producers in the Sunraysia region of southern Australia Bevington (2001) suggested that Cleopatra mandarin would be the preferred rootstock for calcareous soils under Sunraysia conditions.

Murcott tangor grown on Cleopatra mandarin starts to show overgrowth of the scion when trees are about 3 years of age, however this overgrowth almost disappears in later years. There appears to be no detrimental effects on tree growth and yield (Owen-Turner 1995).

In a mandarin-rootstock trial on virgin, alluvial sandy loam to clay loam soils, trees on Cleopatra mandarin produced good yields of smooth textured fruit similar to fruit from trees on the best performing rootstocks. The extent of benching was very low, offering the potential of long-lived commercial orchards. Delayed skin colour development with Imperial mandarin, even when fruit are internally mature, accounts for it being perceived as a late maturing rootstock. The delay in skin maturity might explain why fruit can be left on the tree longer than can fruit on trees growing on many other rootstocks (Smith 2007).

### Cox citrandarin

Cox citrandarin is a hybrid of Scarlet mandarin and *C. trifoliata*. It was bred in NSW by J Cox as part of a breeding program conducted from the late 1950s through to the late 1970s to find better rootstocks for lemons and mandarins. Cox was first released to industry in 1995 for use as a rootstock for Eureka lemon.

It is resistant to Phytophthora root and collar rots. Cox citrandarin has been evaluated for lemons in trials carried out at Gosford, NSW and Nangiloc, Victoria (Sarooshi & Broadbent 1992; Gallasch & Staniford 2004; Gallasch & Hardy 2004). It performed well in virgin and replant soils, producing good quality fruit. In a rootstock trial in Queensland, Cox citrandarin has been found to be unsuitable as a rootstock for Imperial mandarins, with 13 year old trees developing benching at the bud union. It is currently being evaluated for Tang-Gold mandarin (an irradiated W. Murcott/Afourer selection) in a rootstock trial at Dareton, NSW.

### Emperor mandarin

Emperor mandarin originated in Australia from a seed from fruit imported from Asia (Hodgson 1967). Emperor (Australia), Empress (South Africa), Oneco (United States), Batangas (Philippines) and others are probably nucellar clonal bud lines of 'Ponkan' mandarin (Coletta-Filho et al. 2000). Emperor mandarin was grown commercially as a fresh fruit variety until decimated by brown spot (*Alternaria alternata*), but has also been used as a rootstock. Emperor mandarin should only be used on virgin soils because of its susceptibility to Phytophthora root rot and citrus nematode. It is tolerant to CTV, exocortis, cachexia and citrus blight.

Trees on Emperor mandarin are large with extensive root systems but tend to be shy bearing in the early years. Fruit size and quality characteristics are average. Maturity times are mid-season, but fruit can be held on trees later than can fruit on trees growing on the citranges. Emperor mandarin is compatible with all mandarin varieties, including Imperial, but is not widely used because better rootstocks are available.

### Rangpur lime

Rangpur lime is a citrus hybrid originating from India. Its parents are a citron and a mandarin or one of its hybrids (Silva, Marcos & Takita 2016). Rangpur lime is not a true lime but is highly acidic and sometimes used as a substitute. It has been widely used in Brazil because of its drought tolerance.

Rangpur lime is a vigorous rootstock with an extensive root system. It can withstand high salinity and calcareous or high pH soils, deep sandy soils and drought. It should only be used in virgin soils as it is highly susceptible to Phytophthora root rot, citrus blight and citrus nematode. It should only be used with budwood of a high health status (from Auscitrus) as it is intolerant to the exocortis viroid, but tolerant to the CTV and cachexia.

Trees on this rootstock are large, producing good yields of large fruit that mature early, but fruit quality is poorer than that of *C. trifoliata* or the citranges, but better than that of rough lemon or *C. volkameriana*. It is rarely used as a rootstock in Australia. A trial of seven rootstocks with Ellendale mandarins at Dareton found that Rangpur lime was an outstanding rootstock for yield and yield efficiency (highest equal to Carrizo citrange) but fruit from trees on this rootstock had the lowest TSS (Bevington & Duncan 1978).

### Rough lemon

Rough lemon originated in India and has been used extensively as a rootstock for many citrus varieties in Australia and overseas. Rough lemon is only suitable for virgin soils as it is very susceptible to Phytophthora root rot, citrus blight and citrus nematode. It is tolerant of CTV, exocortis and cachexia. It does best on well drained sandy soils and is not suitable for heavy clay soils. It has some tolerance to high pH calcareous soils but has poor tolerance to saline conditions.

Trees on rough lemon are relatively short lived, large and vigorous. They are supported by an extensive root system and as a result are better able to cope with drought. Fruit maturity is very early, but fruit quality is poor and fruit do not hold well on trees.

Rough lemon is compatible with most mandarins. However Ellendale tangor, Imperial, Hickson and Silverhill Satsuma mandarins show symptoms of twig dieback and low vigour between 12 to 15 years after planting (Sarooshi et al. 2000). When budded with Murcott tangor, rough lemon sometimes fails to develop roots evenly around the rootstock, causing trees to topple (Owen-Turner 1995). It is not a wise choice as a rootstock for mandarins because of its poor fruit quality (Chapman 1984). Smith et al. (2004) found that the inferior fruit quality characteristics (thick rinds, low brix and juice content) of fruit from trees on rough lemon over-rode their yield advantage in a long-term rootstock trial for Ellendale tangor.

### Sweet orange

Various sweet orange selections are used as rootstocks, including Symons, Baker, Parramatta and Joppa. Sweet orange is only recommended for virgin soils because of its susceptibility to Phytophthora root rot and citrus nematode. It is resistant to citrus blight and tolerant of cachexia and exocortis. It is tolerant of CTV, but susceptible to orange stem pitting strains of CTV that only occur in Queensland. It is suitable for most well drained soils. It has moderate salt tolerance and good tolerance to high pH soils.

Sweet orange produces large trees with good yields of moderate quality fruit. Fruits are mid to late season and hold well on the tree. It is compatible with most mandarin varieties. Thornton (1976) found that Symons sweet orange and Emperor mandarin were the best rootstock choices for mandarins (Imperial, Emperor, Dancy and Ellendale) in virgin, well drained sandy or sandy loam soils around Mildura. Chapman (1984) recommended sweet orange as the best stock for Ellendale tangor in deep well drained virgin soils in Queensland, but for other varieties it is not as suitable as Cleopatra mandarin for all round performance, particularly yield and longevity.

A recent rootstock trial in Queensland with four early mandarin varieties on ten rootstocks found it offered no significant advantage over other commercial rootstocks (Smith 2007).

### Swingle citrumelo

Swingle citrumelo is a hybrid of Duncan grapefruit and *C. trifoliata*. It was developed in Florida and released to industry in 1974. American literature suggests that Swingle citrumelo is suitable for most soil types apart from heavy clays, soils with layers that impede drainage or highly calcareous soils. However, trees on Swingle performed well in trials on clay soils in Queensland and alkaline soils (pH≈8.0) at Katherine in the Northern Territory (Smith pers. comm. 2016). It has moderate salt and drought tolerance. It is tolerant of Phytophthora root rot and citrus nematode, so is suitable for replant sites. It is tolerant of CTV, cachexia, exocortis and citrus blight.

Trees on Swingle citrumelo are medium to large, bearing medium sized fruits that mature late. Smith (2007) reported that in a rootstock trial for four early season mandarins (Fallglo, Imperial, Nova and Nules) in Queensland, fruit on trees growing on Swingle citrumelo had the latest maturity of the 10 rootstocks evaluated and fruit quality was generally very good. However, Swingle citrumelo (along with Nelspruit × 639) produced the worst benching with all four scions. Imperial mandarin growing on Swingle citrumelo has some compatibility problems, and can develop over-growth at the bud union causing cincturing. Although it has been successfully used as a rootstock for Murcott tangors in Queensland (Owen-Turner 1995), the long-term health of this combination is questionable, as trees in Florida have shown delayed incompatibility when trees reach 6 to 8 years of age, leading to canopy decline (Castle & Stover 2000). This combination is considered risky.

## New rootstock releases

Some additional rootstocks are now being trialled commercially in Australia, or will soon be available as seed from Auscitrus. These include Anjiang hongju, Barkley, Bitters, Cao shixiangju, US812 and four additional selections of *C. trifoliata*, which have all been trialled with Imperial mandarin. These rootstocks have shown merit in Australian and/or overseas field experiments, and it is likely that at least some of them will become established as important rootstocks for mandarins in the future.

## Australian rootstock evaluation trials

### New South Wales

#### *Dareton Research Station, Department of Primary Industries (DPI)*

- **Evaluation of Australian hybrid rootstocks**
  **Lead Investigator: Graeme Sanderson**

A rootstock trial planted at Dareton in 2012 comprises Tang-Gold mandarin (irradiated seedless selection of W. Murcott) on hybrid rootstocks 3812, 3822, 3834 and 3835 (Figure 94). These hybrids are crosses of Scarlet mandarin and *C. trifoliata* from the Gosford breeding program and were identified as having potential for use with mandarins in trials carried out at Gosford between 1987 and 1996 (Sarooshi & Barkley 1997). The trial also includes C-35 citrange, Cox citrandarin, Mantou hong mandarin from China and the industry standard, Carrizo citrange for comparison. Fruit production and assessment began in 2014.

- **Evaluation of Chinese, Vietnamese and CSIRO rootstocks**
  **Lead Investigator: Tahir Khurshid**

Four short-term rootstock trials have been established at Dareton to assess the performance of Chinese, Vietnamese and CSIRO rootstocks for Imperial mandarin. These trials also include the standard rootstocks Symons sweet orange, *C. trifoliata* (Australian selection 22) and Carrizo citrange for comparison. The purpose of these short term trials is to identify candidates for entry into longer-term commercial trials. The various trials were planted in 1999, 2001, 2003 and 2005.

Figure 94. Strong tree growth and early fruit production occurred on 4-year old trees in a Tang-Gold manda-rin rootstock trial at Dareton, NSW in 2016.

The rootstocks from China and Vietnam were sourced as seed by Barkley, Bevington and Sykes, between 1993 and 2002 during two projects supported by the Australian Centre for International Agricultural Research (ACIAR). The first project ('Citrus Rootstock Improvement'), from 1993 to 1996, was a collaborative project with China. The second project ('Evaluation of East Asian Citrus Germplasm'), from 1996 to 2002, was a collaboration with China and Vietnam. Both projects encouraged the exchange of germplasm between Australia, China and Vietnam for the benefit of citrus improvement programs in each country. The Chinese rootstocks were screened for Phytophthora and CTV resistance by Barkley and for chloride and sodium accumulation by Sykes. Of particular interest were strains of trifoliate orange that accumulated low concentrations of sodium and chloride in shoot tissue (Sykes 2011b). Some of these rootstocks have been grafted with a range of scion varieties and exploratory crosses were also made by Sykes to investigate the transmission and inheritance of the chloride and sodium exclusion capacity as background information for breeding new salt-excluding rootstocks.

The results from the first of these trials were published in 2007 (Khurshid et al.). The four rootstocks selected for further long-term trials were based on mean cumulative yields, TSS, fruit weight and tree size. These attributes were applied to the group of rootstocks that had a very smooth graft union. The four identified were False Xiechen (a citrange), Nianju, Nanju, and Anjiang hongju (all mandarins), sourced as seed from China.

Results of the second of these trials planted in 1999 were published in 2013 (Khurshid, Donovan & Sykes). Two rootstocks were identified for further testing: Mantou hong mandarin and Ghana trifoliate orange. The rootstocks were offered to orchardists around Australia for semi-commercial test planting in 2016. Rootstocks include mandarin types: Nianju and Anjiang hongju and trifoliate orange types: Tanghe, Zao Yang and Ghana, all of Chinese origin. Between 60–80 trees were supplied to each grower with a choice of scion (Afourer, Dekopon or Imperial). Results from the other two trials are not yet available.

## Queensland

### *Department of Agriculture and Fisheries*

- **Rootstock trial for early-season mandarins at Tegege**
  **Lead Investigator: Malcolm Smith**

As part of HAL Project CT03025, ten rootstocks (Benton, C-32, C-35, and Carrizo citrange, Cleopatra mandarin, Nelspruit ×639 [Cleopatra mandarin × *C. trifoliata]*, Sweet orange [Symons strain], Swingle citrumelo, Troyer citrange and *C. volkameriana*) were assessed under four early-season mandarin scions (Fallglo, Imperial, Nova and Nules Clementine)and planted in 1998 at Tegege, 22 km NW of Bundaberg in Queensland.

The results from this trial indicated that Benton citrange, Cleopatra mandarin (virgin sites only), Troyer and Carrizo citrange are the preferred rootstock choices for mandarins. Benton citrange was an outstanding rootstock in the early years for Imperial; with good quality fruit, good production and smooth graft unions. As a result of this experiment it has become a major rootstock for new commercial mandarin orchards in Queensland. Fruit growing on trees on Swingle citrumelo matured later than any of the other rootstocks, but severe benching at the bud union was evident and this requires further investigation. Both sweet orange and C-35 offered no real advantage over existing rootstocks and *C. volkameriana*, C-32 citrange and Nelspruit × 639 were the worst performers and are not recommended. For more detailed information on rootstock performance refer to the final project report (Smith 2007).

- **Rootstock trial for Imperial mandarins at Gayndah**

Thirty four different rootstocks (commercial rootstocks, hybrids from deliberate crosses and/or imported from China and South Africa by the NSW and South Australian primary industry departments, hybrids from U.S.A., and wild/native citrus relatives) grafted with Imperial mandarin have been under assessment since 2007 on a replant site.

This experiment has demonstrated how critical tolerance of CTV is for rootstocks used in Australia. Savage citrange, for example, either died within a few years of planting, or was removed because of poor health and cropping. Gou Tou Chen (a Chinese sour orange hybrid) also performed poorly but the exact cause is not clear. The wild/native citrus relatives suffered the same fate and have no value to conventional citriculture until CTV resistance has been incorporated through breeding. Trees on Swingle citrumelo have again developed severe benching at the graft union and may not be suitable for long-term plantings. Of the remaining rootstocks, performance has been similar and most would be suitable for commercial orchards. One of the more promising rootstocks has been propagated on a larger scale to confirm performance prior to commercial release. Results will be finalised in 2017.

- **Rootstock trial for Imperial mandarin, Emerald**

Planted in 2011, this trial consists of 66 different rootstocks on a replant site (Figure 95), with 49 of these rootstocks also being compared with CTV-free and CTV-infected Imperial budwood. Rootstocks include material from local breeding programs at Gosford, Bundaberg, and from USA-based programs, as well as a range of conventional citrus rootstocks. Large differences in fruit quality yield, tree size and benching have already been noted, but observations over a longer period are required before superior rootstocks can be confidently identified.

It has already become evident that CTV-free budwood offers no commercial advantage, and that even if trees are virus free at the time of field planting, they can become infected within 12 months. Hence, the critical importance of CTV-tolerance in any new rootstock. Performance information from this experiment is being used to guide the selection of parents for new hybrids being generated in the Bundaberg breeding program.

- **Evaluation of hybrids from deliberate crosses as rootstocks for Imperial mandarin at Gayndah**

This experiment was established on a replant site at Gayndah in 2013 and consists of 245 different rootstocks (Figure 96). It contains 'man-made' hybrids from deliberate crosses representing germplasm that has never been previously tested as rootstocks, including some of the world's first intergeneric (crosses between different genera) hybrids. It is hoped new useful characteristics will be discovered that can improve commercial citriculture. More than 200 of the rootstocks have been bred with CTV-resistance and will now be evaluated for their effects on fruit quality as trees come into production.

Figure 95. Improved fruit quality is the objective of this Imperial mandarin experiment containing 66 new rootstocks planted at Emerald in 2011.

Figure 96. Unique rootstocks, including CTV-resistant hybrids of Australian native citrus, are included in this experiment planted at Gayndah in 2013, designed to broaden the genetic base and resilience of the Australian citrus industry.

## South Australia

### *South Australian Research and Development Institute (SARDI), Loxton Research Centre*

- **Late mandarin rootstock trial, Loxton**
  **Lead Investigator: Mark Skewes**

Planted in 2002, this trial contains four mandarin varieties, W. Murcott (Afourer) mandarin, Murcott tangor, Topaz (a selection of Ortanique) and Fortune mandarin. These varieties are planted on 10 rootstocks, including a selection of citranges (Benton, Carrizo, Troyer, C-32 and C-35), as well as *C. volkameriana*, Swingle citrumelo, Nelspruit × 639, Florida Cleopatra mandarin and Symons sweet orange.

Trees were evaluated between 2008 and 2010 for size and health, bud union and yield. A current project is revisiting this and other rootstock trials to assess any change in relative performance of the rootstocks with tree maturity. Only Afourer mandarin and Murcott tangor trees are being assessed, as Topaz and Fortune mandarins are no longer of interest to the local industry.

Performance of both Afourer and Murcott trees on Swingle citrumelo is poor, with the most severe benching at the bud union, the poorest tree health and the smallest trees, all contributing to low yield (although these observations are based on only one year of data).

Trees on C-32, Nelspruit × 639 and *C. volkameriana* rootstocks are performing well, although differences are not always significant. A second year of yield data was collected in 2016.

Rootstocks

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# Irrigation

## Introduction

Mature mandarin trees can require between 7–12 ML/ha of water per season, depending on weather conditions, soil type, irrigation system, variety, rootstock and planting density. Research has shown that mandarins can use up to 38% more water than oranges, particularly between March and May (Bevington 2001).

Trees have some natural ability to withstand water shortages and their thick leaves, low stomata numbers per leaf and waxy fruit help conserve water. The rootstock used also has a major effect on the trees' ability to withstand water shortages and waterlogging. For more information see the Rootstock chapter.

Accurate scheduling of irrigation water, including frequency and amount, relies on measuring soil moisture levels in the rootzone and weather conditions.

Irrigation can be used to manipulate vegetative growth, flowering and internal fruit quality parameters such as sugar, acid and juice content.

Water stress, deliberate or otherwise, during the critical growth stages of flowering, fruit set, cell division and the early stages of cell expansion can have a significant impact on fruit yield and quality.

In developing an irrigation program it is critical to understand the:

- annual growth cycle and water requirements during each development stage
- impacts of water shortages during each growth stage
- trees' rooting depth
- soil waterholding capacity and soil water content
- local weather conditions
- irrigation system's capacity for water delivery
- water quality.

## Crop water requirements

Citrus trees, being evergreen, require water all year round. Water moves almost continuously from the soil to the roots, then upwards into the various plant parts and finally into the leaves where most is released (transpired) into the atmosphere as water vapour when stomata are open. Leaf stomata open in the early morning and peak water demand is usually in the early afternoon.

Water use is highest in the warmer months between October and March and lowest during winter. Water is needed for photosynthesis and nutrient acquisition and uptake. It is critical for successful bud initiation, flowering, fruit set and fruit growth. Water stress can restrict vegetative growth and canopy development, affect fruit number and size, fruit maturity and quality.

Tree water requirements are affected by many factors, including:

- **crop conditions** – variety, rootstock, rooting depth and spread, tree age, tree size, growth stage and crop load
- **soil conditions** – texture, rootzone depth, water content and availability
- **weather conditions** – temperature, rainfall, solar radiation, evaporation, humidity and wind.

Knowledge of the various stages of citrus growth is important for irrigation management. Trees go through a number of growth stages annually. This is referred to as the phenological cycle (Figure 97). The timing and length of each stage depends largely on the citrus variety and local weather conditions. For more information refer to the Climate and Phenology chapter.

The most critical times to avoid water stress are at flowering, fruit set and during the early cell division stage of fruit growth (September to February). Avoiding water stress during these critical times maximises fruit set and fruit size. At less critical times the amount and frequency of irrigation can be reduced without significantly impacting on tree yield or health.

The key growth stages and impacts of water availability include:

- bud formation and flower initiation (mid – late winter)
  Moderate water stress during this period can increase flower numbers.
- flowering and fruit set (early spring)
  Water stress during this period can reduce fruit set, cause excessive fruitlet drop, reduce yield and suppress the spring flush, which reduces next season's potential flowering sites.
- Stage **I** fruit growth – cell division (late spring – early summer)
  At this stage fruit are undergoing rapid cell division. Water stress at this time reduces the ability of cells to divide and results in smaller fruit at the end of the season. During the natural fruit drop period there may be an increase in fruit drop and the summer leaf flush may also be reduced.
- Stage **II** fruit growth – cell expansion (mid summer – autumn)
  This period accounts for approximately 40% of a citrus tree's annual requirement for water. The first few months of this stage (mid-December to February) are a critical period; fruit cells are rapidly expanding and final fruit size is being determined. It is important to avoid water stress during the early part of this stage as potential fruit size may be reduced. Minor water stress during the latter period of this stage can be tolerated without a major effect on fruit size.
- Stage **III** fruit maturation (late autumn – winter)
  Water stress during this time can affect fruit maturity and fruit quality parameters such as total acidity (TA), total soluble solids (TSS) and percent juice. In order to improve sugar levels in fruit, irrigation is usually restricted 2–4 weeks prior to harvest.

A survey of 30 Imperial mandarin growers in the Sunraysia region of southern Australia was undertaken between 1995–1998 as part of the HAL funded project CT 95031 '*Improving Imperial Mandarin Fruit Quality and Marketability*'. The aim of the project was to identify the key cultural and management practices that influence orchard performance.

Findings from this survey were:

- Irrigation management was the key cultural practice affecting orchard performance.
- Water use was 38% higher on mandarin blocks than on adjacent orange blocks and annual water requirements of Imperial mandarins may be as high as 12 ML/ha (see Figure 98).
- Mandarin blocks should be irrigated independently of other citrus types and close monitoring of irrigation requirements is strongly recommended.
- Low yielding sites producing a high proportion of small fruit or fruit of low juice content were associated with either high sodium or chloride levels in the irrigation water, or inadequate depth of wetting arising from under-estimation of crop water requirements.

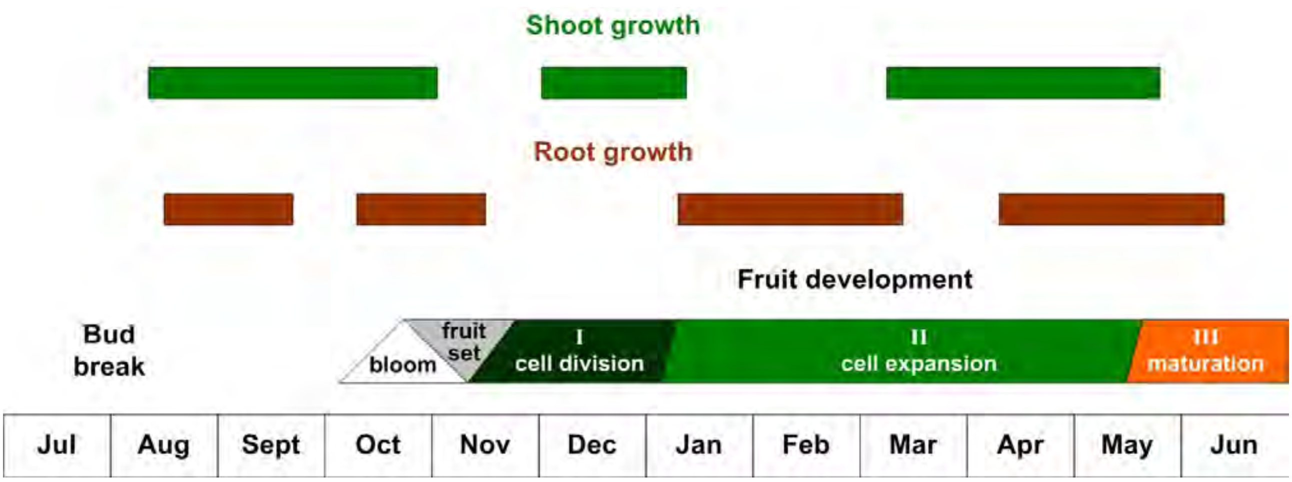


Figure 97. Diagrammatic representation of the citrus phenological cycle in southern Australia. Source: Michael Treeby.

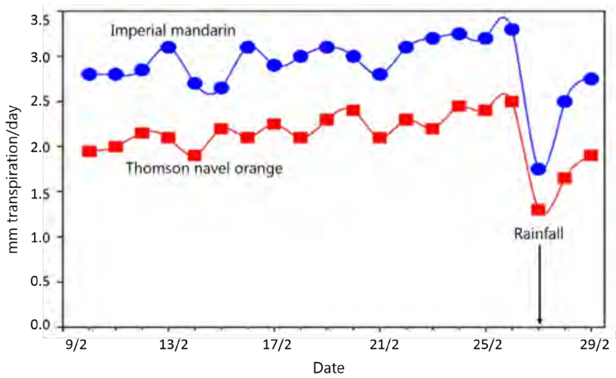


Figure 98. Changes in daily transpiration rate for Imperial mandarin and Thomson navel orange trees during the period 10 February to 29 February 1996. Source: Bevington 2001.

## Rootzone depth

Seventy-five percent of the most active roots are concentrated in the top 30–45 cm of the soil, but there can be roots down to 1.5 m, depending on rootstock and soil conditions. When irrigating, water needs to be applied to the majority of the rootzone for optimum production. Rootzone depth is used to calculate the volume of water that needs to be applied.

$$\text{Water volume (ML)} = \text{rootzone depth (mm)} \times \text{area (ha)}$$

In regions where rainfall is limited, tree roots tend to be concentrated in the area where the irrigation water is applied. In more humid subtropical regions with higher rainfall the tree roots are usually more widespread in the soil.

Rootstock also has a major effect on the depth of the rootzone. *C. trifoliata* tends to be shallow rooted, whilst Cleopatra mandarin, Swingle citrumelo and the citranges tend to have an intermediate rooting depth. Sweet orange has a more extensive root system.

Rootstocks with larger, more extensive root systems are more able to tolerate drought conditions. For more information see the Rootstock chapter.

Soil temperature, oxygen levels and the presence of root pathogens have an effect on root function. Low (<7 °C) and high (>30 °C) soil temperatures and low oxygen levels can slow or stop root function, diminishing water and nutrient uptake from the soil. Pests, such as nematodes and disease pathogens, such as *Phytophthora*, reduce root performance by damaging or killing feeder roots.

## Soil properties

All citrus grow best in soils with good drainage, such as sandy loams and clay loams. The soil type and its condition determines:

- how water moves through the soil profile (permeability, infiltration rate and drainage)
- the waterholding capacity (how much water the soil will hold and for how long)
- the rooting depth (how deep to water).

The soil's physical properties strongly influence irrigation management. A comprehensive soil survey should be carried out before any irrigation system is installed. Soil pits (Figure 99 and Figure 100) are dug throughout the block to determine soil type and depth and any variations that occur. This information is then used to design an irrigation system tailored specifically to site conditions.

Figure 99. Soil pits show the soil type and root development.

Figure 100. Soil pits show the soil type and depth, and also root development and growth.

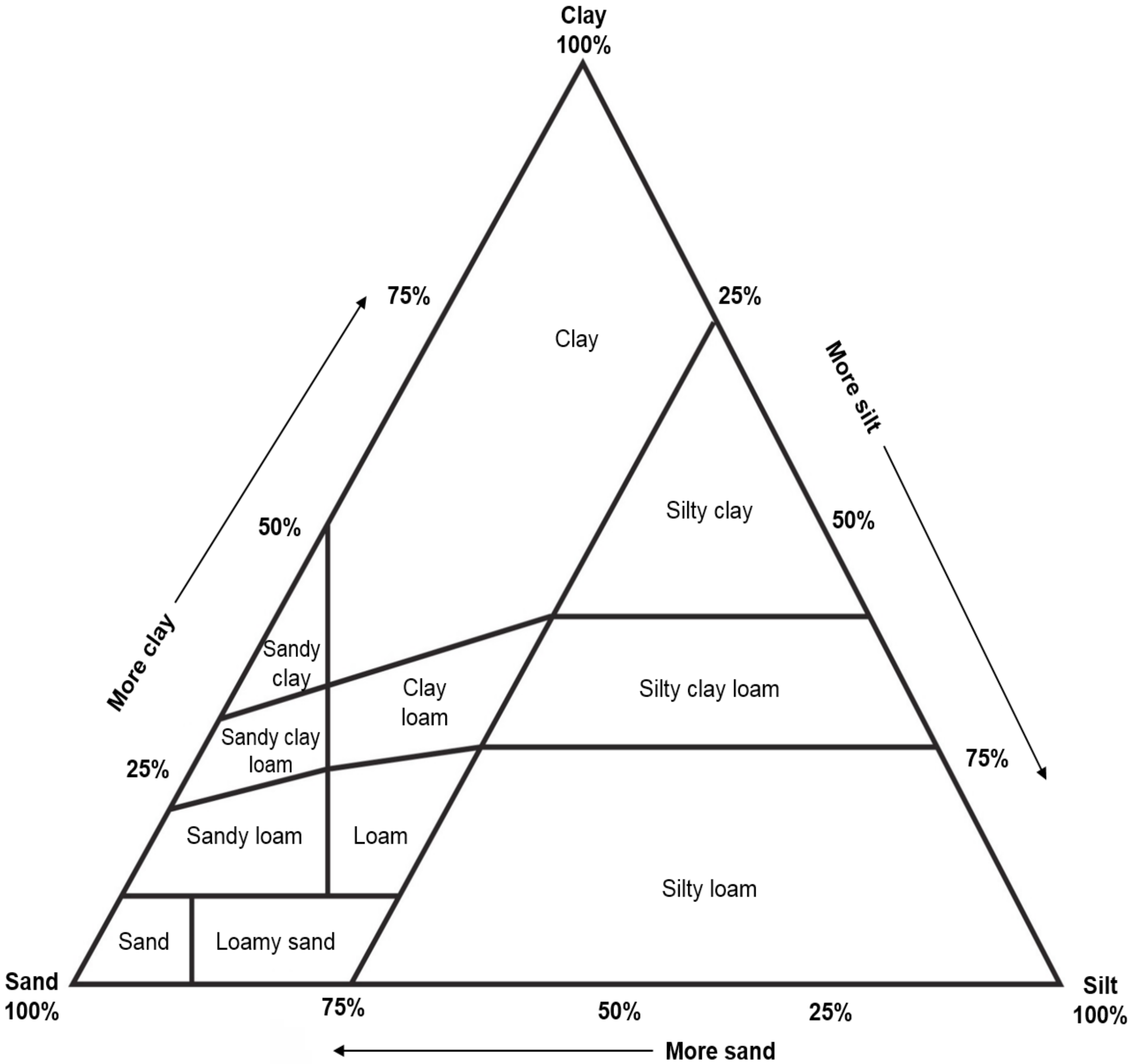


Figure 101. The soil texture triangle. Source: Adapted from Charman and Murphy 2000.

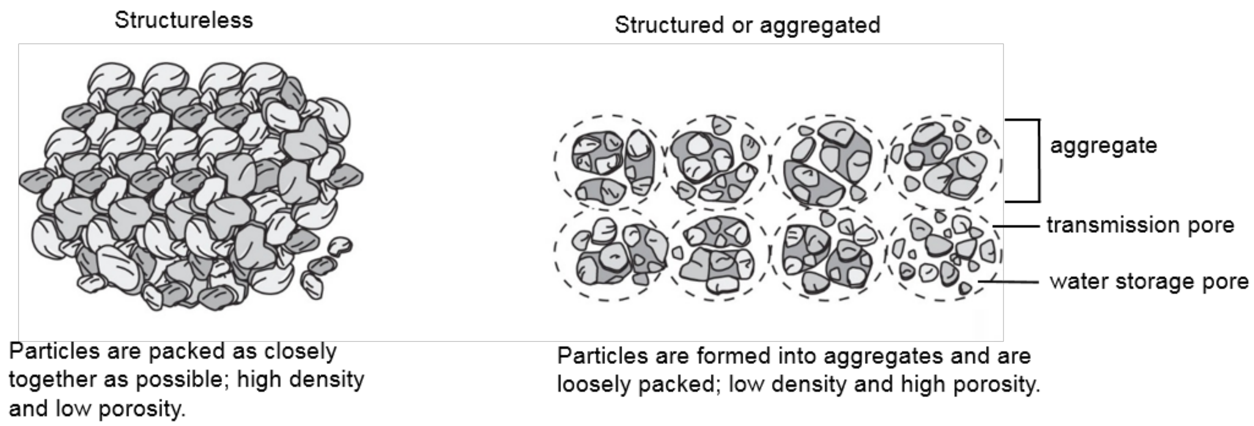


Figure 102. Examples of poorly and well-structured soils. Source: Charman and Murphy 2000.

Soil survey data (soil profiles and descriptions, reports and maps) are also available on the following websites: *Australian Soil Resource Information System* (ASRIS) database; *Queensland Spatial Catalogue – QSpatial*; *NSW Office of Environment & Heritage eSPADE* and the *Victorian Soil Information System* (VSIS).

## Texture

Soil texture is largely determined by the parent rock material and the history of the soil's movement by wind and/or water. Soil texture refers to the composition of the soil in terms of the proportion of the different sized particles – clay, silt and sand. Soil texture can be determined by hand using the ribboning technique or calculated more accurately based on a laboratory measurement of the proportions of clay, silt and sand and using a soil texture triangle (Figure 101). For more information see NSW DPI Primefact 1363 *'Determining soil texture using the ribboning technique'*.

## Structure

Soil structure is the arrangement of soil particles into stable units called aggregates or peds. Aggregates can be loose or friable or form distinct patterns. Well structured soils allow good air and water movement through the soil (Figure 102).

The texture and structure of the soil influences its infiltration rate, permeability and waterholding capacity.

## Porosity

Soil porosity refers to the space (pores) between the soil particles and aggregates. It is dependent on soil texture and structure. The pores are described according to their size, as macropores (>0.5 mm) and micropores (<0.5 mm). Water infiltration, drainage, soil aeration and waterholding characteristics of the soil are largely governed by pore size distribution. Soils with a high proportion of large pores are usually well aerated and have good drainage and infiltration rates.

Bulk density is the common measure of soil porosity. The higher the bulk density measurement the more compact the soil. Bulk density (g/cm$^3$ or mg/m$^3$) = weight of the undisturbed soil divided by the volume of soil. The bulk densities of various soils are outlined in Table 32.

## Infiltration

The movement of water from the soil surface into the soil profile is referred to as infiltration. Soil texture, structure and slope strongly influence infiltration rate. Light sandy soils have a faster infiltration rate than soils with a lot of clay. As a general guide, an application rate of up to 8–10 mm/hour is satisfactory for sandy soils, and 4–5 mm/hour is satisfactory for clay soils.

With drip irrigation, water tends to move more vertically than horizontally in sandy soils, whereas in heavier textured soils the water moves more horizontally giving a better lateral spread. A general guide to typical soil wetting patterns is shown in Figure 103. The infiltration rate of soils is important when designing the application rate of sprinklers and drippers.

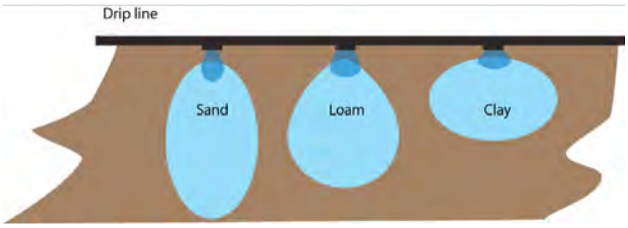


Figure 103. Wetting patterns in different soil types.Source: Giddings 2005.

## Permeability

The rate of air and water movement through the soil is referred to as its permeability. Permeability depends on the soil's texture, structure and porosity (Figure 104). Coarse soils are more permeable than compacted or heavy clay soils. A general guide to permeability rates for different soil types is outlined in Table 33. Some soils can also have hidden impermeable layers (e.g. sandstone floaters or clay) at various depths throughout their profile, which can impede drainage and cause waterlogging. The permeability of a soil is also important when designing irrigation systems and application rates.

## Waterholding capacity

The soil's ability to hold and retain water is referred to as its waterholding capacity (WHC). WHC is determined primarily by soil texture and organic matter content. Soils high in clay and silt particles have a high WHC, whereas sandy soils have a low WHC and require more frequent irrigation. Organic matter has a high affinity for water and increases WHC.

Table 32. Soil texture and bulk density impacts on soil compactness.

| Soil texture and approximate % clay | Bulk density ($gm/cm^3$ or $mg/m^3$) | | | | |
|---|---|---|---|---|---|
| | <1.2 | >1.2–1.4 | >1.4–1.6 | >1.6–1.8 | >1.8 |
| Sandy; <20% clay | Very open | Very open | Satisfactory | Compact | Very compact |
| Loamy; 20–30% clay | Satisfactory | Satisfactory | Compact | Very compact | Extremely compact |
| Clayey; >35% clay | Satisfactory | Satisfactory to compact | Very compact | Very compact | Extremely compact |

Source: Adapted from Department of Natural Resources 2006.


Figure 104. Permeability of different soil textures. Source: Gill 2002.

## Describing soil water status

### Soil water

Soil water is held in the pore spaces and attached to the soil particles. When all the pore spaces in the soil are filled with water, the soil is said to be saturated. As the tree takes up water and the soil dries, the water in the large pore spaces is the first to be used, followed by the water in the smaller pore spaces. The water closely attached to the soil particles is held with such force that it is largely unavailable to plants (Figure 105).

There are several terms used to describe the moisture content of soils. Knowledge of the amount of water held at various soil water potentials such as saturation (S), field capacity (FC), refill point (RP) and permanent wilting point (PWP) are important for scheduling irrigations (Figure 106 and Figure 107).

### Saturation point

When it rains, or following irrigation, all the soil pores fill up with water and the soil is saturated. At this point there are no air spaces in the soil and therefore no oxygen. Once the soil is saturated, any more water that is added causes run-off. Depending on the soil type, drainage characteristics and the amount of water applied, soils may remain saturated for hours or days.

### Field capacity

When the larger soil pores have drained (1–4 days), the soil is said to be at field capacity. At this point the soil is still wet, but not saturated. The water is primarily held in the small capillaries of the soil and is readily available for tree use. As water is progressively removed from the soil by surface evaporation and tree use, the soil dries. The drier the soil, the higher the suction, and the harder the trees have to work in order to extract water. If a tree has to work too hard at extracting water, it will begin to show symptoms of water stress. Field capacity in most soils is at a tensiometer reading of approximately –8 kPa to –10 kPa.

### Readily available water (RAW)

Water that can be easily extracted from the soil by plants is called the readily available water (RAW). Depending on crop type, RAW for horticultural crops is usually the amount of water held between field capacity (–8 to –10 kPa) and a refill point (–20 to –60 kPa). RAW is usually determined by mapping soil profiles and crop rootzones in a soil survey. To achieve high yields irrigation management should aim to ensure that trees are always using RAW.

RAW is expressed in millimetres of water available per centimetre (mm/cm) or metre (mm/m) of soil depth. The RAW capacity of a soil forms the basis for scheduling irrigation. Knowing the RAW and the application rate (mm/hr) of the irrigation system allows the calculation of the approximate number of hours of irrigation needed. For more information on calculating RAW refer to the NSW DPI Primefact 1362 *'Determining readily available water to assist with irrigation management'*.

Table 33. Permeability of different soil types.

| Texture | Infiltration | Permeability (mm/hour) |
|---|---|---|
| Sand | Very rapid | >120 |
| Loam | Rapid<br>Moderately rapid | 60–120<br>20–60 |
| Light clay | Moderate<br>Slow | 2.5–5<br><2.5 |
| Medium to heavy clay | Slow<br>Very slow | 2.5–5<br><2.5 |

Source: Adapted from Charmana and Murphy 1991.


Saturated soil: all the pore spaces are filled with water


Soil at field capacity: good balance between air and water in pore spaces

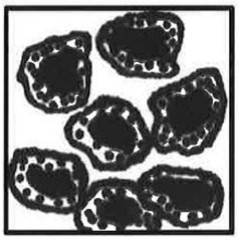
Soil at wilting point: the only water in the soil is held tightly around the soil particles and is largely unavailable to the plant's roots

Figure 105. Soil saturation stages.

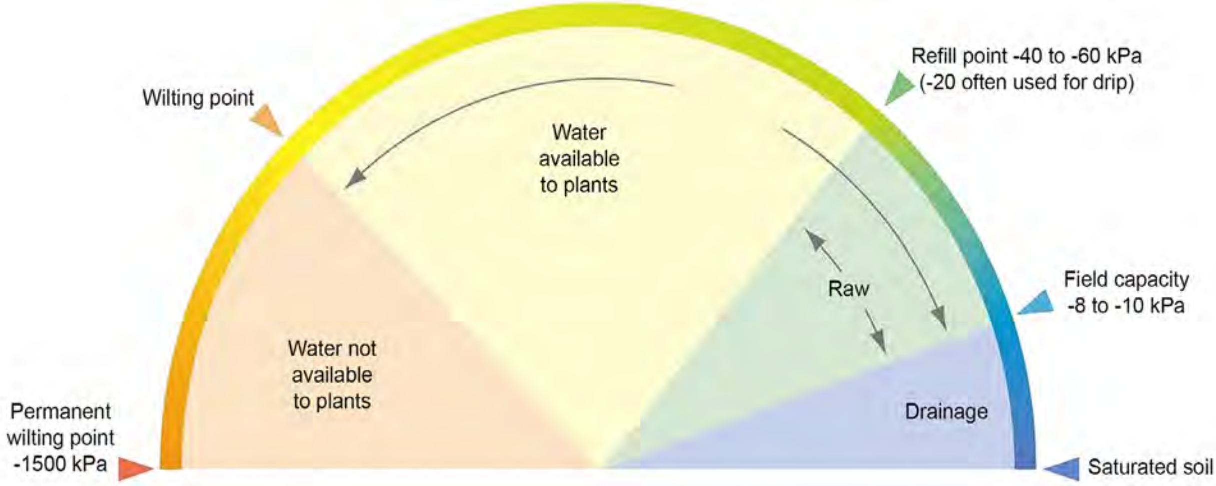


Figure 106. Soil water status and irrigation scheduling. Source: NSW DPI 2014, Primefact 1362.

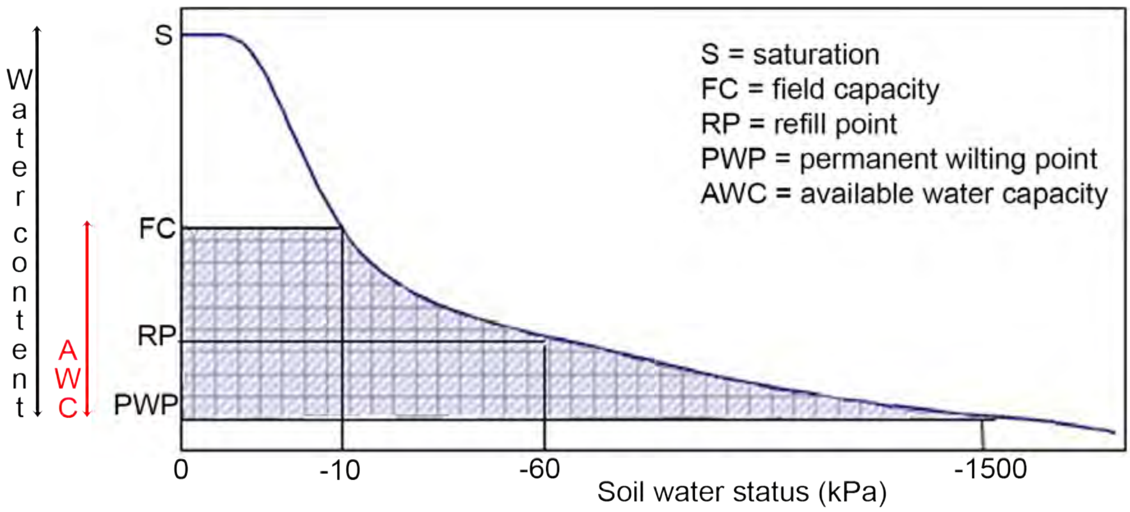


Figure 107. A typical soil water retention characteristic curve. Source: Agriculture Victoria 2016.

Irrigation

### Refill point

When all the RAW has been used the tree roots cannot easily extract water. This stage is referred to as the refill point and this is the time to irrigate to maintain unrestricted tree and leaf function. For most tree crops the refill point is between −40 and −60 kPa, however if drip irrigation is used a refill point of −20 kPa is often adopted. If soil dries beyond the refill point, water is still present and available in the smaller pores, but it is much harder for roots to extract it. Tree growth and fruit development ceases while soil moisture remains at this point (see Figure 106).

### Permanent wilting point

It is relatively easy for tree roots to extract water when the tension is anywhere between −8 kPa to −60 kPa. These figures vary with soil type, crop variety and age. As the soil gets drier, it still contains water but the trees have to exert a tension greater than −60 kPa to extract that water. This extra effort may stress trees and affect fruit development and reduce yields. Eventually the soil reaches a point at which the tree can no longer extract any water; this is known as the permanent wilting point. Once the soil has passed this point, water is held by the soil so tightly that the tree will wilt and die from lack of water. Permanent wilting point is conventionally defined as a soil water tension of −1500 kPa, but in practice this varies with crop type.

## Water quality parameters

There are a number of factors that affect water quality and these can be detrimental to tree growth and development. Any water planned for irrigation use should be tested by an accredited laboratory. The quality of irrigation water should also be monitored regularly because it can change over time and fluctuate with seasonal conditions (especially during droughts or floods).

### Salinity

One of the greatest water quality issues is salinity. Saline irrigation water can result in the build up of salt in the soil to levels which are toxic to plants (Figure 108) and which destroys soil structure. Salt in irrigation water affects crop performance in several ways:

- reduces shoot growth and yield (normally reduces fruit number)
- can decrease % juice, TA and TSS
- the presence of certain elements such as chloride, sodium or boron can cause specific toxic effects, particularly on leaves.

During a drought the salinity of the water usually increases. In conditions of low humidity the effects of salinity can also be intensified. Testing the salinity of the water will indicate if the water is suitable for irrigation.

Figure 108. Citrus trees defoliating due to salt stress.

There are many different salt molecules, some more soluble than others. Highly soluble salts such as sodium chloride move readily in the soil solution and usually do most of the damage to plants.

Salinity in irrigation water is measured by electrical conductivity (EC). EC measures the extent to which water conducts an electrical current and the higher the EC, the higher the salt load. EC can be easily measured using a handheld EC meter or by sending a water sample to a laboratory for analysis. EC is generally expressed as deciSiemens per metre (dS/m) or microSiemens per centimetre (µS/cm). [1 dS/m = 1000 µS/cm].

The water salinity threshold for oranges is <1.1 dS/m or <1100 µS/cm.

EC readings above this threshold may result in a reduction in yield. For example, for oranges it is estimated that water with an EC of 1.6 dS/m could result in a 10% reduction in yield, while an EC of 2.2 dS/m could reduce yield by 25% (NSW DPI, 2016). Other factors, such as soil type, the soil's ability to drain, the method of irrigation (overhead sprinklers which will wet foliage versus drip irrigation which will only apply water to the soil), rainfall, variety and rootstock also affect the ability of trees to cope with salinity.

Citrus is considered fairly sensitive to salinity, however rootstocks exert a significant influence on their tolerance. Rootstocks vary in their ability to restrict the uptake of sodium and chloride ions. Cleopatra mandarin is the most salt tolerant, as it can exclude chloride and trifoliate orange is the least tolerant rootstock as it accumulates chloride. For more information on salinity tolerance refer to the Rootstock chapter.

### pH

Water with a pH reading between 6.0 and 8.5 is generally suitable for irrigation. Highly alkaline water with high carbonate and bicarbonate levels can affect plant uptake of calcium, magnesium and some trace elements. It also tends to precipitate calcium carbonate, which can cause blockages in pipes. Carbonate and bicarbonate levels of up to 150 mg/L are acceptable, while 350 mg/L would be cause for concern.

### Sodium

Soil permeability problems can occur if there is a high sodium ($Na^+$) content in the irrigation water. Sodium (a positively charged cation) will replace two important cations, namely calcium ($Ca^{2+}$) and magnesium ($Mg^{2+}$), causing soil aggregates to disperse, destroying soil structure and making the soil impermeable to water and air. An increase in exchangeable sodium can increase soil pH above 8.5 and reduce the availability of some micronutrients such as iron and phosphorus.

The degree of absorption of sodium by the clay particles in the soil depends on its concentration in the water as well as the concentration of $Ca^{2+}$ and $Mg^{2+}$ ions. If the amount of calcium and magnesium is high compared with the amount of sodium, then the sodium problem is reduced.

The sodium adsorption ratio (SAR) is a measure of the imbalance of $Na^+$ relative to $Ca^{2+}$ and $Mg^{2+}$ in the water:

$$\text{SAR} = \frac{\text{Na}}{\sqrt{[(\text{Ca} + \text{Mg}) / 2]}}$$

High SAR levels cause poor soil structure and so poor water penetration through the soil, poor drainage and low aeration levels. Affected soils often have a hard, blocky structure and surface crusting. High sodium levels in soils can be treated with gypsum. The use of irrigation water with a high SAR value and low to moderate salinity may reduce the soil infiltration rate. Levels of sodium in excess of 200 ppm are considered too high for citrus.

A general guide to SAR values:

- <6.0 mmol/L – waterlogging unlikely
- 6.0–9.0 mmol/L – a problem exists but can usually be managed with gypsum
- >9.0 mmol/L – severe problems.

### Chloride

High chloride levels in water can cause poor growth and death of plant tissue (especially if the water is sprayed directly onto the plant). If the irrigation water is applied by drip or micro sprinklers, and not directly on the tree, levels below 140 mg/L (ppm) are fine. Readings between 140 to 350 mg/L should be treated with caution, and any water measuring above 350 mg/L should not be used. Rootstocks have different tolerances to chloride. *C. trifoliata* is the least tolerant, while Cleopatra mandarin has good tolerance (Table 34). For more information see the Rootstock chapter.

### Calcium carbonate saturation index

The calcium carbonate saturation index gives the relationship between pH, salinity, alkalinity and water hardness. It indicates whether the water is likely to cause corrosion of pumps and pipes and blockages of drippers and pipes. Figures between –0.5 and 0.5 are considered suitable.

### Iron

Soluble iron and bacterial iron can cause blockages to pipes, drippers, and sprinklers and damage pressure gauges. If water with high levels of soluble iron is applied by overhead sprinklers, it can discolour leaves and reduce transpiration and photosynthesis. Iron levels as low as 0.1 mg/L (0.1 ppm) can cause problems with blockages in micro-irrigation systems. The simplest treatment to remove iron from water is to use aeration, followed by settling and then filtration.

### Turbidity

Turbidity is a measure of the amount of solids in water. Turbidity can be high in some rivers and streams. Erosion of soil is a major cause of turbidity. The dispersed clay particles stay suspended in water for long periods and can cause a build-up of sludge causing blockages in drippers and laterals. All irrigation systems should have a suitable filtration system to prevent fine particles getting into drip lines.

Table 34. Chloride toxicity limits for different rootstocks.

| Rootstock | Irrigation water chloride limits: (ppm by root uptake) |
|---|---|
| Trifoliate orange | 120 |
| Rough lemon | 200 |
| Troyer citrange<br>Sweet orange | 300 |
| Rangpur lime<br>Cleopatra mandarin | 600 |

Source: Giddings 2005.

### Nutrients

Excessive nutrients in water can be due to organic or inorganic fertilisers or other sources of soluble nutrients. Excessive nutrient loads in water can result in:

- prolific growth of aquatic weeds and algae which restrict water flow
- reduced water quality from the production of algae and bacterial toxins
- clogged filters.

## Irrigation scheduling

The aim of irrigation scheduling is to keep soil moisture within a desired range, usually between field capacity and a pre-determined refill point for optimum growth. The schedule should match tree water use with water application and allow the right amount of water to be applied at the right time. Scheduling involves deciding when and how much to irrigate by considering:

- the soil's RAW capacity
- the application rate (mm/h) of the irrigation system
- the evenness of water application (distribution uniformity) and efficiency of the system
- the current water content of the soil
- the rate of crop water use.

Incorrect scheduling of irrigation frequently leads to periods of over-watering or under-watering, which can affect tree health and yield.

### Benefits of scheduling:

- ☑ provides optimum soil water conditions for tree health and growth
- ☑ uses water efficiently and effectively
- ☑ maximises productivity
- ☑ minimises leaching, runoff and wastage.

### How to schedule

The RAW and the application rate (mm/hr) of the irrigation system are used to calculate approximately how many hours of irrigation are needed. The right time to irrigate is determined using an estimate of the crop water use.

There are several methods for estimating tree water use.

1. Soil-based – uses measurements of the soil moisture status, either by measuring soil moisture tension or volumetric soil water content.
2. Weather-based – provides an indirect measure of plant evapotranspiration by using either an evaporation pan or local weather data.
3. Plant-based – includes measurements of leaf and stem water potential, stomata conductance, canopy temperature, sap flow and trunk diameter. These plant based measurements are normally not used by orchardists, but are used widely by researchers to develop soil and climate-based yard sticks for orchardists to use.

A combination of soil-based and weather-based measurements are the most commonly used to schedule irrigations in orchards.

### *1. Soil-based scheduling*

Monitoring soil moisture status provides a sound basis upon which to develop and improve irrigation practices. Monitoring soil moisture before irrigating is important in scheduling the amount of water to be applied and to predict the timing of the next irrigation. Monitoring soil moisture after irrigating provides information on where in the profile the applied water reached.

Soil water can be determined by measuring either the soil water tension or the volumetric water content. Various instruments which vary in cost and complexity are available:

- Tensiometers

These devices measure the amount of suction required to draw water out of the soil. They generally operate in a range of 0 to –80 kPa. The higher (more negative) the reading the drier the soil. A guide to the interpretation of tensiometer readings is given in Table 35.

Tensiometer readings should be made 2–3 times per week in summer. Tensiometers are suitable for use in soils that allow good contact between the soil particles and the ceramic tip, such as sandy and clay loams. They should be installed halfway between the tree trunk and the edge of the tree canopy at various depths (e.g. 30, 60 and 90 cm) to measure soil moisture throughout the rootzone (Figure 109). Tensiometers must have good contact between the ceramic tip and the soil and be regularly maintained. They should be installed at several representative sites within the block. For more information see NSW DPI Primefact 1359 *'Tensiometer tips'*.

- Resistance/gypsum blocks

These also measure the amount of suction required by plants to extract water. They measure the resistance to electricity moving between two electrodes embedded in a gypsum or granular quartz matrix. As soils dry out, the moisture in the block is drawn out, increasing the resistance to electricity moving between the two electrodes.

Table 35. General guide for tensiometer readings.

| Reading (–kPa) | Interpretation |
|---|---|
| 0–8 | Soil is saturated (0) to near field capacity (8). Continued low readings indicate waterlogging. |
| 8–10 | Field capacity. |
| 8–25 | Optimum soil moisture and aeration. |
| 25–35 | Consider irrigation at critical stages of crop cycle. |
| 35–50 | Mild stress on well-drained soils. |
| 50+ | Soil is becoming very dry and crop yield will be affected and fruit quality possibly compromised. |

Source: NSW DPI 2014, Primefact 1359.

This resistance is measured and converted to a reading of soil moisture tension. Resistance blocks, like tensiometers, should be placed at several depths in the rootzone. They are suitable for a range of soil types. There are two types:

1. Gypsum blocks: these read from –60 to –600 kPa and are suited to heavier soils.
2. Granular matrix blocks: these read from –10 to –200 kPa and are suited to lighter soils.

Figure 109. Tensiometers installed at different depths to monitor soil moisture.

- Capacitance probes

Capacitance probes measure soil water as a percentage of the total soil volume. The probes are inserted into PVC access tubes that are installed at selected sites which are representative of the whole block (Figure 110). These probes have multiple sensors which can be located at various depths to cover the full rootzone. Each sensor emits a small electric field of known frequency and depth which extends beyond the access tube into the soil. Changes in soil moisture result in changes in frequency of the electric field which is then converted into soil moisture content by a software program. There are portable (Diviner 2000®) and fixed (EnviroScan®) types. Portable devices require the user to visit the site to get readings. Fixed devices can be connected to a data logger or transmit the data to a computer. For more information refer to the NSW DPI Primefact 1365 *'Using capacitance probes for irrigation scheduling'.*

Figure 110. Capacitance probes are placed in selective positions to measure soil water.

- Time domain reflectometry (TDR)

TDR also measures soil water as a percentage of total soil volume. The devices generate a small electromagnetic pulse which passes through the soil before being detected by a sensor. The rate at which the pulse moves through the soil is dependent on the amount of moisture in the soil. These devices can be installed to monitor soil moisture at various depths through the rootzone.

- Neutron Probes

Neutron probes utilise radioactive particles called neutrons to detect the presence of hydrogen in the soil water. The probes are lowered down aluminium access tubes placed at representative sites in the orchard (Figure 111). The probe releases neutrons which are slowed by collision with hydrogen atoms in the soil. This change in the speed of the neutrons is detected in the probe and provides a reading that corresponds to soil moisture. Calibrated readings can then be converted to millimetres of water. Neutron probes are expensive and require the operator to be licensed to use, store and transport the probes in some states. For more information refer to the NSW DPI Primefact 1366 *'Using neutron probes for irrigation scheduling'*.

Figure 111. Neutron probes can also be used to monitor soil water status.

- FullStop™ wetting front detector

The FullStop™ wetting front detector is used to monitor the movement of moisture through the soil profile. The detectors are made of plastic, have no electronics and do not require power. A funnel shaped reservoir buried at a desired depth collects water as it moves through the soil profile. When the reservoir is filled an indicator flag (fitted to an extension tube) is triggered. They are often used as a quick visual aid to gauge when irrigation water has reached a specific level in the rootzone. They can be installed in pairs to gauge if too little or too much irrigation is being applied.

### 2. Weather-based scheduling

Water is lost from soil surfaces through evaporation and from plants through transpiration. The combined losses from evaporation and transpiration is called evapotranspiration (ET). ET is more or less equivalent to plant water use and is used to estimate the irrigation requirements of crops. ET varies between regions and is influenced by local weather and soil conditions and crop type.

Weather stations, such as the Australian Bureau of Meteorology, can provide evapotranspiration measurements. The method uses a standard 'reference' crop (12 cm high green grass) and is referred to as reference crop evapotranspiration, denoted as $ET_O$. Estimation of the ET for different crop types can be made by multiplying the $ET_O$ by a crop factor. The term 'crop coefficient' is synonymous with 'crop factor'.

The common crop factor used for citrus is 0.7 year round. However, in reality different crop factors are used throughout the year and for varieties and regions, as shown in Table 36 where the monthly crop factor for citrus in the Sunraysia region is estimated at between 0.55 and 0.65.

### Calculation example

An $ET_O$ figure of 10 mm was recorded on a day in January in Sunraysia by an automatic weather station. The crop factor for citrus at this time of year is 0.55:

$ET = ET_O \times$ crop factor
$ET = 10 \times 0.55 = 5.5$ mm evapotranspiration on that day.

Table 36. Crop factors for citrus in the Sunraysia region of southern Australia.

| Month | Crop factor* |
|---|---|
| July | 0.65 |
| August | 0.65 |
| September | 0.65 |
| October | 0.55 |
| November | 0.55 |
| December | 0.55 |
| January | 0.55 |
| February | 0.55 |
| March | 0.55 |
| April | 0.65 |
| May | 0.65 |
| June | 0.65 |

*Based on a tree canopy giving about 70% groundcover. Source: Adapted from Giddings 2002.

## Water stress

Under-irrigating trees causes water stress and occurs when the tree cannot replace losses from transpiration. Trees can suffer water stress before there are any obvious visual symptoms. Symptoms can be more severe on trees growing on shallow rooted rootstocks.

Water stress can occur when soil water is low, on hot or windy days or when root function and performance is affected by unfavourable soil temperatures (too low or high), low oxygen levels (e.g. compacted or heavy soils), or the presence of pests (e.g. nematodes) or disease pathogens (e.g. *Phytophthora* root rot). Under-irrigation can also increase salt accumulation in the rootzone. For more information on managing citrus in drought refer to NSW DPI Primefact Number 427 *'Managing citrus orchards with less water'*. Some of the symptoms and effects of water stress are outlined in Table 37.

## Using a period of water stress to manipulate fruit quality

There have been many studies undertaken on the effects of applying various levels of water stress (including regulated deficit irrigation [RDI]) on different mandarin cultivars. The results show that there are large differences in the sensitivity of mandarins to water stress according to growth (phenological) stage, with the most critical being the flowering and fruit set periods (Gonzalez-Altozano et al. 1999).

Generally longer periods of severe water stress (as a result of either no irrigation or irrigating to less than 50% of crop evapotranspiration) will have a negative effect on tree growth and fruit yield, size and quality. However, shorter periods of moderate water stress applied at specific times in the growth cycle can improve fruit quality by increasing total soluble solids (TSS) and titratable acidity (TA); two factors that strongly influence taste and flavour.

Water stress during flowering and fruit set can have the following effects: substantially reduced yield due to more fruit drop and smaller fruit, reduced vegetative growth and shoot length and the encouragement of out-of-season flowering (Ginestar & Castel 1996, Gonzalez-Altozano & Castel 1999).

Ginestar and Castel (1996) found that yield of Nules Clementine was reduced by severe water stress during any period of the production cycle, but the more acute effects were produced by water stress in spring and early summer. Severe stress during growth Stages I and II affected mainly fruit number by causing heavy fruitlet drop. Stress during late summer reduced fruit size. Navarro et al. (2010) found a long period of non-irrigation during the fruit enlargement period (Stage II) causing severe water stress in Nules Clementine, decreased fruit moisture levels, resulting in a higher TA and TSS which drastically delayed maturation – making fruit non-commercial. Koshita and Takahara (2004) found that severe water stress during autumn caused heavy leaf fall on Satsuma mandarins trees and a one third reduction in the number of flowering nodes the following spring.

However, a shorter more targeted period of moderate water stress during fruit maturation may improve fruit flavour by increasing the TSS and TA content of fruit – due to the translocation of photosynthates into the fruit, especially the juice sacs (Yakushiji et al. 1996). Navarro et al. (2010) found that withholding irrigation from Clemenules mandarins for a short period between mid to late autumn during Stage III (maturation) could improve fruit quality by increasing TA and TSS, without altering the maturation process.

There is a large body of literature on assessing the impacts of water stress on different mandarin cultivars and some of these are included in the reference list at the end of this chapter. Different strategies have been tested and it is recommended that relevant research on specific varieties is consulted. Implement small-scale trials on your property to test the potential of various strategies to either save water or improve fruit flavour prior to harvest.

Table 37. Symptoms and effects of water stress and waterlogging.

| Water stress | Waterlogging |
|---|---|
| ☒ wilting and thickening of leaves | ☒ sparse foliage and stunted trees |
| ☒ fruit and vegetative growth slows or stops | ☒ reduced yields |
| ☒ leaf and fruit drop | ☒ decreased TSS andTA |
| ☒ shoot and tree death | ☒ reduced oxygen levels in the soil – reduced root function and possibly root death |
| ☒ reduced fruit set | ☒ increased root diseases such as Phytophthora root rot |
| ☒ decreased fruit size and % juice | ☒ nutrient leaching |
| ☒ nutrient deficiencies | ☒ increased surface runoff and subsurface drainage |
| ☒ salt damage | ☑ increased % juice |
| ☒ can initiate 'out of season' flowering | |
| ☑ can improve skin quality | |
| ☑ increased TSS and TA | |

Irrigation

## Waterlogging

Over-irrigating trees leads to waterlogging which occurs when water enters the soil at a faster rate than it can drain away. Waterlogging results in a lack of oxygen in the soil, causing root death and increasing the likelihood of soil borne diseases such as Phytophthora root rot infecting tree roots. Over-irrigating wastes water, leaches out nutrients and produces excess drainage and runoff. For more detailed information on waterlogging refer to NSW DPI Primefact 1189 *'Impacts and management of flooding and waterlogging in citrus orchards'*. Some of the symptoms and effects of waterlogging are outlined in Table 37.

## Irrigation strategies

There are two irrigation strategies that aim to maximise crop water use efficiency by reducing the total amount of water applied, whilst still achieving good productivity. These strategies push trees to their limit and should only be applied to well established healthy trees. There are many published scientific articles on both these techniques. For more detailed information about these techniques consult previous research (e.g. Kriedemann & Goodwin 2003; Hutton, Landsberg & Sutton 2007; Treeby et al. 2007).

### Partial rootzone drying (PRD)

PRD involves irrigating only one side of the tree row and leaving the other side of the rootzone to dry out. At each subsequent irrigation the alternative side of the tree row is irrigated.

PRD significantly reduces the total wetted soil volume, maintaining a good supply of readily available water to only part of the rootzone.

PRD stimulates various physiological mechanisms in the tree to reduce water use.

### Regulated deficit irrigation (RDI)

RDI is a technique that involves reducing irrigation amounts at specific times in the annual growth cycle. It is most commonly used to manipulate the production of shoots and flowers or to improve fruit quality parameters.

RDI is commonly used to trigger flowering in citrus in tropical regions such as in the Northern Territory, where the temperatures during winter are not low enough to induce flowering.

The use of RDI requires a good knowledge of the annual growth cycle of mandarins in the region. Application of RDI on a large scale should be based on scientifically valid research trials.

In Australia under standard management practices, Satsuma mandarin fruit tend to be large and puffy with a low juice content and poor flavour. An RDI trial was undertaken at the NSW DPI Institute at Dareton in south western NSW from 2002–2004 to improve fruit quality. Results from that trial indicated that a 'mild' water stress (50% of normal irrigation volume) applied between February and April improved fruit quality by increasing TSS while maintaining marketable fruit size (Figure 112).

Figure 112. Effect of water stress applied between February and April on Satsuma TSS at harvest.

## Irrigation systems

Mandarins can be watered by any of the main irrigation systems commonly used in horticulture. Most orchards in Australia use either undertree mini or microsprinklers or drip irrigation. Most new orchard developments are installing drip irrigation systems with which a high level of water use efficiency is possible.

The following information briefly outlines each system. More detailed information is available from primary industries websites or refer to the NSW DPI Primefact 1367 *'Aspects to consider when choosing an irrigation system for horticulture'*.

### Drip

Drip irrigation can be used in most soil types. It allows water to be applied directly to the rootzone and adequate soil moisture is maintained by frequent irrigation. Because only a limited volume of the soil is irrigated, a constant water and power supply is critical as trees will not be able to withstand long periods without water. It is potentially the most water efficient system. Young trees are often set up with one drip line and as trees grow a second line can be added to the other side of the row (Figure 113). For more detailed information refer to *Drip irrigation – a citrus grower's guide*. The main benefits and limitations of drip irrigation are outlined in Table 38.

### Mini, micro or low level sprinklers

These sprinkler systems are suitable for a wide range of soil types, including those with low infiltration rates and water holding capacity. There are three different sprinkler types commonly used:

1. Microjets: no moving parts; provide less coverage than microsprinklers and operate at pressures of 50–150 kPa.
2. Microsprinklers: utilise fast spinning rotors to distribute the water (Figure 114); operate at pressures of 125–200 kPa and have a higher discharge rate than microjets.
3. Under canopy impact sprinklers: similar to overhead systems, but with smaller sprinklers which are spaced closer together and operate at 150–350 kPa.

The main benefits and limitations of microsprinkler systems are outlined in Table 38.

### Overhead sprinklers

Overhead irrigation has become less common in the last 30 years. Overhead irrigation uses medium to large impact sprinklers mounted on risers to deliver water above the canopy (Figure 115). The benefits and limitations of overhead sprinkler systems are outlined in Table 38.

### Furrow

Furrow irrigation is best suited to deep permeable soils (such as loams and clay loams) with gentle slopes and high water holding capacity. Water is channelled down V-shaped furrows in lighter soil types or more broad based furrows in heavier soils (Figure 116). Correct grading of the furrows is critical. The benefits and limitations of furrow irrigation are outlined in Table 38.

Figure 113. Two drip lines are used to irrigate mature trees.

Figure 114. Microsprinklers are able to irrigate the inter-row sods.

Figure 115. Overhead irrigation can also be used for frost control.

Figure 116. Furrow irrigation on newly planted trees.

Irrigation

Table 38. Advantages and limitations of different irrigation systems.

| Irrigation system | Advantages | Limitations |
|---|---|---|
| Drip | • easily automated<br>• highly suitable for fertigation<br>• even distribution of water across whole block<br>• deliver precise water amounts<br>• potential for high water use efficiency<br>• access to orchard when irrigating<br>• low pumping costs<br>• foliage kept dry | • high initial setup costs<br>• need sources of very reliable water and energy<br>• requires good scheduling<br>• little margin for error, trees may stress quickly if the system fails<br>• limited leaching ability<br>• unable to irrigate inter-row sods<br>• orchards hotter with increased chance of damage to leaves and fruit<br>• can be blocked by ants<br>• does not provide frost control |
| Mini or micro sprinklers | • easily automated<br>• suitable for most soil types<br>• well suited to fertigation<br>• delivers precise water amounts<br>• water distribution across the block better than flood, but not as good as drip<br>• able to irrigate inter-row areas<br>• offers some frost protection<br>• leaching irrigations simple<br>• lower pumping costs than overhead sprinklers | • need to keep trees well skirted<br>• need to have good weed control<br>• wind can affect uniformity of water distribution<br>• humidity in the lower tree canopy can increase<br>• prone to damage from machinery, animals and people |
| Overhead sprinklers | • able to automate irrigation<br>• able to irrigate inter-row areas<br>• water distribution across the block better than furrow, but not as good as drip or micro sprinklers<br>• can be used for frost protection<br>• rinses dust from trees<br>• leaching irrigations simple | • high maintenance and pumping costs<br>• poor distribution of water when windy<br>• requires good quality water; slightly saline water causes risk of scorching leaves<br>• difficult to deliver exact amounts of water<br>• not well suited to heavy clay soils due to surface sealing<br>• high evaporation losses if hot and windy<br>• can create conditions conducive to pest and disease development<br>• increased humidity in the tree canopy |
| Furrow | • relatively low set-up and running costs<br>• larger wetted area of the root zone<br>• can fill soil profile quickly<br>• leaching irrigations simple for salinity control<br>• foliage kept dry | • high labour input<br>• poor water use efficiency<br>• not suited to sandy soils<br>• difficult to deliver precise water amounts<br>• access to orchard after irrigation limited<br>• uneven distribution of water along the furrow – leading to over or under irrigation<br>• potentially locked in to a set application time<br>• hard to contain water in root-zone<br>• ground must have the correct gradient for good water delivery<br>• furrows must be well maintained<br>• uses valuable space for open head ditch and supply system |

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# Nutrition

## Introduction

Nutrition is an important part of crop management impacting tree growth, yield, fruit size and quality. There is no single nutrition program that will apply to all orchards. A suitable nutrition program for your orchard must be tailored to suit tree age, variety, rootstock, soil type and local conditions, requiring ongoing monitoring and adjustment.

## Soil characteristics and nutrient supply

Trees need 16 elements for growth: carbon, hydrogen and oxygen are supplied by air and water, while the remaining elements must be obtained from the soil or growing medium, and in some situations, by application to foliage. These elements include nitrogen, phosphorus, potassium, calcium, magnesium and sulphur, which are collectively referred to as the macro-nutrients because they are required in large amounts. The remaining elements (manganese, iron, copper, boron, zinc, molybdenum and chlorine) are referred to as micro-nutrients because they are required in very small amounts.

Plant nutrients exist in both organic and inorganic forms in the soil. Organic sources include any living or dead microbial, insect or plant matter and soil amendments. These are used in the nutrient cycling processes and act as a store of nutrients that are slowly released. Inorganic mineral nutrients attach to soil particles or form solid precipitates. These must be released into the soil solution before they can be taken up by tree roots.

Dissolved mineral ions are carried to the roots passively by the movement of water and by diffusion. Mineral ions are taken up by the roots and pass into the water-conducting (xylem) vessels in the centre of the roots. The mineral ions are then carried passively to the leaves and fruit by the movement of water up the xylem vessels. Once inside the tree, some nutrients such as nitrogen, phosphorus, potassium, sulphur and magnesium are mobile and can be translocated to other sites when needed. Other elements, such as calcium and most of the micro-nutrients, are immobile in the tree once they have reached the leaves or fruit after being transported from the roots. Immobile mineral nutrients are not transported from one plant part to another if they are needed. For example, if the soil is unable to supply enough iron, the iron already in the mature leaves cannot be transported to new growth, which will subsequently show symptoms of iron deficiency.

### Soil texture and structure

Soil texture and structure strongly influence nutrient management. Texture is a function of the relative proportions of the different sized particles – clay, silt and sand. Structure refers to how the soil particles or aggregates are arranged and the shape and size of the spaces (pores) between them. Soil texture and structure largely determine the amount of water and nutrients a soil can hold.

Sandy soils are generally well drained and aerated but have a low capacity to hold and store water and nutrients. They are less prone to waterlogging but more prone to nutrient leaching, especially in heavy rain. Sandy soils require small, more frequent applications of water and fertilisers to avoid leaching. The addition of organic matter to sandy soils helps improve soil fertility and water and nutrient holding capacity. In their natural state, sandy soils are generally less fertile, and unable to support sustained vigorous tree growth.

Clay soils are generally more fertile with a greater capacity to hold and store water and nutrients. However, they are also more prone to compaction, poor aeration and waterlogging. Irrigation management is critical to ensure these soils are not over-watered. The addition of organic matter and gypsum to clay soils helps the soil particles to aggregate, improving their structure.

## Soil pH

Soil pH is determined by the balance between hydrogen ions ($H^+$) and hydroxyl ions ($OH^-$). More $H^+$ relative to $OH^-$ ions means the soil is acid. pH is measured on a logarithmic scale from 0 (most acid) to 14 (most alkaline), with a pH of 7 being neutral. A pH of 5 is ten times more acid than a pH of 6, and one hundred times more acid than a pH of 7. Soil pH is influenced by a range of factors including the parent material, weathering processes and agricultural practices.

Soil pH is measured in either water or in a solution of calcium chloride ($CaCl_2$). The measurement taken using $CaCl_2$ is more stable throughout the year and under different seasonal conditions. Values in $CaCl_2$ are normally lower than those in water by between 0.5–0.9 units. Values referred to in this manual were obtained using the $CaCl_2$ method.

Soil pH has a major effect on the availability of soil nutrients, especially the micro-nutrients. A pH between 5.5 and 7.0 will ensure most soil minerals are available for plant use (Figure 117). In very acid soils elements such as phosphorus, magnesium and calcium become less available and other elements such as aluminium, iron and manganese become more available. In contrast, in alkaline soils, calcium can tie up and make phosphorus, manganese, iron, copper, boron and zinc unavailable. Soil pH also affects microbial activity which is important in nutrient cycling and organic matter breakdown. Very acid soils (<4.8) are detrimental to root growth and most soil micro-organisms.

### *Managing soil pH*

Liming materials are used to increase the pH of acid soils. Liming materials include agricultural lime, hydrated lime, burnt lime, dolomite, magnesite, and burnt magnesite. The two most important properties to consider when choosing a liming material are its particle size and neutralising value (NV). The finer the particle size, the greater the surface area on which the reaction with acids in the soil can occur, and the faster the material dissolves and starts working. The NV of the liming material is its capacity to neutralise acidity. Pure limestone (calcium carbonate) is the standard with a NV of 100. The NV of most commercial limestone products is usually between 96 and 98.

Liming materials are more effective when incorporated into the soil because contact with the soil particles is needed for the neutralising reaction. The material starts to work as soon as the soil is moist, but major changes in pH may take more than a year. When the material is spread on the soil surface it moves slowly down the soil profile. It is more difficult to correct acid subsoils particularly in established orchards where uniform incorporation across the whole area is difficult. Where the soil is acidic at depth it has been shown that if the pH of the top 10 cm of soil is maintained at about 5.5 then the pH at a depth of 15–20 cm will slowly increase over time (Upjohn, Fenton & Conyers 2005).

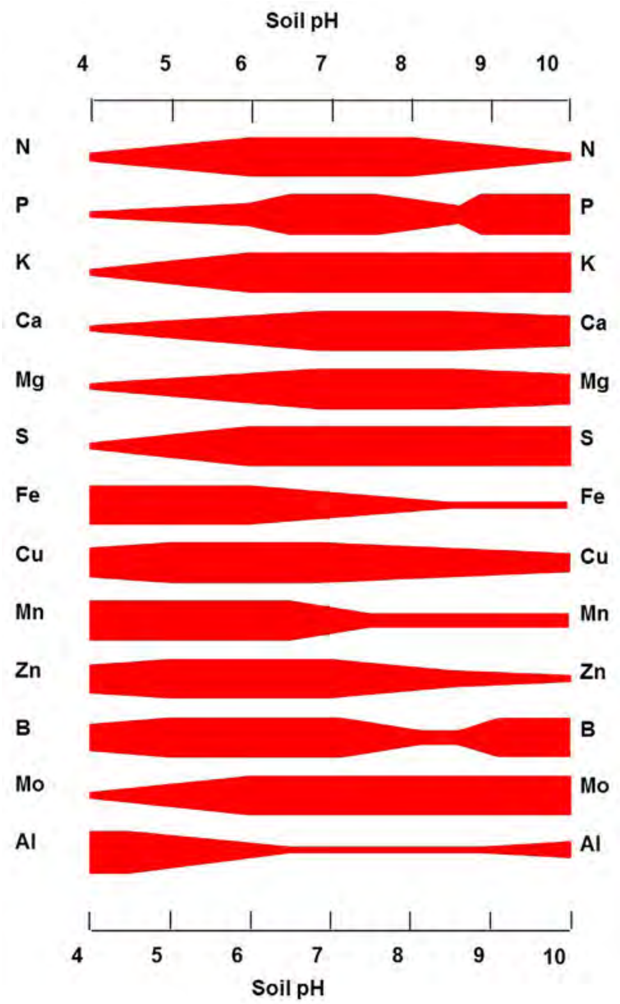



Figure 117. General guide to the availability of nutrients in relation to soil pH. Source: Truog 1947; Lucas and Davis 1961.

The amount of liming material required to increase soil pH is largely governed by soil texture and cation exchange capacity (CEC). CEC is measured in millequivalents per 100 grams of soil (meq/100g). A meq is the number of ions which total a specific quantity of electrical charges. A guide to suggested liming rates is listed in Table 39.

Calcareous or high pH soils are more difficult to correct. Treatment may not be necessary in any case because rootstocks tolerant of high pH are available. The use of particular fertilisers and the removal of fruit from the orchard will naturally lower soil pH over time. Natural soil alkalinity arises from the weathering of parent material to form carbonates, bicarbonates, chlorides and sulphates of sodium, calcium and magnesium.

Table 39. Effect of soil CEC and pH on the amount (tonnes/ha) of limestone (fine and NV >95) required to raise the pH in the top 10 cm of soil.

| CEC (meq/100g) | Soil pH (top 10 cm) | | | |
|---|---|---|---|---|
| | 4.0 → 5.2 | 4.3 → 5.2 | 4.7 → 5.2 | 5.2 → 5.5 |
| | tonnes of lime/ha | | | |
| 1 | 1.6 | 0.8 | 0.3 | 0.2 |
| 2 | 2.4 | 1.2 | 0.5 | 0.4 |
| 3 | 3.5 | 1.7 | 0.7 | 0.5 |
| 4 | 3.9 | 2.1 | 0.9 | 0.6 |
| 5 | 4.7 | 2.5 | 1.1 | 0.7 |
| 6 | 5.5 | 3.0 | 1.2 | 0.8 |
| 7 | 6.3 | 3.3 | 1.4 | 1.0 |
| 8 | 7.1 | 3.8 | 1.6 | 1.1 |
| 9 | 7.9 | 4.2 | 1.8 | 1.2 |
| 10 | 8.7 | 4.6 | 1.9 | 1.3 |
| 15 | 12.5 | 6.7 | 2.8 | 1.9 |

Source: Upjohn, Fenton and Conyers 2005.

These salts and carbonates are then deposited in the rootzone through periodic flooding or capillary rise from water tables and irrigation. It is important in areas with low natural rainfall to periodically leach these salts out of the rootzone with irrigation. Rootstock choice is critical when planting on alkaline soils, and Cleopatra mandarin is the most tolerant to high pH soils. For more information see the Rootstock chapter.

### *Acidifying effects of some nitrogenous fertilisers*

The long-term use of some nitrogenous fertilisers can result in the gradual acidification of the soil. This effect is not related to the acidity of the fertiliser itself, but is the result of changes that take place in the soil. Not all nitrogenous fertilisers are equally acidifying. Some fertilisers, such as potassium nitrate, contain a base which actually makes the soil less acid.

In a long-term fertiliser trial (across 13 years) on Valencia oranges on sandy loam soils in the Sunraysia district, nitrogen applied as ammonium nitrate generally lowered soil pH to a depth of 30 cm, and the more nitrogen applied, the greater the effect. The highest rate of applied nitrogen (450 kg/ha) reduced the soil pH from 7.6 to 3.9 at a depth of 20 cm, whereas 150 kg/ha resulted in a pH of 5.0. The reduction in pH also lowered the levels of the exchangeable cations, calcium, magnesium, potassium and sodium and resulted in higher levels of exchangeable aluminium (Sarooshi, Weir & Barchia 1994).

Table 40 outlines the acidifying effects of various nitrogenous fertilisers on the basis of the amount of lime required to neutralise their effects. For example, about 1.8 kg of lime is required for every kilogram of nitrogen supplied as urea, whereas about three times more lime (5.3 kg) is required to neutralise the acidity produced by a kilogram of nitrogen supplied as ammonium sulphate.

Table 40. The amounts of agricultural lime required to neutralise the acidifying effects of various nitrogenous fertilisers.

| Group | Nitrogen fertiliser source | % N | Kg of lime (calcium carbonate) required to neutralise acidity from application of: | |
|---|---|---|---|---|
| | | | 100 kg of fertiliser | 1 kg of N |
| Basic | sodium nitrate | 16 | 29* | 1.8* |
| | potassium nitrate | 13 | 26* | 2.0* |
| Neutral | calcium nitrate | 20.5 | 0 | 0 |
| Acid | ammonium nitrate | 33.5 | 59 | 1.8 |
| | urea | 46 | 84 | 1.8 |
| Strongly acid | ammonium sulphate | 21 | 112 | 5.3 |
| | mono-ammonium phosphate | 12 | 44 | 5.3 |
| | ammonium phosphate sulphate | 16 | 85 | 5.3 |

* These fertilisers tend to reduce soil acidity (i.e. increase soil pH) by the amount equivalent to the quantity of lime shown. Source: Adapted from Craddock and Weir 1967.

## Cation exchange capacity (CEC)

A cation is a positively charged particle, and an anion is a negatively charged particle. Both are also referred to as positively or negatively charged ions. The positive or negative charge is indicated by a '+' or '–' sign after the element's chemical symbol (e.g. potassium, $K^+$) or molecular formula (e.g. nitrate, $NO_3^-$). The number accompanying the + or – signs indicates the amount of charge (valence) the ion has (see Table 41). Cations and anions are formed when a mineral salt dissolves in water. For example, potassium nitrate ($KNO_3$) dissolves in water to release potassium ($K^+$) and nitrate ($NO_3^-$).

Table 41. Charge and valence of various ions.

| Cations(+)* | Anions(–)** |
|---|---|
| ammonium $NH_4^+$ | nitrate $NO_3^-$ |
| potassium $K^+$ | phosphate $PO_4^{3-}$ |
| calcium $Ca^{2+}$ | sulphate $SO_4^{2-}$ |
| magnesium $Mg^{2+}$ | borate $BO_3^{3-}$ |
| sodium $Na^+$ | molybdate $Mo0_4^{2-}$ |
| manganese $Mn^{2+}$ | – |
| zinc $Zn^{2+}$ | – |
| copper $Cu^{2+}$ | – |
| aluminium $Al^{3+}$ | – |
| iron $Fe^{3+}$ | – |

* Less mobile and strongly adsorbed.
** More mobile and more easily leached.

CEC is a measure of the soil's ability to adsorb and exchange positively charged nutrient ions (i.e. the cations) by electrical attraction. Soil is made up of different materials – clay, silt, sand and organic matter. The surface of the clay and organic matter particles (collectively called colloids) have a negative charge and attract and adsorb cations. The major sources of cations in the soil solution are from mineral weathering, mineralisation of organic matter and the addition of soil ameliorants (e.g. lime, gypsum).

Some cations are taken up by plant roots and the remainder are adsorbed onto the surface of the colloids. In order to become available to the plant, a cation adsorbed onto a clay particle must be replaced by a cation present in the soil solution. Plant roots facilitate this process by excreting a hydrogen ion ($H^+$) into the soil solution in order to exchange this for a cation (Figure 118).

The cations attached to the colloid surface are not easily lost when the soil is drenched by water and provide a nutrient reserve for plant roots. Cations capable of being exchanged between the soil solution and the surface of negatively charged soil particles and vice versa are called exchangeable cations. The main exchangeable cations are calcium, magnesium, potassium, sodium and aluminium. The CEC is the sum of the main exchangeable cations, expressed as milliequivalents per 100 g of soil. Soil analysis reports may also give the relative amounts of each cation as a percentage of the CEC.

Two factors influence the force of attraction between a cation and the negatively charged soil colloids:

- **cation charge:** cations with a higher charge are more readily adsorbed; for example, calcium and magnesium ions have twice more charge than potassium and are more likely to be adsorbed.
- **cation abundance:** if the concentration of a cation in the soil solution is high, there is an increased chance or tendency for that cation to be adsorbed.

CEC is highly dependent on soil texture, especially the clay and organic matter content.

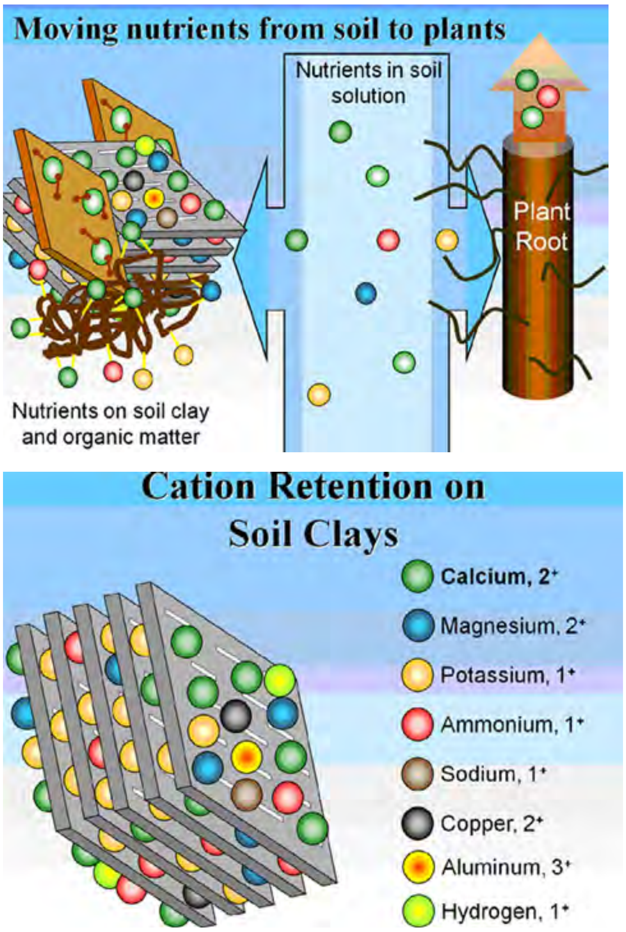



Figure 118. Diagrammatic representation of cation exchange in the soil.
Source: Lajos 2008 (www.tankonyvtar.hu/en/tartalom/tamop425/0032_talajtan/ch05s04.html).

In general, the more clay and organic matter particles in the soil, the higher the CEC. Clay soils have a high CEC and sandy soils a low CEC. Because CEC is largely governed by soil type it is difficult to change the CEC of any soil without the addition of organic matter. Generally CEC increases with an increase in soil pH because the number of negative charges on the soil colloids increases as pH rises. CEC values range from 3 (sand) to 30 (clay) depending on soil texture. CEC is linked with the soil's buffering capacity or ability to withstand change. Sandy soils with a low CEC also have a low buffering capacity. A general guide to the CEC of some soil types is outlined in Table 42.

Soils also have an anion exchange capacity (AEC). AEC increases as soil pH decreases, but because the pH of most agricultural soils is usually high, it generally plays a minor role in supplying plants with negatively charged ions, such as nitrate. This is one reason why nitrate remains mobile in the soil solution in most soils – making it susceptible to leaching and why few reserves are held in the soil.

Table 42. A general guide to the CEC of various soil types.

| Soil texture | CEC (meq/100g) |
|---|---|
| Sands (light-coloured) | 3–5 |
| Sands (dark-coloured) | 10–20 |
| Loams | 10–15 |
| Silt loams | 15–25 |
| Clay and clay loams | 20–50 |
| Organic soils | 50–100 |

Source: Washington State University 2004.

### Organic matter

The main sources of organic matter used on farms are plant material (such as leaves, branches, compost, mulches and cover crops) and animal manures. Organic matter is broken down mostly by earthworms and various soil micro-organisms and this process of decomposition releases nutrients into the soil. The rate of decomposition is dependent on the organic material, soil temperature, moisture, pH and aeration. The term 'humus' is also used to describe soil organic matter.

Organic matter is measured as organic carbon and the greatest amounts are in the top 10 cm of the soil. Very good organic carbon levels in the top soil are >2%, but most soils will have between 1–2%. Sandy soils usually have very low levels (<1%). Many Australian soils have naturally low levels of organic matter. The addition of organic matter to the soil has a range of benefits including improving soil structure, biology, drainage, water holding capacity and CEC, as well as supplying nutrients.

### Soil micro-organisms

Bacteria and fungi are the two most important groups of soil micro-organisms that transform minerals in the soil. The abundance and activity of both groups are affected by soil temperature and pH. The majority of micro-organisms are most active at soil temperatures between 25–35 °C (Leeper & Uren 1993). In tropical areas where soil temperatures are generally always warm, activity is governed by rainfall. Most soil micro-organisms are most active at a pH between 5 and 7.

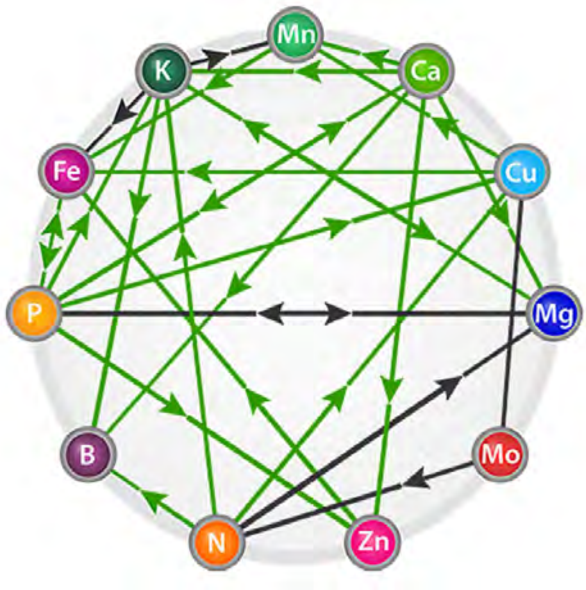
Some soil micro-organisms, such as mycorrhizal fungi, form a symbiotic relationship with plant roots. There are many species of mycorrhizal fungi and the roots of every citrus tree are probably infected by the fungi at some stage. Mycorrhizal fungi increase the contact area between the soil and tree roots. Increased uptake of phosphorus is the primary beneficial effect in low fertility soils, but iron, copper and zinc uptake may also be increased depending on soil pH. Studies have also shown that in some situations these fungi can also improve root hair density, soil structure (stabilisation of aggregates), water uptake and tolerance to drought, salinity, nematodes and root rot (*Phytophthora*) [Wu et al. 2017].

Weir et al. (1978) found that poor establishment and stunted growth of young citrus trees on virgin sand hill soils in the Cudgel and Coleambally districts in the Riverina region of NSW were a consequence of low levels of mycorrhizal infection. Sandmount sands have a low capacity to store water, and, coupled with poor irrigation management at the time, there was inadequate soil moisture for mycorrhizal infection and development, and consequently reduced phosphorus uptake. The use of soil fumigation before planting can also reduce mycorrhizal infection.

### Nutrient interactions

There are also interactions between nutrients. High levels of one nutrient may reduce the uptake of another nutrient (antagonistic relationship), or increase the demand for uptake of another nutrient (synergistic relationship). The interactions represented in this way are known as the 'Mulder's chart' of mineral interactions, and are shown in Figure 119.

For example, high levels of potassium uptake reduces the uptake of magnesium; an antagonist effect. High levels of nitrogen in the tree increases the need for magnesium; a synergistic relationship. High levels of phosphate supply in the tree can induce symptoms of zinc deficiency (West 1938).




Antagonist effect: decreases the availability of the other nutrient to the tree.

Synergistic effect: need of nutrient increases with increased level of the other nutrient.

Figure 119. Plant nutrient interactions 'Mulder's chart'; the arrow on the line indicates direction of effect/s. Source: www.ultrafoliar.ruralliquidfertilisers.com.

## Factors affecting minerals in citrus trees

### Rootstocks

Citrus rootstocks, in combination with the scion, can have an effect on nutrient uptake and absorption. Wutscher (1989) summarised the general effects of rootstocks on mineral element levels in citrus leaves (Table 43). The information in Table 5 is a synthesis of the results from many pot experiments and field studies and the author's experience.

Taylor and Dimsey (1993) found that both scion and rootstock significantly influenced leaf nutrient composition in Ellendale tangors and Emperor mandarins in the Sunraysia region. Concentrations of potassium, calcium and boron in the scion were dependent on rootstock.

Studies on mandarin nutrition around the world have highlighted differences in the nutritional requirements for different varieties, as well as the need to develop specific leaf standards based on different variety/rootstocks combinations, especially with *C. trifoliata* rootstock (Cassin et al. 1977).

### Salinity

The orchards in the lower Murray Valley are irrigated with water of varying levels of salinity, which, depending on weather conditions and cultural practices, can become concentrated within the root zone leading to toxicity problems (Sykes 2011). Apart from the detrimental effects of high concentrations of sodium and chloride on soil structure, high concentrations of these ions in solution also affect the uptake of other nutrients, causing nutrient imbalances in citrus trees. Sodium ($Na^+$) competes with other cations such as potassium, calcium and magnesium, and chloride ($Cl^-$) competes with nitrate. The presence of elevated levels of sodium chloride in the soil can result in sub-optimal levels of calcium, potassium and magnesium in the tree (Grattan & Grieve 1992). However, these effects are strongly dependent on rootstock and growth stage (Grattan & Grieve 1992; Ferguson & Grattan 2005).

High levels of boron are often associated with saline soils and trees show boron toxicity symptoms when leaf concentrations exceed 200 mg/kg (Syvertsen & Garcia-Sanchez 2014). For more information on salinity refer to the chapters on Rootstocks and Irrigation.

Maas and Hoffman (1977) categorised the salt tolerance of over 150 different plant species of agricultural significance and classified citrus as sensitive to salinity. They suggested that for most plants, there is no real change in relative yield as soil salinity increases until a critical salinity threshold is reached, after which relative yield decreases at a constant rate per unit increase in soil salinity. The critical soil salinity threshold for citrus is an $EC_e$ of about 1.4–1.7 dS/m, after which yield will be reduced. Figure 120 combines plant salt sensitivity categories with soil salinity classes and shows that on slightly saline soils there may be substantial reductions in the yield of sensitive crops.

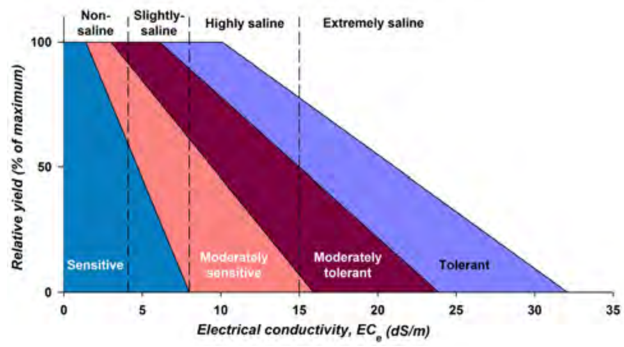



Figure 120. The relative yield response of different categories salinity tolerant crops (Maas & Hoffman 1977) of combined with different levels of soil salinity ($EC_e$). Source: Adapted from Qureshi and Barrett-Lennard 1998.

Tolerance to salinity is related to the rootstock's ability to exclude sodium and chloride: by restricting entry; to accumulate sodium in the basal sections of the rootstock; adjust osmotically; or decrease water uptake. All of these adaptations protect the scion from deleterious ion accumulation (Ferguson & Grattan 2005).

Citrus rootstocks vary widely in their ability to restrict the accumulation of $Cl^-$ and/or $Na^+$ ions from either their own shoots or that of a scion (Grieve & Walker 1983; Walker & Douglas 1983). Cleopatra mandarin is a good chloride excluder whilst Carrizo citrange and Swingle citrumelo are sodium excluders. *C. trifoliata* and its hybrids exclude sodium more efficiently than chloride, which continues to be absorbed, resulting in toxicity symptoms such as leaf tip burning. *C. macrophylla* and rough lemon are chloride and sodium accumulators (Syvertsen & Garcia-Sanchez 2014). In the Sunraysia region, Taylor and Dimsey (1993) found that mandarin trees on *C. trifoliata* accumulated the highest levels of chloride in leaves, trees on the citranges accumulated moderate levels and trees on Cleopatra mandarin had consistently low leaf levels. Sykes (2011) compared numerous selections of *C. trifoliata* from the People's Republic of China and found that three selections (Zhi #5, Zhi 78-85 and Zhi 84-75) were chloride and sodium excluders. These new rootstocks may help overcome the negative effects of root zone salinity on citrus production.

## Main nutrients for citrus

Table 44 outlines the main functions and impacts of each nutrient in citrus. Table 45 outlines the relative mobility and behaviour of nutrients in the soil and tree. Table 46 outlines general deficiency and toxicity symptoms associated with nutrients.

Table 43. Some rootstock effects on mineral element levels in citrus leaves (Wutscher 1989). Note: This table does not include any new published work since that time.

| Element | Induce high levels | Induce low levels |
|---|---|---|
| **Nitrogen (N)** | Rangpur lime, rough lemon, sweet orange | Cleopatra mandarin, *C. trifoliata*, sour orange |
| **Phosphorus (P)** | *C. trifoliata*, rough lemon, sweet orange, Swingle citrumelo | Cleopatra mandarin, Troyer citrange, sour orange |
| **Potassium (K)** | Swingle citrumelo | Cleopatra mandarin, rough lemon, Troyer citrange |
| **Calcium (Ca)** | Cleopatra mandarin, rough lemon, Troyer citrange, sour orange | Sweet orange |
| **Magnesium (Mg)** | *C. trifoliata*, Cleopatra mandarin, Carrizo citrange | Rangpur lime, sour orange |
| **Sulphur (S)** | Rough lemon | *C. trifoliata*, Cleopatra mandarin |
| **Sodium (Na)** | Rough lemon | Sour orange, sweet orange |
| **Chloride (Cl)** | *C. trifoliata*, Carrizo and Troyer citranges | Cleopatra mandarin, sour orange |
| **Iron (Fe)** | Rough lemon, sour orange | *C. trifoliata*, Swingle citrumelo |
| **Manganese (Mn)** | Rough lemon | Sour orange, sweet orange, Swingle citrumelo |
| **Zinc (Zn)** | Cleopatra mandarin, rough lemon | Carrizo citrange, *C. trifoliata*, sour orange, sweet orange |
| **Copper (Cu)** | Swingle citrumelo, sweet orange | Cleopatra mandarin, rough lemon, sour orange, Troyer citrange |
| **Boron (B)** | *C. trifoliata*, Cleopatra mandarin | Carrizo citrange, sour orange |

Table 44. Function and impacts of essential plant nutrients in citrus.

| Nutrient | Function and impacts | Timing of application |
|---|---|---|
| **Nitrogen (N)** | Major component of the metabolic machinery (proteins and chlorophyll). Tissue nitrogen levels are strongly related to photosynthesis by leaves, and the production of carbohydrates for growth, flowering and fruit development. High yields are achieved by managing tree nitrogen supply appropriately. Major impact on fruit quality in combination with P and K, high levels are detrimental to some fruit quality characteristics. | Adequate supplies are needed at times of rapid growth, such as prior to flowering and fruit set, and the spring and summer leaf flushes. |
| **Phosphorus (P)** | Plays a key role in plant processes that require energy, including cell division and growth, photosynthesis, sugar and starch formation, and the movement of carbohydrates within the plant. Major impact on fruit quality in combination with N and K, with low levels detrimental to fruit quality. | Not critical. |
| **Potassium (K)** | Plays an important role in plant metabolic processes including photosynthesis, protein synthesis and sugar transport. Needed for cell division and maintaining the balance of salts and water in plant cells. Potassium regulates the opening and closing of the leaf pores (stomata) and can therefore affect the tree's ability to absorb carbon dioxide for photosynthesis and to cope with high temperatures. The greatest levels of potassium are found in actively growing tissues such as leaves, flowers and fruit. Major impact on fruit size and low levels usually mean smaller fruit. Potassium is the main mineral element in fruit and has more effect on fruit quality than any other element, high levels are detrimental to fruit quality. Potassium helps trees tolerate stress (e.g. cold and drought) and can improve disease resistance. | Adequate supplies are needed prior to flowering, during cell division and the early stages of cell expansion. |
| **Calcium (Ca)** | A major component of cell walls and important in root growth and function. Necessary for growing points especially root tips. Calcium helps slow the ageing process and assists in fruit storage life. | Demand is high during periods of rapid growth, especially the early stages of fruit growth when cells are dividing. |
| **Magnesium (Mg)** | Essential for the production of chlorophyll and important for photosynthesis. Seeds store large amounts of magnesium so demand tends to be higher in seedy varieties. | Timing not critical. |
| **Sulphur (S)** | A component of amino acids which are the building blocks of proteins. | Timing not critical. |
| **Zinc (Zn)** | Involved in metabolic processes including chlorophyll formation, protein synthesis, phytohormone (auxins) metabolism and stress tolerance. Also plays a role in the uptake and efficient use of water. | Timing not critical. |
| **Manganese (Mn)** | Necessary for chlorophyll formation, photosynthesis, respiration, and enzyme activity. | Timing not critical. |
| **Iron (Fe)** | Necessary for chlorophyll formation, in enzyme activation for photosynthesis and respiration, and has an important role in nitrogen metabolism. | Timing not critical. |
| **Boron (B)** | Important in protein formation, the formation of new cells, in the growing tips of shoots and roots, the growth of pollen tubes, seeds and cell walls, flower and fruit formation. | Timing not critical. |
| **Copper (Cu)** | Essential for photosynthesis, stress responses and the formation of lignin which gives strength to shoots and stems. | Timing not critical. |
| **Molybdenum (Mo)** | Important in nitrogen metabolism, playing a role in the conversion of nitrate to a form that is incorporated into amino acids, and so is critical for protein building. Aids in the conversion of gaseous nitrogen to usable forms by nitrogen-fixing microorganisms. | Timing not critical. |

Table 45. Mobility and behaviour of essential nutrients in the soil and tree.

| Nutrient | Mobile in soil? | Mobile in plant? | Behaviour in soil | Nutrient interactions |
|---|---|---|---|---|
| N | Yes, easily leached | Yes | Most Australian soils are low in nitrogen and supplies need to be continuously replenished to achieve high crop productivity. Nitrogen requirements vary enormously from soil to soil and crop to crop. Nitrogen is mostly held in the soil organic matter and soils with a high clay content tend to have higher reserves. Nitrate is very mobile in the soil and easily leached. It is best applied in small amounts throughout the year, especially in areas of high rainfall or in sandy soils. Under waterlogged conditions nitrogen can be lost through a process called denitrification. | High phosphorus levels increase nitrogen requirements and high potassium levels may decrease needs. |
| P | No | Yes | Most Australian soils are naturally low in phosphorus, however most established orchards contain residual phosphorus from previous applications. Most soil phosphorus is present in the upper soil layers and movement of phosphorus down the soil profile is slow. Most is unavailable for tree use. Most orchard soils have adequate reserves (due to over-use of superphosphate) that are released slowly over time.<br>Demand for phosphorus by citrus crops is relatively low. Leaf analysis should be used to determine whether phosphorus is needed. Phosphorus availability is also linked to soil pH and is most readily available in neutral to slightly acidic soils (pH 6–7). In alkaline soils it becomes fixed as calcium compounds and in acid soils as compounds of iron and aluminium. In general, fixation is greatest in clay soils, very acid and very alkaline soils. Optimum soil moisture is also important for good phosphorus uptake, and compacted or dry soils reduce uptake. | Too much phosphorus can affect the availability of micro-nutrients such as zinc, copper and iron, and the use of zinc by the tree after uptake. High levels may result in iron and zinc deficiencies. |
| K | Yes, leached slowly in solution | Yes | Most Australian soils contain large amounts of potassium in various silicate minerals, but most is unavailable for plant use. Most of the potassium in fertilisers attaches itself to the clay particles and soil colloids and little remains in the soil solution. Because of the high fixing power of most soils, excessive concentrations of potassium are seldom a problem. The movement of potassium down the soil profile in high rainfall areas is slow and is more likely to be deficient in lighter sandy soils with low organic matter, especially those under intensive farming practices. Deficiencies can also be a problem in alkaline soils or when high rates of nitrogen are applied. Prolonged cropping will gradually deplete available potassium reserves in the soil. The most important cause of a deficiency is a low content of easily exchangeable potassium and/or low total content in the soil. Drought conditions can also reduce uptake, especially when the top soil is dry as this is where most of the available potassium exists. Waterlogging can also reduce uptake through restricted root activity. Potassium is often taken up in greater quantities than needed ('luxury uptake'). | Dry soils and those with high levels of calcium and magnesium can decrease potassium uptake. Too much potassium can depress calcium and magnesium uptake and can result in a magnesium deficiency. |

Table 44. (continued) Behaviour and mobility of essential nutrients in the soil and tree.

| Nutrient | Mobile in soil? | Mobile in plant? | Behaviour in soil | Nutrient interactions |
|---|---|---|---|---|
| **Ca** | No | No | The natural calcium content of soils can vary from less than 0.1% to more than 25% in calcareous soils. Calcium is more likely to be deficient in low pH or acid soils. High calcium levels are found in alkaline soils which are high in calcium carbonate (i.e. lime). Conditions which stress the tree such as drought, hot weather or factors which trigger rapid tree growth, such as heavy pruning or excessive nitrogen levels, reduce the movement of calcium into the fruit and other developing tissues. | An excess of calcium (generally associated with calcium carbonate) reduces iron uptake, causing iron deficiency, a phenomenon known as 'lime-induced iron chlorosis'. Excessive potassium and nitrogen levels can reduce calcium uptake. |
| **Mg** | Generally no – but more mobile in sandy soils | Yes | Most soils have adequate levels of magnesium predominately in the subsoil. Magnesium is attached to the clay particles and deficiencies are common in coarse textured soils and acid sandy soils, especially in high rainfall areas. | Heavy applications of potassium reduce magnesium uptake. Nitrogen can help ameliorate a magnesium deficiency by mobilising calcium and magnesium which helps suppress potassium absorption and permits more uptake of magnesium. |
| **S** | Yes | Yes | Most sulphur is present in the organic matter and is available to plants only in the sulphate form. It is less available in low pH or acid soils. Sulphur in the mineral form (namely sulphate) is readily leached from the soil. | |
| **Zn** | Yes, especially in acid soils | No | Zinc is present in the soil in minerals and undecomposed plant matter and is attached to soil colloids. Most zinc in the soil is present in forms unavailable for tree use. Soil pH has a major impact on zinc availability, and as pH rises zinc availability decreases. | Excessive phosphorus levels also accentuate a zinc deficiency by reducing uptake. High levels of nitrogen which increase plant growth may also increase zinc requirements. |

Table 44. (continued) Behaviour and mobility of essential nutrients in the soil and tree.

| Nutrient | Mobile in soil? | Mobile in plant? | Behaviour in soil | Nutrient interactions |
|---|---|---|---|---|
| **Mn** | Yes, in acid and waterlogged soils | No | Soil pH has a major effect on manganese availability. Deficiencies are more likely in soils with high organic matter content and when soil pH rises above 7. Excessive manganese can be a problem in very acid (pH <4.5) or waterlogged soils. | High manganese levels can induce an iron deficiency and vice versa. |
| **Fe** | Yes, in acid and waterlogged soils | No | Deficiencies are more common in calcareous or high pH soils where there is low solubility due to high levels of calcium carbonate. Iron availability increases as soil pH decreases. Good drainage and soil aeration improves iron availability, and waterlogging can induce a deficiency. | Very acid soils can have high levels of soluble iron and aluminium which cause phosphate to become fixed and unavailable. High levels of phosphorus, manganese, zinc or copper can also induce an iron deficiency. |
| **B** | Yes, easily leached | No | Soils vary in their capacity to supply boron. Trees on light textured soils with low organic matter in high rainfall areas are more prone to deficiencies. Soils derived from marine sediments often have the largest reserves of boron. Boron is easily leached from the soil and availability is reduced when the soil is dry. Poor drainage or irrigation practices concentrating soluble boron in the rootzone can cause toxicity problems. Organic matter supplies small amounts. Citrus is sensitive to boron so application should always be based on plant analysis results. | Heavy liming reduces boron uptake. Toxicity often occurs in inland areas where salinity is a problem. |
| **Cu** | Yes, in acid soils | No | Soils contain relatively small amounts of copper, from 1 to 200 ppm depending on soil type, with sandy soils low in organic matter having the lowest concentrations. Copper is tightly attached to organic matter and clay particles. Copper availability is related to soil pH, and as pH increases above 7, availability declines. Copper is most available for plant uptake in acid soils. Elevated concentrations of copper in the soil are often found in growing regions where copper fungicides have been routinely used over a long period of time. | Copper accumulation can interfere with iron uptake. Phosphate or lime helps reduce copper solubility and copper toxicity. |
| **Mo** | No | Yes | Availability related to soil pH, decreasing below pH 6.0. | |
| **Al** | No | No | Availability decreases above pH 5.5. Toxicity likely in very acid (pH <4.5) soils. | Fixes phosphorus in acid soils. |
| **Na** | No | Yes | A problem in saline soils, uptake more likely when soils are waterlogged. | Calcium will displace sodium ions and improve soil structure. |

Nutrition

Table 46. General deficiency and toxicity symptoms in citrus associated with the essential nutrients.

| Nutrient | Deficiency symptoms | Toxicity symptoms |
|---|---|---|
| N | Symptoms are seen on the oldest leaves first as nitrogen is redistributed to the new growth. Poor vegetative growth with a general yellowing of foliage (Figure 121). A severe deficiency results in leaves being shed prematurely causing foliage cover to be thin and sparse, with twig dieback and leaf fall. As a result of poor vegetative growth (Figure 122), flowering, fruit set and fruit size are reduced. Some fruit quality parameters can be improved such as skin thickness and colour. The signs of nitrogen deficiency can sometimes be confused with the sudden yellowing of the most recent leaf flush (as starch becomes trapped in the leaves; Figure 123) with the onset of cold weather during autumn (Figure 124). | Promotes excessive vegetative growth at the expense of fruit production. Can promote alternate cropping with small fruit in the 'on' year. A sudden uptake of nitrogen will cause leaf and shoot tip burn within a few days of application. Leaves may also fall, but the petioles remain attached to the stem. Fruit become large and puffy with a thick coarse peel. The fruit can have delayed maturity and colouring and reduced storage life. High nitrogen levels decrease juice content and total soluble solids (TSS), while titratable acidity (TA) is increased. Reduced fruit size due to high fruit numbers. |
| P | Symptoms are seen on the oldest leaves first, which appear dull bronzed or bluish-green in colour with purple tints in the veins on the under-sides of leaves. The biggest impact is on fruit quality. A deficiency can cause misshapen fruit with open centres and thick coarse rinds. Fruit also tend to have a lower juice content and are more acidic. | Excessive levels reduce fruit size. Fruit have thinner peels, higher juice content and reduced TA levels. |
| K | Symptoms, including scorching of the leaf edges and between the veins, are usually seen on the oldest leaves first, as potassium is readily redistributed from old to new leaves. A severe deficiency can cause leaf dieback, pitting and death of shoots and excessive leaf, flower and fruit drop. Low potassium levels reduce fruit size and yield, because potassium is the main mineral component in fruit. Fruit tend to have good juice, TA and TSS content, colour early and have smooth thin skins, which can be more prone to splitting and albedo breakdown. For more information see the Disorders chapter. Trees deficient in K may be more susceptible to drought and frost. | Excessive levels have adverse effects on fruit quality including coarse flesh, increased rind thickness and acid content, and decreased juice content. |
| Ca | Deficiencies of calcium are more likely in low pH soils and result in stunted root growth and a higher incidence of albedo breakdown. Since calcium is relatively immobile in the tree, symptoms are seen on the youngest leaves first. In pot experiments leaf deficiency symptoms similar to those of magnesium deficiency. | Symptoms unknown, but an excess can cause iron deficiency. |
| Mg | Deficiency symptoms are first seen on the older leaves. Symptoms are distinctive with yellowing at the leaf margins gradually expanding to the leaf apex, with a green triangular area remaining at the base of the leaf (Figure 125). A severe deficiency can cause shoot dieback and leaf fall. Fruit size may be smaller, reducing yield. Varieties producing seedy fruit can be more severely affected by a deficiency as the developing seeds and fruit deplete the leaves of magnesium (Chapman, 1968). A lack of magnesium can make trees more susceptible to cold injury. | An excess of magnesium is rare. |
| S | Deficiency symptoms are rarely seen. Symptoms are seen on the youngest leaves first which become pale green to yellow and stunted, with lighter veins. | An excess of sulphur is rare. |

Table 45. (continued) General deficiency and toxicity symptoms associated with nutrients in citrus.

| Nutrient | Deficiency symptoms | Toxicity symptoms |
|---|---|---|
| **Mn** | Symptoms are usually seen on the summer flush in recently matured leaves and are worse on the shady, southern sides of trees. Leaves are a light mottled green to yellow between the veins with a darker band of green around the veins, leaf shape and size is usually normal (Figure 126). Acute deficiencies cause twig dieback and are more noticeable in trees also affected by zinc and magnesium deficiencies. | An excess causes yellowing of the immature leaves, starting at the tip and progressing downwards as they mature. The leaf tips may brown and leaves fall, leaving bare twigs. Scattered 'tar or acid spots' can appear on the leaf surface (Figure 127). |
| **B** | Deficiencies are not common and visual symptoms are usually not seen until a deficiency is severe. Boron deficiency may cause short, misshapen flowers and seeds may be shrivelled, brown and gummy. The most distinctive symptoms are in the fruit which are small, hard and misshapen with pockets of brownish gum in the peel. | Symptoms include leaf tip yellowing and death, with interveinal yellowing progressing downwards from the tip (Figure 128). Other symptoms include twig dieback and heavy leaf fall in spring, with the leaf petioles remaining on the tree. Gum is secreted on lower leaf surfaces of affected leaves. Penman and McAlpine (1949) list citrus varieties in the following decreasing order of susceptibility: lemon, mandarin, grapefruit and sweet oranges. Citrus is sensitive to boron and the need for application should always be based on leaf analysis results. |
| **Zn** | In the early stages of deficiency the youngest leaves have interveinal mottling (Figure 129), becoming bright yellow to white with mottled patches (Figure 130). Leaves are small, narrow, pointed and upright. A severe deficiency stunts terminal growth, causes twig dieback and reduces tree vigour with reduced fruit size and yield. | An excess of zinc is rare. |
| **Fe** | Deficiencies are seen on the youngest leaves which become yellow while the veins remain green (Figure 131). As the leaves mature the network of veins continues to be sharply delineated. In severe cases the yellowing can increase to a point where the leaves appear bleached and burnt areas can also develop (Figure 132). | An excess of iron is not usually a problem in Australian orchards. |
| **Cu** | Deficiencies are uncommon due to the use of copper fungicides, but may occur where these fungicides are not regularly used. Symptoms of deficiency known as exanthema include small, dark green leaves, and young shoots with enlarged leaves on long, willowy, S-shaped branches. Pockets of gum may form on the stem and twigs can die back. Fruit are pale coloured and the skin is hard with brown corky lesions on and in the peel. | Copper toxicity can be a problem in warm, wet tropical and subtropical regions where copper fungicides are regularly applied for disease control. An excess of copper can cause twig dieback and reduce tree vigour and yield. High copper levels in the soil (>50 ppm) damage fibrous roots which become dark and stubby. |
| **Mo** | Only very small amounts are needed, and in most situations in Australia, deficiencies are rare.<br>Molybdenum deficiencies are referred to as 'yellow spot' with large yellow spots on the upper leaf surface and corky cells forming underneath. | An excess of molybdenum is not usually a problem in Australian orchards. |

**Toxicity symptoms of sodium chloride (NaCl)**

First visual symptoms of salinity damage are usually leaf tip burning and yellowing or scorching of the leaf margins (Figure 133). However many salinity induced symptoms such as reduced root and shoot growth, decreased flowering and smaller leaf size, may have occurred prior to initial leaf symptoms appearing. As salinity progresses trees will shed leaves, with a thinning of the tree canopy, followed by defoliation and twig dieback.

## Nutrient deficiency and toxicity symptoms

Figure 121. Nitrogen deficiency symptoms include a colour change from pale green to a general yellowing of the oldest leaves first, as nitrogen reserves are redistributed to the new growth. A severe deficiency results in leaves being shed prematurely, causing foliage cover to be thin and sparse with twig dieback.

Figure 122. Nitrogen deficiency symptoms in young citrus seedlings appear on both young and old leaves as there are no nitrogen reserves available to be redistributed to the youngest leaves.

Figure 123. Sudden yellowing of the most recent leaf flush (as starch becomes trapped in the leaves) with the onset of cold weather during autumn is associated with a condition known as winter yellows.

Figure 124. Winter yellows should not be confused with nitrogen deficiency symptoms.

Figure 125. Symptoms of magnesium deficiency are distinctive with yellowing at the leaf margins gradually expanding to the leaf apex, with a green triangular area remaining at the base of the leaf.

Figure 126. Symptoms of manganese deficiency are usually seen on the recently matured leaves of the summer flush. Leaves are a light mottled green to yellow between the veins with a darker band of green around the veins, leaf shape and size is usually normal.

Figure 127. Symptoms of severe manganese toxicity showing tar (acid) spots on the leaf surface.

Figure 128. Symptoms of boron toxicity include leaf tip yellowing, which progresses into interveinal chlorosis.

Figure 129. Symptoms of zinc deficiency are seen on the youngest leaves which become small, narrow, pointed and upright. Leaves have bright yellow to white mottled patches.

Figure 130. Symptoms of zinc deficiency.

Figure 131. Symptoms of iron deficiency appear on the youngest leaves first, with a general yellowing of the leaves with the veins remaining green.

Figure 132. Symptoms of iron deficiency.

Figure 133. Symptoms of sodium chloride toxicity showing tip burn.

Quick facts:

- Trees require macro-nutrients (N, P and K, Ca, Mg and S) and micro-nutrients (Mn, Zn, Fe, Cu, B, Mo and Cl).
- Soil texture and structure strongly influence nutrient and water holding capacity.
- Organic matter improves soil structure, drainage, water and nutrient holding capacity, CEC and soil biology.
- Cation exchange capacity (CEC) is a measure of a soil's ability to absorb and exchange cations. The main cations are calcium, magnesium, potassium, sodium and aluminium.
- CEC is largely determined by soil texture – especially clay and organic matter content. CEC generally increases with increasing soil pH.
- Inorganic nutrients must be dissolved in the soil solution before being taken up by roots.
- Nitrogen, phosphorus, potassium, sulphur and magnesium are mobile within the tree and can readily move to where they are needed most.
- Calcium and most of the micro-nutrients are relatively immobile in the tree and cannot be re-transported if needed elsewhere.
- Rootstocks affect the uptake and absorption of nutrients. Rootstock choice is critical for high pH soils.
- Salinity affects nutrient uptake and causes nutrient imbalances. Rootstocks have different tolerances to salinity.

## Nutrition and fruit quality

Nitrogen, phosphorus and potassium are the main nutrients that have important effects on fruit quality, including size, rind texture, thickness, colour and internal quality. In general, the effects of nitrogen, phosphorus and potassium on fruit quality are similar for all varieties, but the degree to which they affect quality will vary with variety, rootstock and soil conditions. Nitrogen, phosphorus and potassium must be maintained in the optimum range and leaf analysis is the only reliable means of determining the levels of these nutrients in the tree.

Nitrogen has a major impact on tree yield and fruit quality, so maintaining optimum levels is important. There is a high demand for nitrogen during flowering and fruit set and for the developing spring leaf flush. Fruit quality progressively deteriorates with increasing rates of nitrogen and these effects will be made worse if phosphorus levels are also low. High rates of nitrogen reduce phosphorus uptake. Applying nitrogen during summer and autumn can result in a reduction in soluble solids, increased acidity and poor fruit colour (Chapman 1982, 1986).

In a survey of 30 Imperial mandarin growers in the Sunraysia region, Bevington et al. (1998) found that sites that consistently produced high yields and fruit with a high juice content were moderate users of nitrogen. The report recommended leaf nitrogen levels be kept between 2.9–3.1%. In a fertiliser trial on Ellendale tangor on sweet orange rootstock in Queensland, Lee and Chapman (1988) found that rind colour development was impaired with increasing nitrogen applications.

The effects of phosphorus on fruit quality are generally the opposite to those of nitrogen. Phosphorus leaf levels should be kept in the optimum range of 0.12–0.16 in order to counter the adverse effects of nitrogen on fruit quality.

Potassium has a major impact on fruit size and inadequate levels will lead to a reduction in fruit size. Excessive potassium levels have a similar effect on fruit quality to excessive nitrogen levels, and the effect is greater if nitrogen levels are also high. In a four-year fertiliser trial on Imperial mandarins on Cleopatra mandarin rootstock at Gayndah, Queensland, optimum leaf potassium levels for good yields and fruit size were between 1.2–1.7% (Chapman 1982). Lee and Chapman (1988) found that potassium was more important than nitrogen in determining Ellendale tangor fruit quality.

The general effects of nitrogen, phosphorous and potassium on fruit quality parameters are outlined in Table 47 and Figure 134.

Table 47. General effects of nitrogen, phosphorus and potassium on fruit quality characteristics. Note that some of these effects may not be as significant in mandarins as in other citrus types, such as oranges.

| Element | Effects of increasing supply on fruit quality characteristics |
|---|---|
| **Nitrogen**<br>(most effects greater at low P levels) | Increases fruit numbers, rind thickness and coarseness and juice acidity.<br>Decreases fruit size (due to higher fruit numbers), % juice and °Brix:acid ratio.<br>Delays colouring. |
| **Phosphorus**<br>(high P levels counter the adverse effects of high N) | Reduces rind thickness and coarseness, °Brix and acidity.<br>Increases °Brix:acid ratio and fruit creasing. |
| **Potassium**<br>(most effects greater at high N levels) | Increases fruit size (sometimes excessively), rind thickness and coarseness, and acidity.<br>Decreases % juice, °Brix:acid ratio, fruit creasing and splitting.<br>Delays colouring. |

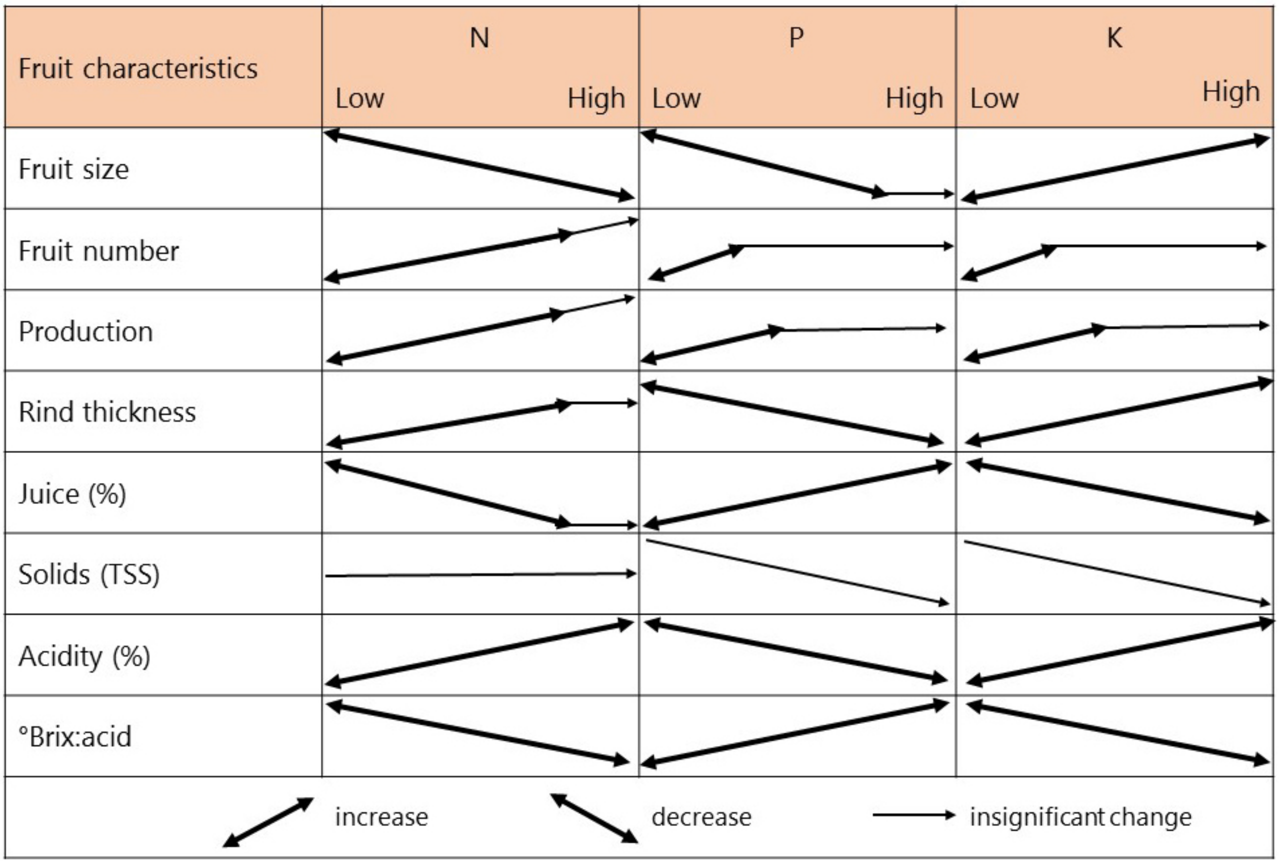



Figure 134. A summary of the effects of increasing nitrogen, phosphorus and potassium levels (in leaves) on the quality of the citrus fruit. Source: Unknown, but likely based on Embleton et al. 1973.

## Leaf and soil analysis

Soil and particularly leaf tissue analyses are key components of managing tree mineral nutrition for optimal tree performance. Leaf analysis provides a snapshot of the nutrient levels in the leaves at the time of sampling and is a proxy for overall tree nutrient status. Soil analysis provides estimates of the ability of the soil to provide mineral nutrients to the tree. Both sets of analyses are approximations sink strength of the adjacent fruit and recommended leaf levels are usually lower (Raveh 2013). of what the true soil fertility and tree nutrient status are. Both rely on samples being collected correctly and being representative of the management unit. Jorgensen and Price (1978) recommended that leaf analysis be used as a primary indicator of the nutrient status of a block, while soil analysis is an indicator of the nutrient resources available, and is especially beneficial in determining the requirements for phosphorus, potassium, calcium and magnesium.

## Leaf analysis

Leaf analysis can be used for diagnosing a specific nutrient problem, but is usually used to monitor the nutritional status of trees. Leaf analysis is based on the fact that the amount of each nutrient present in the sampled tissue is closely related to both the supply of that element and the overall nutrition of the tree. The concentrations of most nutrients in plant tissue are restricted to a narrow range. Samples for analysis should be collected from a fairly uniform block of trees of the same age, variety and rootstock and growing on the same soil type. Annual leaf analysis allows more confident monitoring of the nutrient status of trees, and is a good tool to assess and fine-tune a fertiliser program.

Australian leaf analysis standards are based on leaf samples collected from non-fruiting branches (Robinson, Treeby & Stephenson 1997). Some countries (such as Israel, Brazil, Morocco and South Africa) use standards based on leaves collected from fruiting branches. Be aware that the leaf mineral concentrations from fruiting branches are strongly affected by the nutrient sink strength of the adjacent fruit and recommended leaf levels are usually lower (Raveh 2013).

Nutrient levels in leaves will also vary with the cropping pattern of trees. For example, Chapman (1982) found potassium levels in non-fruiting terminals of Imperial mandarins on Cleopatra mandarin rootstock fluctuated from year to year inversely to the alternate bearing pattern. Potassium levels were lower in 'on-crop' years, while levels in fruiting terminals remained stable.

### *Sample collection and handling*

Leaves should be taken at the correct growth stage as specified in the analysis standard because the nutrient composition of a leaf changes with its age and its position relative to any fruit. The samples are normally collected at a time or growth stage when the nutrient concentrations in the plant are relatively stable.

For citrus, leaf sampling is done between February and mid-March, depending on the region. The correct leaves to sample are healthy, 5–7 months old mature leaves from the middle of non-fruiting spring growth – this is the spring flush which has hardened off, but carries no fruit (Figure 135).

Tagging the spring flush helps to easily identify the correct branches from which to sample in the autumn (Figure 136). Collect leaves at shoulder height from all sides of the tree and avoid terminals that have made additional growth flushes. The sample needs to be representative of the crop/block: so the more trees sampled, the more representative the results. Sample trees can also be tagged and used for long-term monitoring.

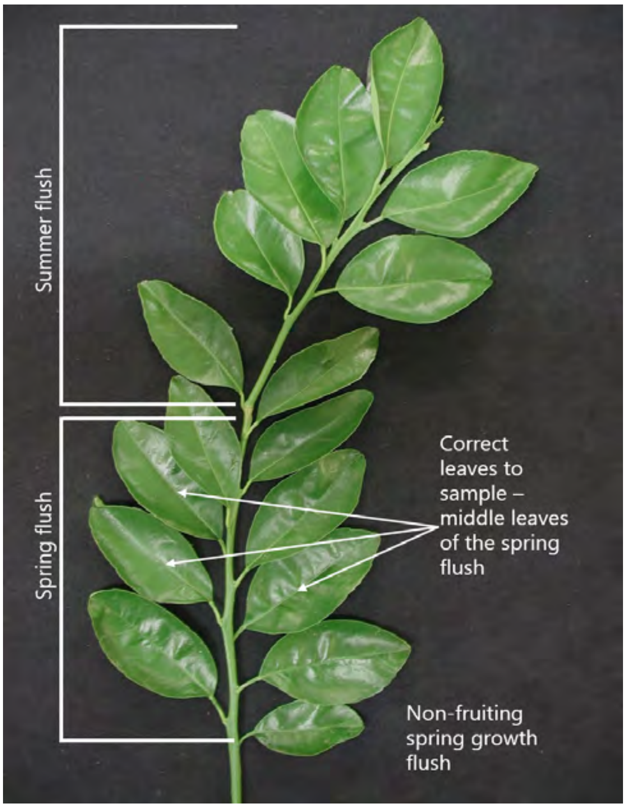



Figure 135. The correct leaves to sample are healthy, 5–7 months old mature leaves from the middle of the non-fruiting spring growth flush.

Figure 136. Tagging the spring flush allows easy identification of the correct branches from which to sample in the autumn.

Collect leaves in the morning after they dry, taking samples from at least 20–25 trees throughout the block. Do not sample boundary trees or those suffering from obvious stress or pest and disease problems. The sample needs to be between 100–200 g fresh weight, equivalent to about 100–200 leaves. The leaves should be clean and dry and placed in a paper bag and kept in a fridge (but do not freeze) until despatch. Do not use plastic bags because leaves may sweat and rot in transit. The samples should be despatched to a NATA (National Association of Testing Authorities, Australia) certified analytical laboratory as soon as possible. For more information on leaf sampling, refer to NSW DPI Primefact 1449 '*Citrus leaf nutrient analysis: leaf sampling guide*'.

### *Interpretation standards*

The results of the analysis are compared to standards that were developed for healthy productive citrus crops. A key reference containing a range of leaf analysis standards is '*Plant analysis – an interpretation manual*' (Reuter & Robinson 1997). Additionally, there are other reference papers that have fine-tuned these standards for specific regions or citrus types.

The standards are based on five classes of tree nutrient status:

- deficient – too low for optimum performance; visual plant symptoms usually present.
- low/marginal – nutrient levels may be too low for optimum performance; visual plant symptoms may not be present.
- adequate – levels adequate and no visual symptoms present.
- high – levels higher than necessary and may cause nutritional imbalances and a loss of product quality; visual plant symptoms not necessarily present.
- excessive/toxic – levels too high for optimum performance; visual toxicity symptoms may be present.

The interpretation standards for citrus are presented in Table 48. These standards are based on the work of Embleton et al. (1978) in California, with some modifications based on Australian experience. There is no complete standard developed specifically for mandarins, but there have been some recommendations for specific nutrients, such as potassium. For example, the work of Chapman (1982) indicates that an optimum potassium range of 1.2–1.7% may be more appropriate for mandarins. Bevington et al. (1988) suggested leaf nitrogen levels be kept between 2.9–3.1%, which are slightly higher than the general standard recommended for citrus.

When interpreting leaf analysis results be aware that leaves can also be contaminated by copper, zinc, magnesium and manganese residues from foliar fertiliser and/or pesticide sprays, resulting in apparently high or excessive levels in leaf tissue. Additionally, if soil calcium levels are satisfactory but leaf calcium levels are less than optimal, there is a possibility that the wrong leaves (too young) were sampled.

Major changes to a fertiliser program should not be based on the results of only one year's leaf analysis. Annual sampling allows a profile of the nutrient status of the orchard to be built up over time, and the fertiliser program fine-tuned for best results.

Leaf analysis: best practice tips

- ☑ Annual leaf analysis is a good tool to assess tree nutrient status.
- ☑ Provides a snapshot of leaf nutrients at time of sampling.
- ☑ Tag the spring flush to more easily identify the correct leaves for sampling.
- ☑ Leaves should be collected between February and mid-March at the specified growth stage – from the middle of non-fruiting mature spring growth, 5–7 months old.
- ☑ Take samples from at least 20–25 trees throughout the block.
- ☑ The more trees sampled, the more representative the results.
- ☑ Collect leaves in the morning, after dew has dried.
- ☑ Collect leaves at shoulder height from a fairly uniform block of trees of the same age, variety and rootstock.
- ☑ The sample needs to be between 100–200 g fresh weight, ≈ 100–200 leaves.
- ☑ Collect leaves into a paper bag.
- ☑ Use a NATA-certified analytical laboratory for testing.
- ☒ Do not sample boundary trees or those suffering from obvious stress or pest and disease problems.

Table 48. Leaf analysis interpretation standards for citrus.

| Element | Deficient | Low/marginal | Adequate | High | Excessive or toxic |
|---|---|---|---|---|---|
| *% dry matter* | | | | | |
| **Nitrogen** | <2.2 | 2.2–2.3 | 2.4–2.6<br>2.9–3.1[1]<br>2.8–3.0[3] | 2.7–3.0[4] | >3.0[4] |
| **Phosphorus** | <0.09 | 0.09–0.11<br>0.09–0.13[4] | 0.12–0.16<br>0.14–0.16[1] | 0.17–0.25<br>0.17–0.30[4] | >0.25<br>>0.3[4] |
| **Potassium** | <0.04 | 0.04–0.69 | 0.7–1.5<br>1.2–1.7[2]<br>1.2–1.5[3] | 1.6–2.3<br>1.5–2.0[4] | >2.3<br>>2.0[4] |
| **Calcium** | <1.6<br><2.0[4] | 1.6–2.9<br>2.0–2.9[4] | 3–6<br>3–5.5[4] | 5.6–7.0[4] | >7 |
| **Magnesium** | <0.16<br><0.15[4] | 0.16–0.25<br>0.15–0.29[4] | 0.26–0.6<br>0.3–0.69[4] | 0.7–1.2<br>0.7–1.0[4] | >1.2<br>>1.0[4] |
| **Sodium** | – | – | <0.16 | 0.17–0.25 | >0.25 |
| **Chloride** | – | – | <0.3 | 0.4–0.7<br>0.3–0.6[4] | >0.7<br>>0.6[4] |
| **Sulphur** | <0.14 | 0.14–0.2 | 0.21–0.4 | 0.41–0.5 | >0.5 |
| *mg/kg (parts per million or ppm) dry matter* | | | | | |
| **Zinc** | <16 | 16–24 | 25–80<br>>65[3]<br>25–60[4] | 81–300<br>61–300[4] | >300 |
| **Manganese** | <16 | 16–24 | 25–80<br>>65[3]<br>25–60[4] | 81–300<br>61–300[4] | >300 |
| **Iron** | <36 | 36–60<br>35–49[4] | 61–120<br>50–129[4] | 121–200<br>130–400[4] | >200<br>>400[4] |
| **Copper** | <3 | 3–5 | 6–10<br>6–15[4] | 11–15<br>16–20[4] | >15<br>>20[4] |
| **Molybdenum** | <0.06 | 0.06–0.09 | 0.1–3 | 3.1–100 | >100 |
| **Boron** | <21 | 21–30 | 31–100<br>31–129[4] | 101–260<br>130–250[4] | >260<br>>250[4] |

Suggested ranges for mandarins: [1]Bevington et al. 1998; [2]Chapman 1982; [3]Moulds 1999.
Suggested ranges for oranges and mandarins in Sunraysia/Riverland area: [4]Gallasch 1992.
Source: Robinson, Treeby and Stephenson 1997.

## Soil analysis

Soil analysis provides estimates of the soil's ability to provide sufficient mineral nutrients to trees for best performance. The results of a soil analysis are not absolute, but should be considered more as indicators of soil fertility. Soil analysis is also an important indicator of potential soil problems such as pH, which impacts on nutrient availability (see the section on pH). Comprehensive soil testing should be repeated every 3–5 years.

Undertaking a soil survey is especially important before planting and is used to identify any potential problems such as pH, fertility, salinity and sodicity, for which remedial actions may be required. A soil survey is critical for good irrigation design because it enables valve sections for irrigation to be accurately matched to soil types and soil depths across a site. For more information see the Orchard basics and Irrigation chapters.

### *Sample collection and handling*

Soil sampling should be carried out across homogeneous areas. Assess the soils in the block or irrigation section you intend to sample and identify any major differences in topography or soil type and depth. Submit a separate soil sample from each area if differences are identified. In unplanted sites soil samples can be collected in a zigzag pattern across the block. In planted blocks, samples should be taken in close proximity to where the majority of feeder roots are growing (i.e. close to dripper lines for drip irrigated trees). In young orchards samples should be collected from the tree row. In established orchards samples are collected halfway between the tree trunk and the dripline of the tree. The sites can be marked for future sample collection and monitoring over time.

For established orchards two samples can be collected, one from the top soil (0–15 cm) and a second from the subsoil (15–30 cm; Figure 137). Some laboratories may specify the depth of sampling. Before taking the sample remove any leaf litter or other organic material lying on the soil surface. Use a spade or soil auger to collect at least 25 samples/ha (the more cores taken the more reliable the sample) and place in a clean plastic bucket. Once all the samples are collected, thoroughly mix and then take a sub-sample from the bucket and fill the container or bag supplied by the laboratory. This bag should specify the amount of soil to be submitted (usually 500 g). Each sample bag should be clearly labelled with the block name, variety, rootstock and age of the trees. The samples should be sent to a NATA-certified analytical laboratory as soon as possible.

Figure 137. The majority of feeder roots are located in the top 30 cm of the soil – so take samples from the top soil (0–15 cm) and subsoil (15–30 cm).

### *Interpreting results*

Some laboratories will provide an interpretation of the analyses and make fertiliser recommendations. There are no specific standards for citrus, just general recommendations for horticultural crops. The most important information provided by soil analysis is the soil type and texture, pH, CEC, amounts of exchangeable cations (calcium, magnesium, potassium, sodium and aluminium), electrical conductivity (EC), and the amount of organic carbon. Table 49 provides general guidelines on interpretation results for horticultural crops.

**Soil analysis: best practice tips**

- ☑ Important prior to planting and for identifying potential soil problems e.g. pH, fertility, salinity and sodicity.
- ☑ Undertake every 3–5 years.
- ☑ Take samples across homogeneous areas – avoid boundary rows.
- ☑ Collect samples on unplanted sites in a zigzag pattern across the block. In young orchards collect samples from the tree row. In established orchards collect samples halfway between the tree trunk and dripline, in close proximity to the majority of feeder roots.
- ☑ Collect at least 25 samples/ha – the more the better.
- ☑ Mark sampling sites for ongoing monitoring.
- ☑ Take samples from the top soil (0–15 cm) and subsoil (15–30 cm).
- ☑ Label each sample bag with block name, variety, rootstock and tree age.
- ☑ Use a NATA-certified analytical laboratory for the analyses.

Table 49. General guide to soil interpretation results for horticultural crops.

| Chemical Property | Low range | Medium range | High range | Comments |
|---|---|---|---|---|
| pH (in $CaCl_2$) | <5 | 5.1–7.4 | >7.5 | Actual critical value depends on rootstock tolerance. |
| Cation exchange capacity (CEC) (meq/100g) | <3 | 3–10 | >10 | CEC increases as clay content increases, sandy soils will have a low reading and clay soils a high reading. The lower the CEC the lower the amount of organic carbon. CEC is also influenced by soil pH; CEC increases as soil pH rises. |
| Organic carbon (%) (Walkley Black), as a proxy for nitrogen | <1.2 | 1.2–1.8 | >1.8 | Organic carbon x 1.7 = organic matter level and is an indicator of the ability to supply nitrogen. As organic carbon increases so too will the amount of nitrate. Plant analyses provide a more useful indicator of the status of nitrogen in the tree. Available sources of nitrogen are very mobile in the soil and are either readily taken up by tree roots, used by micro-organisms, or lost down the profile through leaching. Soil analyses provide a reading for the nitrate (mg/kg) form of nitrogen – which is of limited value. Other sources of nitrogen include ammonium, organic nitrogen and those locked up in the organic matter. |
| Electrical conductivity (EC) (1:5) (dS/m) | Critical value depends on soil texture class<br><2 very low<br>2–4 low<br>4–8 moderate – may affect crops<br>8–16 high – only tolerant crops<br>>16 very high – affects all crops | | | Salts increase the ability of a solution to conduct an electrical current. EC (1:5) is an estimate of total soluble salts and a high value indicates a high salinity level. However, soil texture influences the degree to which the amount of salt present in the soil will affect plant growth. $EC_e$ is the preferred indicator of soil salinity as it takes soil texture into account. |
| Soil salinity ($EC_e$) (dS/m) | <2 | 2–6 | >6 | Soil salinity is EC (1:5) × conversion factor for soil texture. Crops have different tolerances to soil salinity and citrus is regarded as very sensitive. Fruit yields decrease by about 10% for every 1.0 dS/m increase in ECe once a threshold of about 1.4–1.7 dS/m is reached (Maas 1992, Maas & Hoffman 1977). For example, an $EC_e$ of 2.3 results in a 10% loss in yield, while an $EC_e$ of 4.8 will reduce yield by 50%. |
| Phosphorus buffer index (PBI) | <140 | 141–280 | >280 | PBI is a measure of the soils ability to fix phosphorus, which is largely based on soil type. Adequate levels are thought to be between 25 and 50, and if values are >100 there is no benefit in applying more phosphorus. Sandy soils tend to have a low PBI and clay soils a high PBI. PBI increases with soil texture and acidity. Heavy clay or acidic soils can have PBI values >280. |
| Phosphorus (mg/kg) (Colwell) | <35 | 35–50 | >50 | Critical values for low PBI soils. Values increase for higher PBI soils. Plant analyses provide a more useful indicator of the status of phosphorus in the tree. There are three pools of phosphorus in the soil – mineral, organic and readily available. About 40–90% of phosphorus is fixed by minerals such as aluminium, iron and calcium. Most soil analyses will provide a measure of soluble phosphorus, which is usually less than 1% of the total phosphorus present. |

| Chemical Property | Low range | Medium range | High range | Comments |
|---|---|---|---|---|
| Sulphur (mg/kg) (KCl 40 °C) | <5 | 5–10 | >10 | Sulphur is mobile in the soil and largely comes from organic matter. Some soils may have high levels of sulphur in the subsoil. A value of 10 mg/kg is considered adequate for most tree crops. Organic matter recycling and leaching, due to high rainfall, influences values. |
| Calcium (meq/100g) | <0.5 | 0.5–1 | >1 | Calcium deficiencies occur most commonly in acid soils (pH <4) or sodic soils. Calcium levels between 0.7 and 1.0 meq/100 g are considered adequate for most crops. |
| Magnesium (meq/100g) | <0.2 | | >0.5 | Magnesium is usually deficient in coarsely textured, acid soils, especially in high rainfall regions. Deficiencies can also occur when there is a high calcium to magnesium ratio, high levels of potassium and luxury uptake of potassium. Some subsoils can have high levels of magnesium. Suitable levels of magnesium for horticulture crops are around 0.5 meq/100g. |
| Calcium: magnesium ratio | | 2–20 | | In the past a calcium:magnesium ratio between 4 and 6 was considered suitable. However, recent studies have indicated that the calcium:magnesium ratio can vary between 1 and 20, with little effect on plant production (Fenton & Conyers, 2002). As long as the soil contains adequate quantities of calcium, magnesium and potassium, the ratios of these cations do not influence plant yield within the ranges commonly found in soils (Kopittke & Menzies 2007). |
| Potassium (meq/100g) | <0.2 | 0.2–0.6 | >0.6 | Adequate levels of potassium in the soil for horticulture are considered to be between 0.2 and 0.6 meq/100g. Some plants take up luxury amounts of potassium at the expense of magnesium, so high levels can induce a magnesium deficiency. Responses are unlikely unless phosphorus levels are high. Plant analyses provide a more useful indicator of the status of potassium in the tree. |
| Sodium (% of CEC) | <2 | 2–6 | >6 | High values may indicate a sodic soil, which is undesirable. |
| **Micro-nutrients**<br>For most micro-nutrients, plant analysis results give a better indication of the status of these nutrients in trees. Soil pH plays a significant role in their availability. | | | | |
| Zinc (mg/kg) | <0.5 | 0.5 | >1.5 | Zinc levels around 0.2 mg/kg are usually adequate, but higher levels may be required for some horticultural crops. Indicative levels are lower in sandy soils. |
| Copper (mg/kg) | <0.2 | >2 | >100 | The copper content of most natural soils is low, but in some agricultural soils high levels of copper can accumulate as a consequence of the use of copper fungicides. Soil pH is the most important factor determining copper availability. Aim for copper levels of 0.2 mg/kg. Levels >15 mg/kg are detrimental to most soil micro-organisms. Most likely to be toxic in acidic soils in a dry summer or waterlogged winter. |
| Manganese (mg/kg) | <0.5 | >5 | >100 | Most manganese is retained in the topsoil and availability is governed by soil pH. Seasonal conditions can also have an effect, and low soil temperatures and low rainfall will reduce availability. Actual critical values depend on plant tolerance and location. Levels vary throughout the year, related to temperature and rainfall. |
| Aluminium (% of CEC) | <2 | 2–5 | >5 | As soil pH rises aluminium levels decline. Levels should be <5% of CEC. Actual critical value depends on plant tolerance. Leaf analyses may be better indicators. |

Source: Waters 2009.

## Developing a fertiliser program

The aim of a fertiliser program is to provide adequate supplies of the right nutrients to the trees, when, and if, they are needed. Managing tree nutrition is a dynamic process and the fertiliser program needs to be assessed, monitored and adjusted annually (Figure 138), especially with alternate bearing varieties such as mandarins. It is critical that the fertiliser program is adjusted according to predicted crop load, and reviewed again in early summer, after natural fruit drop has finished.

Keeping records of fertiliser application rates and timing, fruit maturities, yields and packouts, seasonal conditions and previous soil and leaf analysis records are essential in managing a fertiliser program to achieve good tree nutrition. It is preferable to base modifications to a fertiliser program on multiple seasons' records. One season's records alone are useful, but may be inadequate because the direction of any trend is unknown. Keeping good records enables trends over time to be seen and allows application rates and timing to be assessed in relation to tree growth, fruit quality and production levels. Adjustments to the fertiliser program should be made gradually. If changes need to be made, try not to vary application rates of the major nutrients by more than 25–30% annually.

The main goal when fertilising young non-bearing trees (<4 years old) is to promote maximum shoot growth and canopy development. At this time nitrogen is the element with the greatest effect on tree growth. Production potential depends on the size of the bearing canopy, and promoting good canopy growth remains important until the trees have reached the desired size. Frequent light applications of nitrogen-rich, mixed fertilisers should be made annually (in winter, spring and summer) in close proximity to the root zone.

The nutrition program for bearing trees needs to support both canopy growth and fruit production. Regulating the balance between nitrogen, potassium and phosphorus becomes increasingly important to ensure adequate vegetative growth, good yields of suitably sized fruit with attractive rinds and good eating quality.

Annual leaf nutrient analysis is the most effective and reliable means of correctly identifying any excessive or deficient levels of a nutrient, and whether particular parts of a fertiliser program need to be adjusted. Along with yield and fruit packout data, leaf analysis is a valuable part of assessing and modifying a fertiliser program. Table outlines the information and various steps that are important in developing and managing a fertiliser program. Annual rates of nutrients will vary across sites depending on local soil conditions.

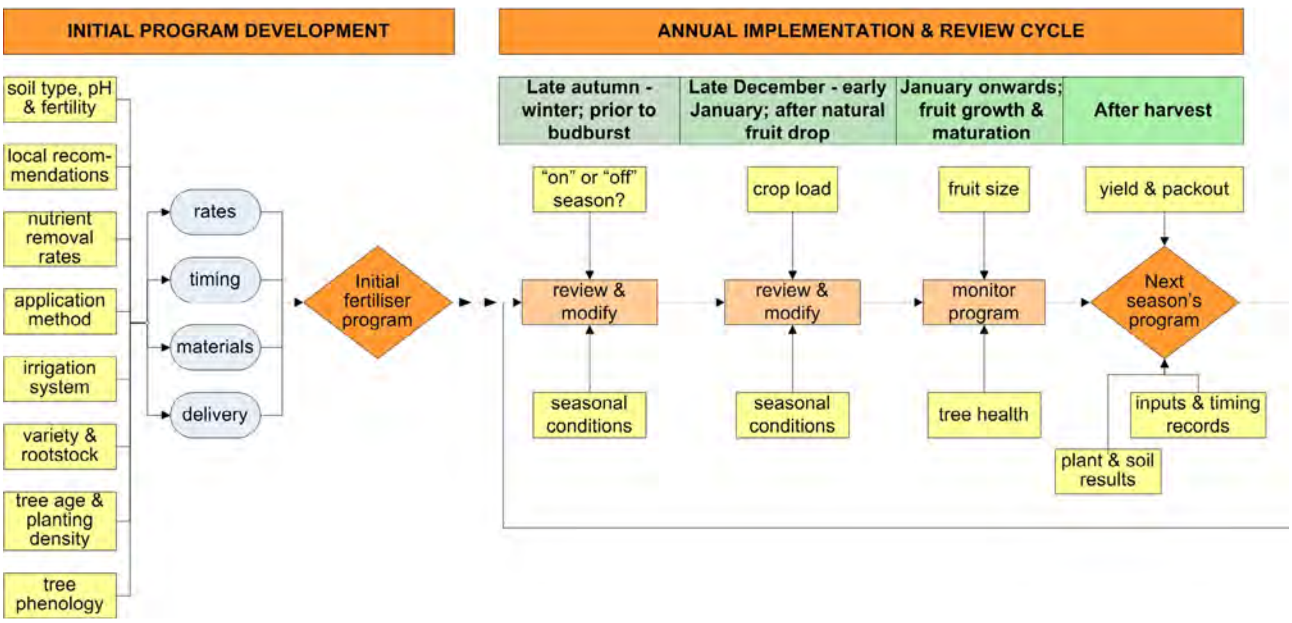



Figure 138. Diagrammatic representation of the key information and steps in developing a fertiliser program.

## Fertiliser application rates

The amount of fertiliser required is dependent on a range of factors including variety and rootstock combination, tree health, age, planting density, crop load, soil type and fertility, and seasonal weather conditions.

At a minimum, a fertiliser program should aim to replace the nutrients removed in fruit, leaves and prunings, as well as provide enough for annual tree growth and storage, losses from leaching, soil erosion, lock-up, volatilisation and replenishing the soil nutrient reservoir. Nutrient losses can vary considerably between sites, and losses from leaching and soil erosion are usually preventable by appropriate irrigation and orchard floor management and avoiding applying nitrogen before predicted significant rainfall (>10 mm). The amount of nutrients applied to an orchard generally needs to be greater than the amount removed by the system (e.g. through crop harvest, pruning and leaching losses) because the tree roots seldom take up 100% of the amount supplied.

Additionally, nutrient recycling from fallen leaves, tree prunings, mulching materials and cover crops can significantly contribute to soil fertility, but the turnover (i.e. release of most nutrients from the organic matter into the soil solution) is generally slow. The exception is nitrogen; a large amount is stored in plant tissue, especially the leaves, and decomposition of organic nitrogen into inorganic forms (known as nitrogen mineralisation) can contribute significantly to the mineral nitrogen pool. Dou, Alva and Khakural (1997) found that nitrogen mineralisation under the canopy of citrus groves can contribute from 40 to 153 kg/N/ha annually depending on tree age, soil type, weather and orchard management. Weather, especially temperature and rainfall, significantly affect nitrogen mineralisation and regions with high rainfall and high temperatures favour rapid decomposition. The optimum temperature for nitrogen mineralisation is 25–30 °C (Beck 1983).

## Crop nutrient removal rates

Crop nutrient removal rates are an estimate of the amount of nutrients removed annually from the tree in the harvested fruit. They account for a major proportion of annual nutrient removal from orchards. Removal rates can also include estimates of nutrients lost through leaf fall, pruning and leaching. These figures are a starting point for estimating how much of each nutrient needs to be replaced annually. If the nutrients are not replaced, the amount stored in the soil will become depleted over time, and this can be difficult to correct.

Calcium, potassium, nitrogen and phosphorus are the elements removed from the soil in the greatest quantities. Calcium is the most dominant mineral in vegetative parts, followed by potassium, then magnesium, phosphorus, sulphur and silicon in relatively equal amounts. In fruit the dominant element is potassium which partly accounts for the reduction in fruit size if potassium is deficient (Chapman 1968). In citrus varieties such as mandarins that tend to have an alternate bearing habit with heavy and light crop years, mineral removal rates will vary from year to year as a result of crop load.

Most published crop nutrient removal charts are based on research in oranges, and estimates for mandarins tend to be slightly less as a result of there being less fruit mass per tree compared to oranges. Table 50 contains a range of crop nutrient removal rates for mandarins and the mineral levels in various citrus types Table 51.

Table 50. Crop nutrient removal rates for mandarins.

| Nutrient | Fruit (tonnes/ha) | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| | kg nutrient/ha | | | | |
| **Nitrogen** | 15 | 31 | 46 | 61 | 77 |
| **Phosphorus** | 2 | 3 | 5 | 6 | 8 |
| **Potassium** | 21 | 41 | 62 | 82 | 103 |
| **Calcium** | 5 | 10 | 15 | 20 | 25 |
| **Magnesium** | 1 | 2 | 3 | 4 | 6 |

Source: Cittgroups Australia.

## Fertiliser trials and recommendations

Information generated from fertiliser trials can provide data on the amount of nutrients required by different variety and rootstock combinations. These general recommendations are normally provided on a district or regional basis to take into account local soil characteristics and the regional climate. They are another tool to assist in developing a fertiliser program.

There is a relationship between nutrient supply and yield – referred to as the crop yield response curve (Figure 139). If the soil was totally depleted of available plant nutrients, and no fertiliser was applied, yield would be at a minimum and trees would suffer a deficiency. As fertiliser applications are increased, a point is reached where maximum yield is achieved (i.e. the 'adequate zone'), after which additional applications will not result in a yield response. When fertiliser application rates are excessive, trees may suffer toxicity symptoms and nutrient salts will build up in the soil, causing salinity problems, or be leached through the rootzone contaminating waterways.

Table 51. Mineral nutrient levels in different citrus fruit types.

| Nutrient | N | P | K | Mg | Ca | S | Fe | Mn | Zn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg/tonne of fresh fruit | | | | | | g/tonne of fresh fruit | | | | |
| **Orange** | 1.77 | 0.51 | 3.19 | 0.37 | 1.01 | 0.14 | 3.0 | 0.8 | 1.4 | 0.6 | 2.8 |
| **Mandarin** | 1.53 | 0.38 | 2.47 | 0.18 | 0.71 | 0.11 | 2.6 | 0.4 | 0.8 | 0.6 | 1.3 |
| **Lemon and lime** | 1.64 | 0.37 | 2.09 | 0.21 | 0.66 | 0.07 | 2.1 | 0.4 | 0.7 | 0.3 | 0.5 |
| **Grapefruit** | 1.06 | 0.30 | 2.42 | 0.18 | 0.57 | 0.09 | 3.0 | 0.4 | 0.7 | 0.5 | 1.6 |

Sources: Koo 1958; Chapman 1968; Malovolta 1989 in Koo (n.d.).

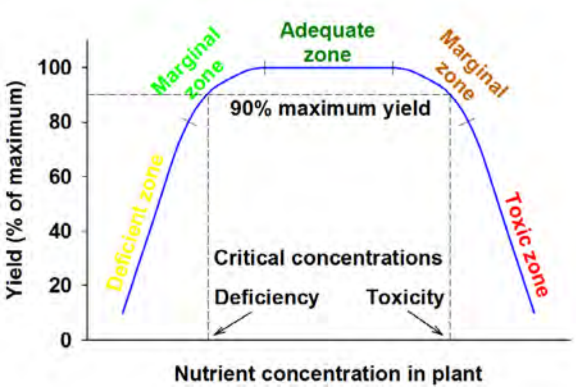



Figure 139. Crop yield response curve to fertiliser application. Source: Adapted from Smith and Loneragan 1997.

Recommended rates per tree or hectare for the main macro-nutrients for bearing trees can vary greatly as a result of variety, rootstock, tree age, planting density and local soil and climatic conditions. Rates can be in the range of 100–200 kg of nitrogen/ha, 100–220 kg of potassium/ha and 20–40 kg phosphorus/ha. Equal or slightly more potassium than nitrogen is usually required once trees start fruiting. Researchers worlwide have suggested that different mandarin varieties have different responses to increasing potassium supply. Rates of calcium and magnesium will depend on soil conditions such as pH, soil texture and CEC. Coupled with a standard annual fertiliser program, judicious foliar application of certain macro-nutrients at key growth stages has been shown to improve flowering, fruit set and size and fruit quality. Table 52 shows the nutrient rate recommendations for mandarins in Western Australia based on tree yield. Table 53 shows the soil application rates of nitrogen, phosphorus and potassium for a range of varieties in different countries, highlighting the large variation in recommendations.

Chapman (1982 and 1986) in fertiliser trials in Queensland found that application rates of nitrogen per hectare did not vary greatly with planting distances for three citrus cultivars (Washington navels, Imperial mandarins and Ellendale tangors). Optimum yields were achieved at nitrogen rates of 163–176 kg/ha, while planting densities ranged from 188 to 440 trees per hectare. A six year fertiliser trial on Ellendale tangors on sweet orange rootstock (440 trees/ha) near Gayndah, Queensland, showed that the optimum rate of nitrogen on a red-brown sandy loam was between 160–180 kg/ha and that yield did not increase with higher rates. For potassium there were no yield responses to any of the fertiliser treatments, indicating that the site's soil already had ample potassium reserves (Lee & Chapman 1988). Bevington et al. (1998) found in a survey of 37 Imperial mandarin orchards in the Sunraysia region, that sites producing the largest fruit had annual maintenance applications of potassium, including one or more foliar applications of potassium nitrate at key growth stages.

Table 52. Nutrient application rates for mandarins in WA.

| Nutrient | Fruit (tonnes/ha) 20 | 30 | 40 | 50 |
|---|---|---|---|---|
| | kg nutrient/ha | | | |
| **Nitrogen** | 76 | 114 | 152 | 190 |
| **Phosphorus** | 14 | 21 | 28 | 35 |
| **Potassium** | 80 | 120 | 160 | 200 |
| **Calcium** | 32 | 48 | 64 | 80 |
| **Magnesium** | 6 | 3 | 4 | 15 |

Source: www.agric.wa.gov.au.

## Fertiliser timing

The nutrients required for growth, flowering and fruit production have to be present in the tree when they are needed. Depending on the form of nutrient present in the fertiliser applied, it may take 4–6 weeks for the nutrient to be converted into a form that is taken up by tree roots. However, soil conditions such as temperature, moisture content and microbial activity will also have an influence. For foliar applications or fertigation the nutrients can be applied much closer to the time when they are required.

Citrus trees go through a cycle of developmental phases annually known as phenological stages. For more information see the Climate and phenology chapter. These stages include several leaf flushes (the most important being in spring and early summer), root flushes and fruit development stages from floral induction through flowering, fruit set, fruit growth and maturation. Each stage requires an adequate supply of specific nutrients.

The highest nutrient demand extends from late winter through to early summer, coinciding with the spring leaf flush, flowering, fruit set and early fruit development periods (Paramasivam et al. 2000).

The developing fruit are a major sink for plant nutrients (especially potassium and calcium) during the growing season. Work on fruit nutrient accumulation in Bellamy navel oranges on *C. trifoliata* rootstock showed that for the macro-nutrients (potassium, calcium, magnesium, phosphorus and sulphur) and the micro-nutrients (boron, iron, manganese, zinc and copper), net influx into the developing fruit increased during Stage I fruit development and reached a maximum 8–10 weeks after flowering (2 weeks after the end of Stage I) [Storey & Treeby 2000 and 2002].

During early fruit growth, potassium and boron (phloem mobile) and calcium and copper (phloem immobile) increased linearly with fruit dry weight. There was a four-fold increase in calcium in the fruit when cell division was occurring. During Stages II and III of fruit development the concentrations of all macro-nutrients decreased (apart from sodium). At fruit maturity the relative order of concentration of the macro-nutrients in whole fruit was K > Ca > Mg = P > S > Na. Figure 140 depicts the accumulation of macro-nutrients into the leaves and fruit of oranges in southern Australia throughout the growing season.

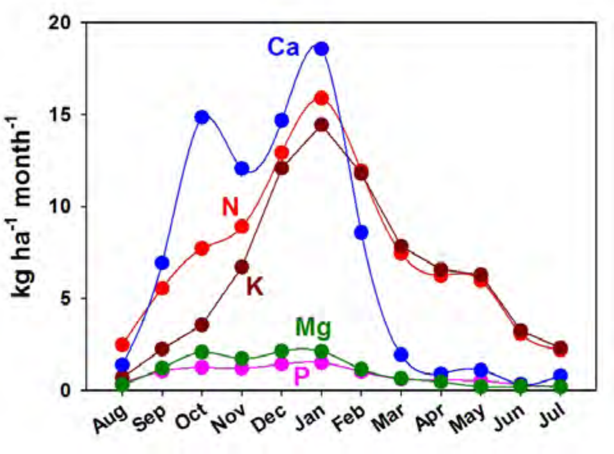



Figure 140. Accumulation of macro-nutrients into the leaves and fruit of oranges throughout the growing season in southern Australia. Source: Adapted from Storey and Treeby 2002.

## Nitrogen

The timing for nitrogen application is critical and shortages during flowering and fruit set can significantly reduce yield. Nitrogen is required for shoot growth, especially during the spring flush and for flower bud differentiation and fruit set. There is an increase in leaf ammonium content in buds and leaves prior to flowering and trees need an adequate nitrogen supply to ensure that leaves and buds are well supplied. If tree reserves are not sufficient and root growth and the uptake and transfer of nitrogen and other mineral elements to the scion is limited by low soil temperatures (<18 °C) in late winter/early spring (Monselise 1947), floral bud initiation and differentiation may be adversely affected.

For bearing trees, nitrogen should be applied several weeks before flowering, between late June and late July, depending on the region (Weir & Sarooshi 1991).

Table 53. Recommended soil application rates of N, P and K for different mandarin varieties across a range of citrus growing countries.

| Variety | Country | N | P | K | Source |
|---|---|---|---|---|---|
| | | g/tree | | | |
| **Clementine** | Algeria | 600 | 150 | 600 | Dris 1997 |
| **Dancy** | Spain | 240 | 40 | 100 | Pedrera et al.1988 |
| **Satsuma** | China | 22.5–25 | 5–12.5 | 10–12.5 | Wang 1985 |
| **Satsuma** | China | 1500 | 250 | 1250 | Yin et al.1998 |
| **Satsuma** | Turkey | 475 | 320 | 355 | Koseoglu 1990 |
| **Satsuma** | China | 125 | 175 | 100 | Hong and Chung 1979 |
| **Satsuma** | Turkey | 475 | 320 | 355 | Koseglu et al. 1995 |
| **Satsuma** | China | 1002 | 580 | 550 | Liu et al. 1994 |

Source: Adapted from Srivastava et al. 2008.

Nutrition

Chapman (1982 and 1986) reviewed nitrogen fertiliser trials on citrus (including mandarins) in Queensland and firmly established that the majority of nitrogen should be applied between mid to late winter for optimum yield and fruit quality. This was consistent with research findings from other parts of the world. There was no advantage in applying nitrogen during summer and autumn, and sometimes this had adverse effects on fruit quality, such as a reduction in soluble solids, increased acidity and poor fruit colour, as well as unnecessary vegetative growth and decreased fertiliser use efficiency.

### Phosphorus

Phosphorus is important for canopy growth and flowering and generally has beneficial effects on citrus fruit quality. Phosphorus uptake increases during early fruit development up until the early part of Stage II fruit growth and then tends to remain fairly constant.

Phosphorus tends to stay where it is applied, especially in heavy soils, so application should be made in close proximity to the majority of feeder roots. Phosphorus is usually applied as a ground application, annually or bi-annually, during late autumn or winter and banded at a depth of about 15–20 cm in the rootzone. Where high nitrogen levels are being maintained, higher levels of phosphorus are required to offset the adverse effects of nitrogen on fruit quality.

Jorgensen and Price (1978) found that many citrus blocks in Queensland had high levels of phosphorus in the soil due to long-term applications and suggested that in some cases, annual applications of phosphorus fertilisers were unnecessary. Based on leaf analysis, Hardy (pers. comm.) reported a similar situation for orchards on the sandy soils of the Central Coast plateau of NSW. Many leaf samples showed excessive levels of phosphorus, possibly as a result of long-term annual applications of superphosphate and poultry manure. The conclusion reached was that annual applications of phosphorus could be foregone in some seasons.

### Potassium

Potassium has a significant role in fruit set, fruit size and maturation; inadequate potassium levels will lead to smaller fruit (El-Otmani et al. 2000). Adequate supplies are needed prior to flowering and for cell division and expansion, and peak demand is during late Stage I and early Stage II of fruit growth. Mandarins tend to require slightly higher rates of potassium than oranges. However, excessive potassium levels have a similar effect on fruit quality as excessive nitrogen and these effects are greater if nitrogen levels are also high.

Foliar applications of potassium at key times in the fruit development cycle can also be effective in increasing fruit size. Three foliar applications of potassium nitrate applied in winter, post-bloom and mid-summer increased fruit size in Sunburst tangerines grown in Florida (Boman 2002). A single foliar application of potassium phosphite to Nour clementine mandarins in Morocco at the early green flower bud stage increased fruit set (El-Otmani et al. 2000).

### Calcium

Calcium is a major component of cell walls and helps reduce albedo breakdown and assists in fruit storage life. Demand for calcium is high during periods of rapid growth, especially the early stages of fruit growth when cells are dividing. Calcium is mostly taken up in the first few months of fruit development (Stage I) [Smith & Reuther 1953].

Ground applications are usually made during winter and supplementary foliar applications in January and February to improve rind quality. Calcium is present in single strength superphosphate, but is only slightly soluble and moves very slowly into the soil. Calcium sprays during late spring and summer have been shown to decrease albedo breakdown in the Sunraysia region (Treeby & Storey 2002).

### Magnesium

Magnesium plays an important role in photosynthesis. It can be readily supplied to leaves as magnesium nitrate or alternatively as Epsom salts (magnesium sulphate) mixed with calcium nitrate. Foliar applications can be made to the recently expanded leaf flush in spring, summer and early autumn. Magnesium can also be supplied via fertigation as magnesium nitrate and magnesium sulphate.

### Micro-nutrients

Most micro-nutrients can be applied as foliar sprays in spring, summer and early autumn to the recently expanded leaf flush. Foliar sprays do not give long-term control and several sprays may be required annually and repeated each year. Soil applications can be done at any time; but, depending on soil pH, may not deliver any long-term benefit. Table 54 outlines the suggested application times for the main macro-nutrients (nitrogen, phosphorus, potassium and calcium) with reference to the key growth stages. Table 55 lists the fertigation program for mandarins grown at NSW DPI Dareton Research Station.

Table 54. Suggested application times for the main macro-nutrients with reference to the key growth stages.

| Growth stage | Timing (depending on location) | N | P | K | Ca |
|---|---|---|---|---|---|
| | | % of total annual application | | | |
| **Pre-bloom to flowering** | July–September | 50–75% | banding: 100%<br>fertigation: 50% | 30–40% | 70–80% |
| **Stage I: Cell division** | October–December | 50–25% | fertigation: 50% at monthly intervals | 30–50% | |
| **Stage II: Cell expansion** | January–March (after natural fruit drop) | – | – | 30% | 20–30% |

Table 55. Fertiliser program for 5 year-old Tang-Gold mandarins growing on a sandy loam soil at NSW DPI Dareton Research Station.

| Element, application type and rate and % of annual requirement | | Winter | | | Spring | | | Summer | | | Autumn | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May |
| **Nitrogen** (fertigation) | kg N | – | – | – | 35 | 14 | 14 | 11 | 16 | 11 | 5 | – | – |
| | % of annual | – | – | – | 33 | 13 | 13 | 10 | 15 | 10 | 5 | – | – |
| **Phosphorus** (fertigation) | kg P | – | – | – | 11 | 5 | 4 | 3 | 5 | 3 | 2 | – | – |
| | % of annual | – | – | – | 33 | 15 | 12 | 9 | 15 | 9 | 6 | – | – |
| Double strength superphosphate (banded every 2–3 years as needed) | 250kg/ha | – | – | | – | – | – | – | – | – | – | – | – |
| **Potassium** (fertigation) | kg K | – | – | – | 9 | 4 | 4 | 3 | 5 | 3 | 2 | – | – |
| | % of annual | – | – | – | 30 | 13 | 13 | 10 | 17 | 10 | 7 | – | – |
| **Zinc and manganese** (foliar sprays) | – | – | – | – | – | – | | – | – | – | | – | – |
| 1 to 2 foliar sprays of **potassium nitrate** (2% in 2000 L water/ha) for improving fruit size in heavy crop years | – | – | – | – | – | – | – | – | | | | – | – |
| Fertiliser sources for fertigation include urea, MAP (mono-ammonium phosphate), potassium sulphate, 740 trees/ha planted at 5 x 2.7 m. Drip irrigation system with 2 lines/tree row. | | | | | | | | | | | | | |

## Fertilisers

There are a range of fertiliser materials that can provide essential plant nutrients, including synthetic fertilisers, organic fertilisers and natural minerals or salts, such as rock phosphate.

### Synthetic or mineral fertilisers

Synthetic or mineral fertilisers undergo a manufacturing or transformation process to concentrate the nutrient elements or convert them into forms that are more readily available to plants. Mineral fertilisers are reasonably chemically and physically uniform and so it is possible to apply precise amounts of each nutrient. Common terms used to describe mineral fertilisers include straight (which supply a single nutrient e.g. urea) and mixed or compound (which supply more than one nutrient, e.g. superphosphate). Synthetic fertilisers are also available in a range of forms: powders, granules and prills (solid fertilisers), and liquid suspensions and soluble solids which dissolve completely. Table 56 lists some of the most common fertiliser products for different plant nutrients and their use, while Table 57 provides typical analysis figures.

Table 56. General guide to common fertiliser sources for plant nutrients.

| Nutrient | Common fertiliser sources | Comments |
|---|---|---|
| **Nitrogen** | Ammonium nitrate, urea, ammonium sulphate, calcium ammonium nitrate, calcium nitrate, mixed NPK fertilisers and organic manures | N is taken up by plants mainly as nitrate ($NO_3^-$) but can also be extracted as ammonium ($NH_4^+$). Nitrogen as ammonium is mineralised by soil micro-organisms in a process that ranges from days to months, depending on the soil conditions, especially soil temperature. Bacterial activity is greatest when the soil conditions are warm and moist and slower in cold and dry soils.<br>Nitrate nitrogen is soluble in water and immediately available, so is usually used when a quick response is required. Ammonium sources of nitrogen such as urea should never be allowed to sit on the surface of high pH soils or recently limed soils because the ammonia may be lost to the atmosphere as ammonia gas. Urea is best applied by mixing into the soil to avoid significant amounts of gaseous losses due to volatilisation. Urea applied to the soil surface will absorb moisture from the atmosphere and dissolve and losses as ammonia gas can be high. Always water urea in after application. The long-term use of some nitrogenous fertilisers can result in the gradual acidification of the soil.<br>Soluble forms of nitrogen used in fertigation include ammonium nitrate, ammonium sulphate, calcium ammonium nitrate, calcium nitrate, potassium nitrate and urea. |
| **Phosphorus** | Single, double and triple strength superphosphate, mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP), rock phosphate, mixed NPK fertilisers | In calcareous soils where phosphorus has low solubility, use of soil acidifying agents, such as sulphur and ammonium sulphate, increases phosphorus availability in the upper rootzone, but prolonged and excessive applications should be avoided due to effects on the availability of other nutrients. The phosphorus in rock phosphate is predominantly in an unavailable form. The phosphate is released very slowly unless the soil pH is <5.5. Most dry phosphorus products have low solubility and cannot be used in fertigation. Soluble forms of phosphorus include ammonium polyphosphate, MAP and DAP. Phosphate can form insoluble precipitates when mixed with calcium or magnesium in solution. Phosphoric acid is sometimes used to reduce this, because it lowers the pH of the solution, but is only effective if the pH of the solution remains low (<4.0). |
| **Potassium** | Muriate of potash or potassium chloride, potassium sulphate, potassium-magnesium sulphate and potassium nitrate, mixed NPK fertilisers. | Muriate of potash or potassium chloride is the cheapest form of potassium, but has a high chloride content and should not be used where soil salinity is a problem. Soluble forms of potassium used in fertigation include potassium chloride, potassium nitrate and potassium thiosulphate. Potassium phosphates should not be injected into micro-irrigation systems. |
| **Calcium** | Lime (calcium carbonate), dolomite (calcium magnesium carbonate), gypsum (calcium sulphate), calcium nitrate, single superphosphate. | There are various forms and grades of lime. Gypsum is used mainly on soils with high levels of sodium where it displaces sodium on the soil colloids and improves soil structure. Gypsum has no effect on soil pH. Soluble forms of calcium used in fertigation include calcium nitrate and gypsum. It is preferable to have a separate tank for calcium products. Calcium should be flushed from all parts of the system prior to injecting with any phosphorous, urea or ammonium nitrate products. |
| **Magnesium** | Magnesium sulphate (Epsom salts), dolomite, magnesite (magnesium carbonate) | Depending on soil pH, foliar sprays of magnesium sulphate mixed with calcium nitrate may be the only effective treatment for magnesium deficiency in the tree. Soil applications of dolomite or magnesite may be slow to control symptoms. |

| Nutrient | Common fertiliser sources | Comments |
|---|---|---|
| **Sulphur** | Elemental sulphur, calcium sulphate, ammonium sulphate, potassium sulphate, superphosphate, gypsum | Elemental sulphur must be converted by soil bacteria into the sulphate form that can be used by trees. The conversion process is slow and is affected by soil temperature, moisture and particle size. Sulphur is resistant to leaching and has a long residual effect. Heavy application rates of elemental sulphur lower soil pH. Sulphate fertilisers such as potassium sulphate are a source of quick acting sulphur, and single superphosphate is also a good source. |
| **Zinc** | Zinc chelates, zinc sulphate | Soil applications of zinc chelates (zinc EDTA or HEDTA) are usually ineffective and foliar sprays of zinc sulphate heptahydrate are mostly used. |
| **Manganese** | Manganese sulphate | Foliar sprays of manganese sulphate are most commonly used to correct deficiencies. Soil application of manganese sulphate can be used but soil pH will dictate whether the manganese will be available to trees for long. |
| **Iron** | Iron chelates, iron sulphate | Iron deficiencies can be corrected with foliar sprays of iron sulphate or iron chelates (iron EDTA or iron EDDHA). Soil applications of iron chelates can also be used but only iron EDDHA will be effective in high pH soils. |
| **Boron** | Polyborate powder | Do not apply boron unless a deficiency has been diagnosed by leaf analysis because citrus is highly sensitive to boron toxicity. Foliar sprays of polyborate powder can be applied at any time apart from during flowering as it may affect fruit set. |
| **Copper** | Copper sulphate, copper oxide, copper oxychloride, copper hydroxide, copper oxysulphate, copper chelates | Copper can be applied to the soil or as foliar sprays. Where copper fungicide sprays are used routinely there is usually no need to apply additional copper. Most copper fertilisers need to be applied in solution either to the soil or foliage, these include copper sulphate, copper oxide, copper oxychloride and copper hydroxide. Copper fertilisers applied to the soil include copper oxysulphate (25% Cu) and copper chelates. |

## Organic fertilisers

Organic fertilisers are derived from biological sources such as animal manures, plant and food waste materials. Some organic fertilisers are often used with little further processing but may be composted, mixed or pelletised. Organic fertilisers are typically more variable, but offer other benefits, besides simply supplying trees with essential mineral nutrients. For example, organic fertilisers can improve the physical, chemical and microbiological properties of the soil. When applied regularly in large quantities, organic materials improve soil structure, biological activity and nutrient supply and increase soil aeration and water holding capacity.

Mineral nutrients in organic materials are slowly released because the material must be broken down by soil micro-organisms into inorganic forms that can be used by plants. Organic materials can be bulky to transport and apply, and are often more expensive per kilogram of nutrient compared to synthetic fertilisers.

The nutrient content of wholly organic products is generally low compared with synthetic products and the analysis can be quite variable because of differences in the type of material, its age, its moisture content and the degree to which it has been composted, making it more difficult to predict exactly how much nutrient is being applied. A guide to the nutrient content of some common organic fertilisers is given in Table 58. When using organic materials as a significant component of a fertiliser program, it is recommended that a nutrient analysis on the materials be obtained to decide on the rate of application needed to deliver the desired amount of mineral nutrient. Large volumes will usually need to be applied in order to provide mature trees with the quantities of nutrients required.

Table 57. Typical analysis figures for some common synthetic fertilisers. Analyses may vary between manufacturers.

| Fertiliser | Percentage concentration | | | | | | |
|---|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | S | Other |
| Ammonium nitrate | 34 | – | – | – | – | – | – |
| Ammonium sulphate | 21 | – | – | – | – | 23 | – |
| Borax | – | – | – | – | – | – | 11 B |
| Calcium nitrate | 15.5 | – | – | 20 | – | – | – |
| Calcium sulphate (gypsum) | – | – | – | 23 | – | 18 | |
| Copper sulphate | – | – | – | – | – | 12 | 25–35 Cu |
| Di-ammonium phosphate (DAP) | 18 | 20 | – | – | – | 0–2 | – |
| Dolomite | – | – | – | 10–21 | 12–18 | – | – |
| Elemental sulphur | – | – | – | – | – | 30–99 | – |
| EDDHA iron chelate | – | – | – | – | – | – | 13 Fe |
| Iron sulphate heptahydrate | – | – | – | – | – | 16 | 20 Fe |
| Lime (calcium carbonate) | – | – | – | 28–36 | – | – | – |
| Magnesium carbonate/ magnesite | – | – | – | 0.5–1.0 | 20–28 | – | – |
| Magnesium sulphate/Epson salts | – | – | – | – | 10 | – | – |
| Manganese sulphate | – | – | – | – | – | 13 | 24 Mn |
| Mono-ammonium phosphate (MAP) | 11 | 48 | – | – | – | 0–2 | – |
| Phosphoric acid | – | 54 | – | – | – | – | – |
| Potassium chloride/muriate of potash | – | – | 60 | – | – | – | 44 Cl |
| Potassium-magnesium sulphate | – | – | 22 | – | 11 | 22 | – |
| Potassium nitrate | 13 | – | 48 | – | – | – | – |
| Potassium phosphite | – | 28 | 26 | – | – | – | – |
| Potassium sulphate | – | – | 46 | – | – | 18 | – |
| Rock phosphate | – | 34 | – | – | – | – | – |
| Solubor | – | – | – | – | – | – | 20 B |
| Single-strength superphosphate | – | 7–9 | – | 20 | – | 10–14 | – |
| Double-strength strength superphosphate | – | 17.5 | – | – | – | – | – |
| Triple-strength strength superphosphate | – | 20 | – | 15 | – | 1 | – |
| Urea | 46 | – | – | – | – | – | – |
| Zinc sulphate | – | – | – | – | – | 12 | 22 Zn |

Table 58. Average range of nutrient content of some organic fertilisers.

| Product | %N | %P | %K |
|---|---|---|---|
| Poultry manure (litter) | 1.6–3.9 | 1.3 | 1.7 |
| Poultry manure (cage) | 1.2–4.0 | 0.4–1.3 | 0.4–1.7 |
| Cow manure | 0.5–2.0 | 0.1–0.7 | 0.3–1.5 |
| Sheep manure | 0.6–3.0 | 0.1–0.7 | 0.2–2.6 |
| Horse manure | 0.4–0.5 | 0.1 | 0.3–0.6 |
| Pig manure | 0.5–0.6 | 0.2 | 0.1–0.3 |
| Blood and bone | 5.3 | 5.2 | – |
| Seaweed (kelp) | 0.2 | 0.1 | 0.5 |
| Fish meal | 10.4 | 2.5 | – |
| Compost | 1.4–3.5 | 0.3–1 | 0.4–2.0 |

Source: Burgess 1992; Madge 2009.

## Compost and composting

Using un-composted fresh materials on trees can cause a number of problems. Fresh manures can contain significant amounts of nitrogen as urea or ammonia, which when released have the potential to burn plant roots. Applying some un-composted materials (such as tree prunings) directly under trees can require the application of additional nitrogen, to feed the soil micro-organisms during the composting process. If insufficient nitrogen is available in the material during composting, then nitrogen is taken from the soil. This is know as 'nitrogen drawdown' (Figure 141).

To reduce the likelihood of fertiliser burn and/ or nitrogen drawdown some plant materials and especially animal manures are best composted before they are spread in the orchard. Composting also reduces the weight and volume of the original material by about 50%. If the composting process is done correctly, compost heaps will reach temperatures of 60 °C to 70 °C, which kills most pathogens. The nutrient value of compost is directly related to the quality of materials used.

The composting process requires a good balance of materials, as well as oxygen and moisture (about 40–50%). Cutting or mulching plant materials, as well as turning the compost heap frequently, will also speed up the composting process. One of the most important factors in the composting process is the carbon to nitrogen ratio (C:N) as this will affect the rate of breakdown and need for additional nutrients. Micro-organisms need both carbon and nitrogen to make protein and they use about 30 parts (by weight) of carbon for each part of nitrogen used. So the materials used in a compost heap need to have a C:N ratio of between 25–30:1. Higher ratios reduce microbial activity and low ratios can result in nitrogen losses as ammonia gas. Organic matter with a C:N ratio >30:1 does not contain enough nitrogen for soil microbes to build protein, and to meet this shortfall they extract mineral nitrogen from the soil. In contrast, organic matter high in nitrogen (C:N <20:1) usually contains all the nitrogen required by the micro-organisms and some nitrogen will be released into the soil, and the material will be quickly broken down.

So, depending on the C:N ratio, its state of decomposition, and other factors such as the soil moisture content and soil temperature, organic materials can exhibit different rates of nitrogen release. To increase the C:N ratio for animal manures with high nitrogen levels, mix in a carbon source such as straw. For high carbon materials, such as wood chips or sawdust, urea or ammonium sulphate can be used to supply additional nitrogen. Micro-organisms also need other nutrients such as phosphorus. A C:P ratio of 1:75–150 is ideal and some woody materials such as sawdust and eucalyptus leaves with lower ratios may need a light dressing of superphosphate.

A guide to the carbon and nitrogen content of common organic materials is listed in Table 59.

Table 59. A guide to the carbon and nitrogen content of some common organic materials.

| Waste material | %C | %N |
|---|---|---|
| **High in carbon** | | |
| Non-legume hay | 42 | 1.3 |
| Tree prunings | 50 | 1.0 |
| Straw | 56 | 0.7 |
| Softwood sawdust | 50 | 0.1 |
| Hardwood sawdust | 50 | 0.06 |
| Newspaper | 25 | 0.04 |
| **High in nitrogen** | | |
| Blood and bone | 42 | 13 |
| Vegetable wastes | 30 | 3 |
| Chicken litter | 58 | 3.4 |
| Grass clippings | 38 | 2.7 |

Source: Jenkins and Van Zwieten 2003.

Figure 141. Non-composted mulch materials that are high in carbon relative to nitrogen (i.e. C: N ratio >30), may require the application of additional nitrogen to reduce the likehood of 'nitrogen drawdown'.

## Cover and green manure crops

A cover crop or permanent sod is often planted between the tree rows to help protect the soil from erosion, to improve soil structure, increase organic matter content and microbial activity, as well as keep soils cooler in summer and warmer in winter. In areas with good rainfall or an irrigation system that allows the inter-row area to be watered, a permanent sod of perennial grasses such as ryegrass, or legumes such as medics and clovers, can be maintained. In drier areas, self-seeding annual species are often used.

Green manure crops are grown specifically to be incorporated into the soil before they go to seed. Their purpose is to improve soil structure, health, fertility, organic matter content and biological activity. Plant varieties such as cereals (millet, barley, rye and oats) and legumes (field peas, beans and lupins) are often used. There are also bio-fumigant brassica crops, such as forage rape and Indian mustard, that can help reduce populations of citrus nematode, as long as good growth is achieved.

Most legume species are able to form a symbiotic relationship with specific *Rhizobium* bacteria that are capable of extracting nitrogen from the atmosphere. The amount of nitrogen fixed will vary with crop type and variety, soil moisture, temperature and nutrient status. The bacteria infect the plant roots, which then form a gall or nodule, to house the bacteria. The bacteria are able to incorporate atmospheric nitrogen into special compounds in their cells and then supply it to the host plant. In return the host plant supplies the bacteria with carbohydrates to live. To ensure effective nodulation, legume seed needs to be inoculated with the correct *Rhizobium* strain prior to planting. Nodulation of legumes is inhibited by soil acidity (≤5.5 pH) and high levels of aluminium (Kopittke & Menzies 2007). Studies have shown that the amount of nitrogen fixed can vary between 50–300 kg/N/ha (Madge 2009). Trials in the Sunraysia region have shown that a Paraggo medic crop could put 70–80 kg/N/ha into the soil and that nitrate levels peaked about five weeks after incorporation of the crop into the soil (Sanderson et al. 2002). Table 60 provides a guide to the nitrogen content and C:N ratio of some common cover and green manure crops.

Table 60. A guide to the nitrogen content and C:N ratio of some common cover and green manure crops.

| Crop type | Species | N (% dry matter) | C:N ratio |
|---|---|---|---|
| **Pulses** | Faba bean (*Vicia faba*) | 3.4 | 13 |
| | Field pea (*Pisum sativum*) | 2.3 | 19 |
| | Sandplain lupin (*Lupinus cosentinii*) | 2.4 | 18 |
| **Medics** | Burr medic (*Medicago denticulata*) | 2.8 | 17 |
| | Barrel medic (*M. truncatula*) | 3.9 | 11 |
| | Paraggio medic (*M. truncatula*) | 2.9 | 15 |
| | Prostrate lucerne (*M. sativa*) | 3.6 | 12 |
| **Cereals** | Wheat (*Triticum aestivum*) | 0.8 | 52 |
| | Oats (*Avena sativa*) | 0.9 | 49 |
| | Triticale (*T. aestivum* × *Secale cereale*) | 1.1 | 41 |
| | Perennial ryegrass (*Lolium perenne*) | 0.6 | 78 |
| **Brassicas** | Indian mustard cv. Nemfix (*Brassica* spp.) | 4.3 | 9 |
| | Weedcheck (*Raphano* × *Brassica* spp.) | 3.0 | 13 |

Source: Wheatley and Treeby, unpublished data in Madge 2009.

### Calculating the carbon:nitrogen ratio

$$\text{Weight of total C} = \text{weight of material A} \times \frac{\%\text{ C in A}}{100} + \text{weight of material B} \times \frac{\%\text{ C in B}}{100} + \text{etc.}$$

$$\text{Weight of total N} = \text{weight of material A} \times \frac{\%\text{ N in A}}{100} + \text{weight of material B} \times \frac{\%\text{ N in B}}{100} + \text{etc.}$$

**Then calculate the C:N ratio using the following formula:**

$$\text{C:N} = \frac{\text{weight of total C}}{\text{weight of total N}}$$

For example, using the data in Table 59, if you are using 100 kg of chicken litter and 100 kg of tree prunings, the C:N ratio would be:

$$100 \times \frac{58}{100} + 100 \times \frac{50}{100} = 108 \text{ kg total C}$$

$$100 \times \frac{3.4}{100} + 100 \times \frac{1}{100} = 4.4 \text{ kg total N}$$

$$\text{C: N} = \frac{108}{4.4} = 24.5$$

## Fertiliser delivery

Solid fertilisers can be spread on the soil surface, generally either broadcast in the tree row (mostly used for the macro-nutrients required in large amounts) or banded in the tree row (commonly used for applying superphosphate). Alternatively fertilisers can be applied as dissolved mineral salts through the irrigation system (fertigation) or as a foliar application. Foliar application is more commonly used for correcting micro-nutrient deficiencies or supplying nutrients at key times in the phenological cycle, when soil conditions are unfavourable for uptake by tree roots (e.g. during winter when soil temperature are low). Fertilisers applied to the soil generally are of a lower grade ('agricultural-grade') compared to fertilisers applied through drip irrigation or as foliar sprays ('technical-grade').

### Fertigation

Fertigation is the delivery of dissolved mineral salts in water (the nutrient solution) to the tree roots through the irrigation system. It is now commonly practiced in most orchards. The approaches to fertigation vary from using it to deliver nutrients a few times a year right up to more-or-less daily dosing. When using fertigation it is critical to have the appropriate equipment and a good understanding of tree phenology. The main benefit of fertigation is the more efficient use of fertilisers and water, as well as the ability to deliver small doses of nutrients directly to the root zone when they are needed. Fertigation systems have higher set-up costs, use more expensive fertilisers and require a higher level of management skill.

There is a wide range of fertigation equipment available which varies in complexity and cost. The basic requirements are mixing tanks (at least 2), a dosing unit to manage the injection of the nutrient solution and a controller to operate the irrigation pumps. Although most nutrients can be applied by fertigation – it is more commonly used for the application of the major elements, nitrogen, phosphorus and potassium, and sometimes calcium and magnesium. The fertilisers used must be 'technical-grade' which have fewer impurities and leave very little undissolved solid residues, and are injected into the system in solution.

Correcting micro-nutrient deficiencies with fertigation is rarely successful and some forms of micro-nutrients are relatively insoluble (e.g. carbonate, oxide and hydroxide forms of zinc, manganese, copper and iron) and should not be used. The sulphate forms of copper, iron, manganese and zinc are water soluble.

Other important considerations include fertiliser solubility and the compatibility of different elements and ions. The amount of fertiliser that can be dissolved in a given volume of water (known as solubility) varies with the mineral salt and the temperature of the water. Generally less fertiliser can be dissolved in cold water, compared to warmer water. For example, 85 kg of urea can be dissolved in 100 L water at 10 °C, and 108 kg dissolved at 20 °C (see Table 61).

Some fertilisers are incompatible and should not be mixed because chemical reactions take place that result in insoluble solids being formed that can cause blockages. The most danger is with the use of calcium formulations, hence it is preferable to have a separate tank for fertilisers containing calcium (see Table 62).

Fertiliser solubility and compatibility charts and guides are widely available. Further information on fertigation can be found in the book '*Drip irrigation – a citrus grower's guide*', or on various websites.

Table 61. General guide to the relative solubility of some commonly used fertilisers for fertigation at different temperatures. Note: Always check the manufacturers' guidelines before mixing.

| Fertiliser | Solubility* (max. kg/100 L water) | | Comments |
|---|---|---|---|
| | 10 °C | 20 °C | |
| Ammonium nitrate | 151 | 190 | Moderately corrosive and highly soluble. Solution cools as it dissolves. Slightly acidifying to soil. |
| Ammonium sulphate | 73 | 75 | Extremely corrosive and moderately soluble. Very acidifying – use only on alkaline soils. Do not mix with calcium compounds. |
| Ammonium thiosulphate | – | 64 | Used as a fertiliser and acidifying agent. Ideal for treatment of calcareous soils. |
| Calcium nitrate | 113 | 131 | Moderately corrosive. Non-acidifying. Do not mix with any products containg phosphate, sulphates or thiosulphates. |
| DAP | 62 | 67 | Moderately corrosive and moderately acidifying. Adds nitrogen but does not dissolve completely requiring tanks to be cleaned regularly. Do not mix with calcium compounds. Do not use if water is high in calcium or magnesium. |
| MAP | 28 | 36 | Both moderately corrosive and acidifying. Adds nitrogen but does not dissolve completely requiring tanks to be cleaned regularly. Do not mix with calcium compounds. Do not use if water is high in calcium or magnesium. |
| Mono-potassium phosphate | 18 | 22 | Slightly corrosive. Useful on soils where both phosphorus and potassium are limiting – use in conjunction with di-potassium phosphate. Do not mix with calcium compounds. |
| Potassium chloride | 31 | 34 | Non-corrosive and moderately soluble. Non-acidifying. Not recommended where irrigation water has high salinity levels. |
| Potassium nitrate | 21 | 32 | Extremely corrosive and moderately soluble. Non-acidifying. Suitable for use where water salinity problems are present. |
| Potassium sulphate | 9 | 11 | Extremely corrosive. Has low solubility especially if mixed with potassium chloride or ammonium nitrate. Do not mix with calcium compounds. |
| Potassium thiosulphate (KTS) | – | 160 | Used on calcareous soils to provide potassium and sulphur. Should not be acidified below pH 6.0. Mixing sequence is water, then add KTS. Compatibility with other fertilisers needs to be tested prior to injection. |
| 60% phosphoric acid | Supplied as a liquid | | Add acid to water, not the other way around. Do not use if water has high levels of calcium or magnesium. Do not mix with calcium compounds. |
| 85% phosphoric acid | Supplied as a liquid | | Add acid to water, not the other way around. Do not use if water has high levels of calcium or magnesium. Do not mix with calcium fertilisers. |
| Urea | 85 | 108 | Slightly corrosive and highly soluble. Must be thoroughly dissolved before mixing with other chemicals. Solution cools as it is dissolved reducing solubility. Slightly acidifying. Do not mix with sulphuric acid. |

*Solubilities are based on practical solubility (not maximum solubility) as the initial water temperature is not maintained during mixing.
Source: http://sites.chem.colostate.edu/diverdi/all_courses/CRC%20reference%20data/solubility%20of%20inorganic%20compounds.pdf and Giddings 2005.

Table 62. Compatibility chart for some common fertilisers used in fertigation.

| Fertiliser | Ammonium nitrate | Ammonium sulphate | Calcium nitrate | Magnesium sulphate | MAP | Mono-potassium phosphate | Potassium nitrate | Potassium sulphate | Potassium chloride | Soluble boron | Urea |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ammonium nitrate | | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible |
| Ammonium sulphate | compatible | | incompatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible |
| Calcium nitrate | compatible | incompatible | | incompatible | incompatible | compatible | compatible | incompatible | compatible | incompatible | compatible |
| Magnesium sulphate | compatible | compatible | incompatible | | incompatible | incompatible | compatible | compatible | compatible | incompatible | compatible |
| MAP | compatible | compatible | incompatible | incompatible | | compatible | compatible | compatible | compatible | compatible | compatible |
| Mono-potassium phosphate | compatible | compatible | incompatible | incompatible | compatible | | compatible | compatible | compatible | compatible | compatible |
| Potassium nitrate | compatible | compatible | compatible | compatible | compatible | compatible | | compatible | compatible | compatible | compatible |
| Potassium sulphate | compatible | compatible | incompatible | compatible | compatible | compatible | compatible | | compatible | compatible | compatible |
| Potassium chloride | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible | | compatible | compatible |
| Soluble boron | compatible | compatible | incompatible | incompatible | compatible | compatible | compatible | compatible | compatible | | compatible |
| Urea | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible | compatible | |

Source: www.growcom.com.au  compatible  incompatible

## Open hydroponics

Open hydroponics (OH) is a management system based on intensive fertigation practices in a soil-based production system. OH was originally developed to address low-fertility gravelly soils and poor quality saline water present in some regions of Spain. The Martinez open hydroponics technology (MOHT) system is one variant of OH. It was developed by Professor Rafael Martinez Valero from Spain and introduced to Australia in 1999.

A continuous balanced nutrient mixture is applied through the irrigation system and soil moisture levels are kept near field capacity. The emphasis with this approach is on achieving a small root system that provides the ability to manipulate and control trees for more efficient nutrient and water uptake through all stages of the annual growth cycle. Some OH systems have fewer drippers per plant, and water is applied more frequently in very short irrigations (i.e. pulsing), resulting in a much smaller root zone. For example, under OH, citrus roots can be confined to a root volume as small as 0.5 $m^3$ compared to 6–10 $m^3$ under conventional irrigation/fertigation (Treeby, Falivene & Skewes 2011).

Although OH has the potential to increase orchard productivity, it is complex, capital intensive, highly technical and carries some risk. The restricted root volume means that any disruption to the water supply could significantly impact trees, so on-farm water storage, back up pumps and electric generators are required to reduce the risk. On the other hand, over-irrigating carries with it the risk of waterlogging tree roots, root rot (*Phytophthora*) and leakage of nutrient rich water below the root-zone causing pollution of waterways and the watertable. High nutrient application rates could also increase root-zone salinity. Expert management is required and many users engage the services of a consultant to reduce the risk of over or under irrigating trees.

### Foliar fertilisers

Foliar applications of dissolved fertilisers are normally used to correct micro-nutrient deficiencies, but can also be used to supply key macro-nutrients at critical growth stages in the phenological cycle. Foliar fertilisers are used when soil conditions such as pH, temperature, and adverse structural and moisture conditions (such as compacted or waterlogged soils) prevent nutrient uptake by tree roots. Foliar fertilisers are not intended to replace soil-applied fertilisers. Damage to foliage may occur if high rates are used or under certain conditions such as high temperatures (>32 °C), hot dry winds, drought conditions or when trees are stressed. When applying foliar fertilisers follow all manufacturers' recommendations carefully and keep records of weather conditions at the time of spraying including relative humidity, temperature and wind speed and direction. Foliar fertilisers are normally applied in high volumes of water, at least 2000–3000 L/ha.

When fertilisers are applied to the leaves, uptake into the plant is a two-part process. First the dissolved compound moves into the leaf either through the cuticle (which is the thick waxy layer on both sides of the leaf and which prevents leaves drying out), or through the stomates (which are the pores that open and shut to let carbon dioxide in and water out). The dissolved compounds then move into other cells or tissues. The effectiveness in correcting a deficiency depends on the rate of uptake and mobility of the element in the tree. Macro-nutrients are generally more mobile than micro-nutrients, whose movement in tissues varies greatly (see Table 63) [Weir 1992; Srivastava, Singh & Albrigo 2008; Fageria et al. 2009]. Responses are seen within 3–4 days, but the effects are often only temporary and with severe deficiencies several sprays may be required. In situations with chronic deficiencies (e.g. zinc in Sunraysia/Riverland regions), foliar sprays are a regular management input.

Table 63. Mobility of foliar applied nutrients.

| Mobility | Nutrients |
|---|---|
| Highly mobile | N, K and Na |
| Mobile | P, Cl and S |
| Partially mobile | Zn, Cu, Mn, Fe and Mo |
| Relatively immobile | B, Ca and Mg |

Source: Weir 1992.

A range of factors can affect the performance of foliar fertilisers, including:

- chemical properties of the formulation – molecular size, solubility, pH, electrical charge, surface tension, retention and dispersion
- environmental conditions during spraying – relative humidity, wind conditions, temperature and light
- plant variety and physiology – leaf age, shape and chemistry, cuticle composition, surface wax, and mobility of the nutrient in the plant (Fernandez & Brown 2013).

Some spray materials can alter the pH of the spray solution and some formulations may have extreme pH values which can affect plant uptake or possibly cause phytotoxicity. Although pH alters leaf penetration there is no consistency in plant response, and other factors, such as the nutrient being applied, are equally or more important in leaf penetration (Fernandez & Brown 2013). Work done by Orbovic et al. (2001) on grapefruit showed that the pH of urea spray solutions should be maintained between 7 and 8. Conversely, El-Otmani et al. (2000) recorded the highest uptake of foliar urea by citrus was at a pH of between 5.5 and 6. The solution pH also affects nutrient solubility and interactions with other dissolved compounds in the spray mix. Generally a slightly acidic pH improves the penetration of most nutrients into the leaf.

Light, temperature and humidity can also affect the rate of absorption through effects on droplet size and the drying rate of the spray, leaf developmental processes and stomatal opening. Orbovic et al. (2001) found that most urea penetrated the leaf cuticle of grapefruit within the first 12–24 hours after application and that higher penetration was achieved at

28 °C than at 19 °C. They suggested that for maximum penetration of urea, trees should be sprayed when relative humidity is high and when temperatures are between 25–31 °C. Spray drying times will be longer under higher humidities, enabling a longer uptake period.

To increase the rate of absorption it is recommended that applications be made when leaf stomata are open and during a growth flush because young leaves absorb more readily than older leaves. When the leaves are fully expanded there is a greater surface area from which nutrients can be absorbed. The best time to apply foliar fertilisers is in the early morning or late afternoon, when leaf stomata are open.

Foliar fertilisers need to be water soluble, with low levels of impurities. They are usually applied at low concentrations (especially the macro-nutrients); generally less than a 2%, typically 1–1.2%, to avoid leaf burn. Chemical reactions can occur when certain elements are mixed together causing precipitates to form, clogging nozzles and rendering the nutrients unavailable for absorption into the leaf.

Some nutrients such as urea can stimulate the absorption of other nutrients by increasing permeability of the leaf tissue (Zekri 2014). Urea applied to foliage should have less than 0.25% biuret to avoid leaf burn. Biuret is formed during manufacturing and high amounts can be toxic to plants, whether applied to the soil or foliage. In citrus the tips of leaves are the most sensitive to damage. Plants are unable to metabolize biuret and it interferes with nitrogen metabolism. For example, biuret was still found in orange leaves 8 months after a foliar spray (Impey & Jones 1960) and soil applied biuret similarly accumulates in plants for long periods. A general guide for the safe use of urea applied to the soil is a maximum of 2% biuret, but for foliar sprays the amount is much lower, for citrus, the concentration should not exceed 0.25% (Jones & Embleton 1957). Table 64 outlines some spray treatments for correcting micro-nutrient deficiencies in citrus.

Foliar fertilisation: best practice tips

- ☑ Mostly used to correct micro-nutrient deficiencies.
- ☑ Apply to new growth flushes when leaves have fully expanded.
- ☑ Apply in the early morning or late afternoon when leaf stomata are open.
- ☑ Use good quality, water soluble fertilisers with low levels of impurities.
- ☑ Used in low concentrations e.g. <2%. Use high volumes of water, 2000–3000 L/ha.
- ☑ High humidity decreases drying times, allowing a longer uptake period.
- ☑ Urea can stimulate absorption of other nutrients.
- ! Urea should have <0.25% biuret content.
- ! Young trees are more sensitive to damage than older trees.
- ☒ Do not apply in hot (>32 °C) or windy conditions.
- ☒ Do not apply if rain is forecast within 4 hours.
- ☒ Do not apply to water stressed or waterlogged trees.

Table 64. Treatments for correcting some micro-nutrient deficiencies in citrus.

| Nutrient deficiency | Treatment | Application rate/100L | Comments |
|---|---|---|---|
| Magnesium | Magnesium nitrate | 1 kg | – |
| | Magnesium sulphate (Epsom salt) + calcium nitrate | 1 kg<br>1 kg | Mix magnesium sulphate in ½ full vat then add calcium nitrate separately while agitating, then fill vat. |
| Zinc | Zinc sulphate heptahydrate (23% Zn) | 150 g | – |
| Manganese | Manganese sulphate | 100 g | 500 g of urea is often added to improve uptake of manganese. |
| Manganese + Zinc | Zinc sulphate + Manganese sulphate | 150 g<br>100 g | – |

Source: Weir and Sarooshi 1991.

Nutrition

## Fertiliser calculations

Fertiliser recommendations are usually given in amounts (i.e. grams or kilograms) of the actual nutrient (e.g. nitrogen) per tree or hectare. However, a kilogram of nitrogen is not the same as a kilogram of fertiliser. Fertilisers are not 100% pure and contain different amounts of nutrients. For example, to supply the same amount of nitrogen requires different amounts of urea (46% N) compared to calcium nitrate (15.5% N). See example below. The nutrient analysis of a fertiliser should be marked on the bag or container as a percentage such as N:P:K:Ca. For example, calcium nitrate would be listed as 15.5:0:0:20 which equates to 15.5% nitrogen, 0% phosphorus, 0% potassium and 20% calcium.

For more information including calculating the cost of a nutrient using different fertiliser products, refer to NSW DPI Agnote DPI 496 *'Fertiliser calculations'*.

### Fertiliser calculation example

To calculate out how much fertiliser is required or the amount of nutrient applied, use the following formulae:

$$\textbf{Amount of fertiliser needed} = \frac{\textbf{amount of nutrient (g or kg)/tree or hectare required}}{\textbf{\% of nutrient in fertiliser}} \textbf{ x 100}$$

To apply 100 kg/nitrogen/ha using a single fertiliser such as urea, which contains 46% nitrogen, the calculation would be:

$$\frac{100}{46} \times 100 = 2.17 \times 100 = 217 \text{ kg of urea per hectare}$$

To apply 100 kg nitrogen/ha when using a mixed fertiliser, such as calcium nitrate which contains 15.5% nitrogen and 20% calcium, the calculation would be:

$$\frac{100}{15.5} \times 100 = 6.45 \times 100 = 645 \text{ kg of calcium nitrate/hectare}$$

Because calcium nitrate is a mixed fertiliser, some calcium is also being applied. To calculate how much, use the following formula:

$$\frac{100}{15.5} \times 100 = 6.45 \times 100 = 645 \text{ kg of calcium nitrate/hectare}$$

$$\textbf{Amount of nutrient applied (kg/ha)} = \frac{\textbf{amount of fertiliser (kg/ha) x \% nutrient in fertiliser}}{\textbf{100}}$$

So, if 645 kg of calcium nitrate is applied per ha, the amount of calcium applied is:

$$\frac{645 \times 20}{100} = \frac{12{,}900}{100} = 129 \text{ kg of calcium/hectare}$$

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# Crop management

## Flower biology

Citrus flowers contain both male and female parts (Figure 142). The male part of the flower comprises the anthers that sit on top of a stem or filament. The anthers produce pollen which are the male sex cells (sperm or gametes). The female part of the flower is made up of the stigma and style attached to the ovary, which contains the female sex cells called ovules.

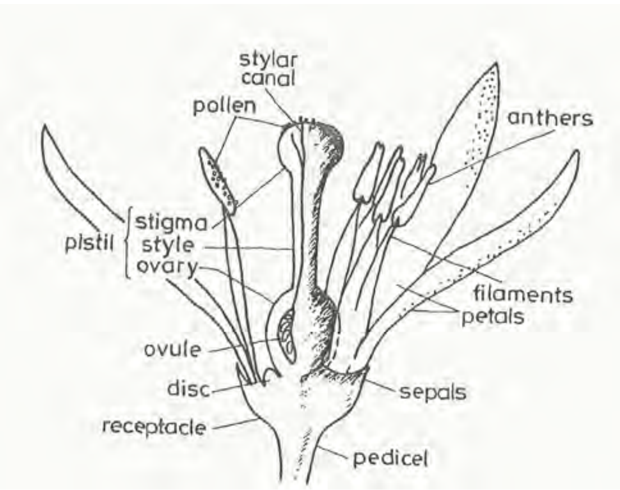


Figure 142. Schematic drawing of an open citrus flower. Source: Spiegel-Roy and Goldschmidt 1996.

Pollination is the successful delivery of pollen to the stigma. Citrus pollen is heavy, sticky and dispersed by insects, predominantly bees. Dispersal by wind is not significant (Sykes 2008b). The pollen grains germinate on the stigma and the pollen tube grows down inside the stylar canal into the ovary. Fertilisation is the successful fusion of the pollen tube with an ovule; the ovules are then said to be fertilised. Fertilised ovules develop into seeds, and the ovary, which contains the fertilised ovules, develops into the fruit.

Temperature is an important factor affecting citrus pollination, fertilisation and seed set. The optimum temperature for pollen germination *in vitro* is 25 °C and the most favourable temperature to accelerate pollen tube growth ranges from 15 to 25 °C (Distefano et al. 2012).

Pollination and fertilisation are essential in most seed bearing plants for the ovary to develop into a fruit. In many commercial citrus cultivars, however, pollination and/or fertilisation are not always necessary for fruit production.

## Understanding seediness

Citrus cultivars vary in their degree of seediness from almost totally seedless to heavily seeded. 'A cultivar is considered seedless if it is able to produce fruit that contain no seeds, aborted seeds or a significantly reduced number of seeds' (Vardi, Levin & Carmi 2008). For mandarins, seedless fruit are now one of the main requirements for the fresh fruit market. In the past decade plant breeders around the world have focussed their research on the development of seedless or low seeded mandarin selections.

Seedless fruit production is a combination of parthenocarpic ability and female and/or male sterility, self-incompatibility, embryo-sac abortion, polyploidy, abnormal climatic conditions or treatment with plant growth regulators, such as gibberellins (GA) [Ye et al. 2009].

### Parthenocarpy

Fruit production in the absence of fertilisation is called parthenocarpy – meaning 'virgin fruit'. Most commercial citrus cultivars exhibit some degree of parthenocarpy and the most successful parthenocarpic cultivars possess an exceptional ability to set fruit without seeds. 'Parthenocarpy is the primary requirement for the production of seedless fruit because in parthenocarpic plants the unfertilised ovary can develop into a normal fruit' (Vardi, Levin & Carmi, 2008).

Parthenocarpy is mostly a genetic trait and is called obligatory or natural parthenocarpy. However, parthenocarpy can sometimes be artificially induced (facultative parthenocarpy) by certain climate and growing conditions not conducive to pollination and fertilisation, the application of a suitable growth regulator such as gibberellic acid (GA), or the application of copper sulphate.

The degree of parthenocarpy varies between cultivars from very strong (e.g. Satsuma mandarins) to very weak (e.g. Murcott tangor) (Talon, Zacarias & Primo-Millo 1992). Parthenocarpy among Clementine mandarin cultivars are highly variable; some cultivars are strongly parthenocarpic (e.g. Marisol) and others are weak (e.g. Nules/Clemenules) (Mesejo et al. 2012). Strongly parthenocarpic cultivars can usually set commercial yields of fruit without cross- or self-fertilisation, whereas weakly parthenocarpic varieties may have problems setting good yields of fruit if they are not pollinated.

A few citrus varieties are not parthenocarpic at all (e.g. the American grown tangelo, Osceola). In these varieties the ovule or ovules must be fertilised in order for the ovary to develop into a fruit. Non-parthenocarpic varieties will always be seedy.

### *Obligatory or natural parthenocarpy*

Obligatory parthenocarpy can be either autonomic or stimulative (Figure 143). The more common autonomic parthenocarpy involves the development and growth of fruit without any stimulus (such as pollination or fertilisation of the ovules). The other type, stimulative parthenocarpy, requires an external stimulus (e.g. pollination, pollen germination or pollen tube growth) to trigger fruit set, but does not result in ovule fertilisation and seed development.

### *Facultative parthenocarpy*

Conditions such as very low or high temperatures or low humidity can reduce pollen viability, pollen germination and the growth of the pollen tube, which can sometimes result in parthenocarpic seedless fruit.

For example, in southern Australia in 2016 there were fewer seeds in low-seeded mandarin varieties compared to the 2015 season. Temperatures during flowering were higher in 2015, compared to temperatures during flowering in 2014. The higher temperatures during flowering in October 2015 possibly reduced pollen germination and/or pollen tube growth, resulting in lower seed numbers in fruit at harvest in 2016 (G Sanderson 2016, pers. comm.). Imperial mandarins grown at Merbein (north western Victoria) have shown a strong parthenocarpic tendency which has not been as evident when grown in Queensland (M Smith 2016, pers. comm.). Some cultivars, such as Nova tangelo and Fino Clementine, reported as weakly parthenocarpic in some countries, readily set seedless fruit in Spain (Guardiola 1997). Bermejo et al. (2012) found that in Spain low temperatures during flower formation decreased pollen germination and seed number in Murcott tangor.

The application of GA during flowering also impaires fertilisation and induces facultative parthenocarpy in Clemintine mandarins under cross-pollination conditions (Mesejo et al. 2008 and 2013).

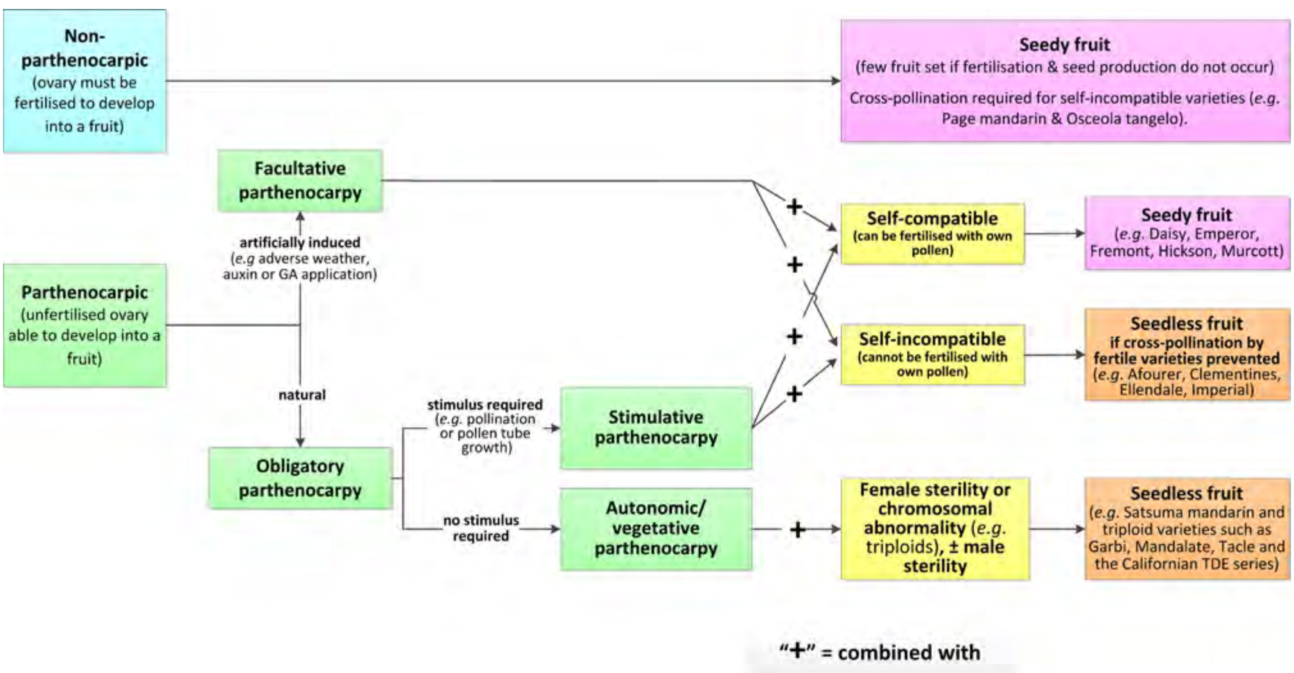


Figure 143. Schematic diagram outlining the role of parthenocarpy and flower fertility in seediness of citrus.

In Uruguay the application of GA to Afourer mandarin tress during flowering reduced the percentage of seeded fruits and seed number per fruit under open-pollination conditions (Gambetta et al. 2013). In Spain and Uruguay the application of copper sulphate at flowering has also been shown to reduce seed numbers in Afourer mandarin under cross-pollination conditions (Mesejo et al. 2006, Gambetta et al. 2013).

For more information on the use of GA and copper for this purpose, refer to the section on reducing seediness in self-incompatible varieties.

## Flower fertility

The combination of parthenocarpy and flower fertility determines the seediness of fruit (Figure 143). Strong sterility coupled with parthenocarpy is essential for the consistent production of seedless fruit. Most commercial citrus cultivars have some form of flower sterility. Sterility can be divided into three main types: female, male, and self-incompatibility (unable to be pollinated by their own pollen). In a few cultivars (e.g. Tahiti lime, Tacle and Yosemite Gold mandarins) sterility is a result of a chromosomal abnormality (see Triploidy). Table 65 summarises the fertility of selected citrus cultivars.

### *Female sterility*

Female sterility is directly related to seediness, since the ovules are incapable of being fertilised. In some cases fruit will have occasional seeds as a result of incomplete female sterility (e.g. Washington navels). Washington navel oranges and Satsuma mandarins, being both strongly parthenocarpic and female sterile, are able to produce commercial yields of fruit that are always seedless regardless of where they are grown. In addition, these cultivars are pollen sterile and cannot cross-pollinate other varieties. They can be planted alongside self-incompatible varieties, such as Afourer mandarin, to ensure seedless fruit.

### *Male-sterility or self-incompatibility*

Cultivars with male sterility or self-incompatibility produce seedless fruit only when cross-pollination with pollen from other fertile varieties is prevented (see Table 65). Examples include cultivars such as Afourer (also known as W. Murcott or Nadorcott), most Clementines, Fremont, Imperial and Page mandarins and Minneola, Nova and Orlando tangelos. For these varieties, strong parthenocarpy combined with a lack of cross-pollination will result in seedless fruit. However, some self-incompatible varieties (e.g. Nova tangelo, Nules Clementine) with low or weak parthenocarpy may be unable to produce commercial yields of seedless fruit if cross-pollination is prevented.

### *Triploidy*

Flower fertility is a very complex process involving many genes, and disruption of any of these genes may help to reduce fertility and hence seed number. Sometimes seedless selections can result from bud mutations, (e.g. Tahiti lime) or as a result of conventional breeding programs (e.g. Nectar mandarin).

The creation of triploid hybrids is a breeding strategy used to produce seedless varieties. Triploidy is a type of polyploidy. Polyploidy means cells contain more than two sets of chromosomes. Polyploidy occurs naturally in citrus and other plants through spontaneous mutations. Triploids have three sets of chromosomes and, during cell division when the chromosomes replicate themselves, they cannot pair up evenly.

Triploid plants are sterile and can only be propagated vegetatively by cuttings or grafting. Triploids can be pollinated and bear fruit, but will not be fertilised and will not have seeds (or have very few seeds). Triploids are not affected by cross-pollination or other environmental factors (Recupero, Russo & Recupero 2005). Examples of seedless triploid mandarins include the Spanish-bred Garbi and Safor, the Italian-bred Clara, Mandalate, Tacle and the Californian-bred TDE series, Shasta Gold (TDE 2), Tahoe Gold (TDE 3) and Yosemite Gold (TDE 4).

### *Gamma irradiation*

Most recent seedless cultivars have been developed by using gamma irradiation. Budwood of selected cultivars are exposed to gamma irradiation and then propagated and multiplied to assess seediness and its stability. Gamma irradiation not only affects seed formation in the fruit, but can sometimes affect fruit quality and nutritional components (Bermejo, Pardo & Cano 2012). Examples of cultivars that have been successfully irradiated to produce low seeded selections include Daisy (Figure 144), Fremont and Tango (a low seeded selection of W. Murcott/ Afourer) mandarins. IrM1, IrM2 (Figure 145), Mor and Phoenix are all low seeded selections of irradiated Murcott tangor.

Figure 144. Normal Daisy mandarin (left) compared to irradiated low seeded selection of Daisy (right).


Figure 145. Low seeded selections of Murcott tangor (IrM1 and IrM2) alongside a normal seedy Murcott tangor.

## Pollination capability of citrus cultivars

Based on pollination capability, citrus cultivars can be divided into three main groups (see Table 65):

**1** ***Varieties with non-functional pollen (male sex cells) and/or ovules (female sex cells); or triploids.***

These varieties will always have little or no seed – no matter where they are planted or if they are cross-pollinated by other fertile varieties. Examples include Satsuma, Mandalate, Tacle, Shasta Gold, Tahoe Gold and Yosemite Gold mandarins, Tahiti lime and Washington navel orange.

**2** ***Varieties that have functional pollen and ovules and are able to self-pollinate or be cross-pollinated by other fertile varieties.***

These varieties rely on pollination for fruit set – and will always have seeds. Examples include Daisy and Hickson mandarins and Ellendale and Murcott tangors. Some low-seeded selections of these seedy varieties, have been developed using gamma irradiation.

**3** ***Varieties that have functional pollen and ovules, but are self-incompatible (cannot pollinate themselves), although can be pollinated by other fertile varieties.***

Self-incompatibility is often due to sterility prior to fertilisation, failure of the pollen to germinate or slow growth of the pollen tube due to inhibitors in the style. If these varieties are grown in isolation, protected from pollination with netting, or grown near varieties without viable pollen, they will be seedless. If they are grown near other citrus varieties that produce viable pollen, then cross-pollination can occur and fruit will be seedy. Varieties in this group include most Clementines, Afourer (W. Murcott/Nadorcott), Fremont and Imperial mandarins, Ellendale tangor and Minneola tangelo.

There are some varieties in this group with low or weak parthenocarpy may fail to set commercial yields of fruit if cross-pollination is prevented. However, there are some techniques used overseas to improve fruit set and reduce seed numbers in some of these varieties under open-pollination conditions. Refer to the sections on reducing seediness in self-incompatible varieties and manipulating fruit set.

## Reducing seediness

### Preventing cross-pollination

Self-incompatible parthenocarpic varieties can set seedless fruit if they are grown in isolation or are protected from cross-pollination by other fertile varieties. Bees must be prevented from visiting flowers. Be aware that some varieties will fail to set commercial yields of fruit if they are prevented from being cross-pollinated (e.g. Nules/Clemenules Clementine mandarins and Minneola, Nova and Orlando tangelos).

The main techniques used to prevent cross-pollination are:

#### *Physical isolation*

The design and location of orchard plantings can be used to reduce cross-pollination in potentially seedless varieties, such as Afourer mandarin. This involves planting trees far enough away from other fertile citrus varieties to reduce the likelihood of bees carrying pollen between plantings. The trees can be isolated by open space or the use of buffer rows containing pollen sterile varieties, such as Washington navel oranges or Satsuma mandarins. The use of buffer rows is intended to limit the movement of bees and dispersal of pollen – but exactly how many buffer trees or the distance needed is difficult to determine. Travel distances by bees can depend on local site conditions, bee populations and the availability of other pollen sources attractive to bees.

A range of distances has been suggested. Sykes (2001) showed that a distance of 400–800 m was not enough to prevent pollination of Fina Clementine mandarins from nearby Valencia oranges. Other observations conducted in a Nules Clementine mandarin orchard in South Australia by Sykes (2001) showed that a physical barrier may be enough to impede bee flight and prevent cross-pollination. A block of Nules Clementine mandarins produced seedless fruit when separated from Lisbon lemons by 170 m of high-trellised grapevines.

Studies at two sites in California by Chao, Fang and Devanand (2005) found that Nules Clementine and Afourer mandarin pollen could be carried up to 520 and 960 m respectively, by bees across many buffer rows of navel oranges. This study highlighted the difficulty in actually isolating such cultivars under commercial orchard conditions and the conclusion reached was that a distance of at least several kilometres was needed to avoid cross-pollination by bees.

#### *Netting*

Temporary retractable bee-proof nets are used to protect selected mandarin varieties such as Afourer (W. Murcott/Nadorcott) from pollination (Figure 146). The nets are placed over trees for about 4–6 weeks during flowering. Afourer mandarins under open-pollination conditions had a lower percentage of seedless fruit (7–34%), compared to 98–99% of fruit being seedless under bee-proof nets (Gambetta et al. 2013).

Figure 146. Netted citrus trees. Source: http://www.smart-net-systems.com/agricultural-nets.

Retractable netting is being trialled on an orchard near Mildura. The netting lasts about ten years and currently costs between $11,000 and $14,000/ha, depending on net type. The netting is applied with a boom attachment (cost approximately $13,000) that runs over the tree row and soil is used to keep the net in place. A team of seven can cover 7–10 ha of trees/day. Net retrieval is slightly faster (Citrus Australia 2014, Sampson 2014).

#### *GA application at flowering*

Overseas research showed that applying GA during flowering reduced seed numbers and the percentage of seeded fruit in some self-incompatible varieties in open-pollination conditions. GA is also used routinely during flowering to improve fruit set in some Clementine mandarins in Morocco, Spain, South Africa and South America.

In Spain, applying 5–10 mg GA/L to Nules Clementines during flowering impaired fertilisation by either enhancing ovule abortion or reducing pollen tube growth in flowers under cross-pollination conditions. This induced facultative parthenocarpy and reduced seed numbers in fruit (Mesejo et al. 2012). Three applications of 50 mg GA/L combined with copper sulphate (25 mg/L) during flowering to Afourer mandarins in open-pollination conditions in Uruguay increased seedless fruit from 19% to 31% and reduced seed numbers per fruit from 3.7 to 2.3 (Gambetta et al. 2013).

***Note: GA is not registered for this purpose in Australia.***

Table 65. Fertility and seediness of selected citrus cultivars.

| Citrus type | Group number* | Cultivar | Amount of functional pollen | Self-incompatibility | Level of parthenocarpy | Potential to pollinate other citrus varieties | Low seeded if planted with other citrus cultivars producing viable pollen | Low seeded or seedless if cross-pollination is prevented by isolation |
|---|---|---|---|---|---|---|---|---|
| **Grapefruit** | 1 | Seedless e.g. Marsh, Oroblanco, Ruby Red, Star Ruby, Thompson | Low | No | Moderately high | Moderate | Yes | Yes |
| | 2 | Seedy e.g. Duncan, Wheeny | High | No | Low | High | No | No |
| **Lemons** | 2 | Eureka, Fino, Lisbon, Meyer, Verna | Moderate | No | Moderately high | Moderate | No | No |
| | 1 | Seedless Eureka | Low | No | Moderately high | Low | Yes | Yes |
| **Limes** | 2 | Mexican (syn. West Indian or Key) | Moderate | No | Moderately high | Moderate | No | No |
| | 1 | Tahiti (syn. Bearss) | None | No | Very high | Zero | Yes | Yes |
| **Mandarins and mandarin hybrids** | 3 | Afourer/W. Murcott/ Nadorcott | High | Yes | Very high | High | No | Yes |
| | 3 | Clementines | Variable depending on cultivar | Yes | Generally low, but variable depending on cultivar | High | No | Yes |
| | 2 | Daisy | High | No | Moderately high | High | No | No |
| | 1 | Daisy – low seeded selection | Low | No | Moderately high | Low | Yes | Yes |
| | 2 | Dancy | High | No | Low | High | No | No |
| | 2 | Ellendale | High | No | Moderately high | High | No | No |
| | 3 | Fairchild | High | Yes | Moderately high | High | No | Yes |
| | 3 | Fremont | High | Yes | High | High | No | Yes |
| | 1 | Fremont – low seeded selection | Low | Yes | High | Low | Yes | Yes |
| | 2 | Hickson | High | No | Moderately low | High | No | No |
| | 3 | Imperial | High | Yes | Moderately high | Moderate | No | Yes |
| | *1 Seedless | | | 2 Always seedy | | 3 Seedless if cross-pollination prevented | | |

| Citrus type | Group number* | Cultivar | Amount of functional pollen | Self-incompatibility | Level of parthenocarpy | Potential to pollinate other citrus varieties | Low seeded if planted with other citrus cultivars producing viable pollen | Low seeded or seedless if cross-pollination is prevented by isolation |
|---|---|---|---|---|---|---|---|---|
| **Mandarins and mandarin hybrids** | 1 | IrM1 and IrM2, Mor and Phoenix (low seeded Murcott tangor selections) | Low | No | Low | Low | Yes | Yes |
| | 2 | Kara | Low | No | High | Moderate | No | No |
| | 2 | Kinnow | High | No | Low | High | No | No |
| | 3 | Minneola and Orlando tangelo | High | Yes | Moderate | High | No | Yes |
| | 2 | Murcott/ Honey Murcott | High | No | Low | High | No | No |
| | 1 | Nectar | Low | No | Moderate | Low | Yes | Yes |
| | 3 | Nova tangelo | High | Yes | Low | High | No | Yes |
| | 3 | Page | High | Yes | Moderately high | High | No | Yes |
| | 1 | Satsumas | None | No | Moderately high | Very low | Yes | Yes |
| | 1 | Tango (low seeded selection of W. Murcott/ Afourer) | Very low | Yes | Very high | Low | Yes | Yes |
| | 1 | Triploids hybrids e.g. Clara, Garbi, Mandalate, Safor, Tacle and the TDE series Shasta Gold, Tahoe Gold and Yosemite Gold | Low | No | Very high | Very low | Yes | Yes |
| | 2 | Wilking | High | No | Very low | High | No | No |
| **Oranges** | 1 | Navels | None | No | Very high | Very low | Yes | Yes |
| | 2 | Valencia | Low | No | Moderate | Moderate | No | No |
| | 1 | Valencia – Midknight | Low | No | High | Low | Yes | Yes |
| | 2 | Tarocco | Low | No | High | Low | No | No |
| **Pummelos** | 3 | All | High | Yes | Erratic | High | No | Yes |
| | *1 Seedless | | | 2 Always seedy | | 3 Seedless if cross-pollination prevented | | |

Source: Adapted from Kahn 1998 and Kahn and Chao 2004.

### *Copper application at flowering*

The application of copper sulphate at flowering has also been shown to reduce seed numbers in Afourer mandarins in Spain, under cross-pollination conditions (Mesejo et al. 2006). Applying 25 mg/L of copper sulphate to Afourer mandarin trees when approximately 60% of the flowers were open significantly reduced average seed numbers per fruit by 55–81% and increased the percentage of seedless fruit, without any reduction in fruit yield. The copper is thought to affect pollen germination and/or pollen tube growth. In contrast, Gambetta et al. (2013) reported that an application of copper sulphate to Afourer mandarin trees under open-pollination conditions in Uruguay failed to decrease the percentage of seeded fruit and seed number per fruit.

## Factors affecting development stages

Flowering (anthesis) and fruit set are influenced by a range of external (exogenous) and internal (endogenous) factors. Citrus flowers are mostly produced on one year old wood, predominately on the previous seasons' spring and summer shoots that did not bear fruit. In cooler growing areas, including parts of the subtropics, flowering is triggered by cold temperatures. The trigger for flowering in tropical areas is a period of water stress. The key phenological stages and their timings are outlined in Table 66 For more information on the annual growth cycle of citrus refer to the Climate and Phenology chapter.

The most important external factor affecting fruit set is temperature, but stress caused by drought, waterlogging and salinity are also important. Fruit set occurs over a very wide temperature range. For varieties that require pollination, temperature also affects the growth rate of the pollen tube. Plant stress causes elevated levels of the natural plant hormone abscisic acid (ABA), triggering ethylene production which causes fruit and leaf drop. High temperatures and water stress can be particularly detrimental during fruit set, leading to a massive drop of fruitlets (Monselise 1986).

There is a strong demand for water and nutrients during the flowering and fruit set periods. Low soil temperatures in spring can reduce nutrient and water uptake. Therefore, it is critical that trees are well supplied with water and nutrients leading into this stage to reduce competition between the fruitlets and the spring leaf flush.

Internal factors regulating flowering and fruit set are a complex mix of genetic, metabolic and molecular processes. Auxin levels (especially gibberellins) and carbohydrate availability are very important in controlling fruit set.

Table 66. Key phenological stages of mandarins, outlining timing for Queensland and southern Australia.

| Development stage | Approximate timing for mandarins | |
|---|---|---|
| | **Gayndah/ Mundubbera Queensland** | **Sunraysia, southern NSW and Victoria** |
| Bud break | Late July to August | August |
| Pre-bloom | August | September |
| Full bloom | Late August to September | October |
| End of petal fall | September to early October | Late October to early November |
| Stage I fruit growth – cell division | October to early December | November to December |
| Stage II fruit growth – cell expansion | Mid December to March | Late January to April |
| Colour break | Late March to May | Mid-April to June |
| Stage III fruit growth – maturation | April to August | June to late August |
| Harvest | April to August | June to late September |

Other important factors are the number of flowers on the tree and the type of inflorescence (Figure 147) on which flowers are borne. Flowers on leafless inflorescences are less likely to set a fruit than flowers on leafy inflorescences. The number of flowers produced depends on cultivar, tree age and environmental conditions (Monselise 1986).

Citrus trees flower profusely, but the majority of flowers abscise (i.e. drop off) and the proportion that fall is partly dependent on the number of flowers produced. The percentage of fruit set is inversely related to flower number, and large numbers of flowers result in a lower proportion setting fruit compared with those trees with a low number of flowers. Final fruit set ranges between 0.1 and 10% of total flower number (Guardiola 1997, Guardiola & Garcia-Luis 2000).

The majority of flower or fruit drop occurs during two periods, both of which coincide with increased fruit growth rates. The first abscission period occurs at flowering or soon after, with a massive drop of flowers. At this time levels of gibberellins in the ovaries are a significant controlling factor. The second drop is about 6–8 weeks later, at the end of cell division (Stage I fruit growth). This second drop is referred to as physiological or December drop (or June drop in the northern hemisphere) and accompanies an increase in fruit growth. At this time the survival of fruitlets is largely determined by the tree's capacity to supply metabolites, especially carbohydrates (Guardiola 1988).


Figure 147. Shoot type categories where:
A: vegetative shoot (all leaves, no flowers)
B: single terminal flower
C: more leaves than flowers
D: more flowers than leaves
E: leafless inflorescence (all flowers, no leaves).

## Temperature

Floral bud induction is strongly correlated with the number of hours of low temperatures. As the hours of low temperature accumulate, bud differentiation in spring shoots shifts from predominantly vegetative (no flowers) to leafy inflorescences (leaves and flowers), and then to leafless inflorescences (also known as white blossom; Figure 147.

Temperature also affects the date and intensity of flowering. High temperatures during bud initiation and differentiation shorten development time and advance flowering, while cool conditions lengthen the development time (Albrigo 2004). Low to moderate temperatures (<20 °C) usually result in a more protracted bloom period, whereas higher temperatures shorten the flowering period.

## Presence of fruit

Citrus bud differentiation starts during winter and buds can be either floral or vegetative. The presence of fruit has a strong negative effect on the sprouting of both vegetative and generative buds in spring, but depends on fruit number and harvest date. The presence of fruit has also been found to suppress key flowering genes during the floral bud induction period (Munoz-Fambuena et al. 2011). Floral intensity is inversely proportional to the number of fruit produced in the previous season and shoots carrying fruit seldom produce flowers (Moss 1973; Verreynne & Lovatt 2009).

Studies on Pixie mandarin in California have shown that fruit inhibit bud break at two key stages in the phenological cycle (Verreynne & Lovatt 2009). Firstly, young growing fruit inhibit bud break during summer and autumn, thereby reducing the number of shoots that develop and the number of nodes in which floral buds can be produced in the following winter. Secondly, mature fruits inhibit spring bud break and the development of floral shoots, reducing the potential number of flowers that can set a fruit.

## Inflorescence type

The type of inflorescence (Figure 147) also affects fruit set and fruit size. Leafy inflorescences have a better chance of setting fruit than leafless inflorescences and final fruit size will be larger. The size of the ovary at flowering is inversely related to flower number. Fruit growth is more rapid and final fruit size greater when the ovaries are larger. It is thought that leafy inflorescences are better able to supply carbohydrates and hormones (especially gibberellins) to developing fruitlets and those fruitlets are better supplied with water and mineral elements.

An exogenous application of GA (e.g. Ralex®) to some citrus varieties during the bud differentiation period in winter has been shown to reduce floral bud formation and increase the proportion of terminal flowers in leafy inflorescences, thereby improving fruit set.

## Plant growth regulators

Various natural plant growth regulators – especially gibberellins and auxins – are involved in the processes that follow pollination and fertilisation, and are pre-requisites for fruit set. Gibberellins are particularly important in fruit set and fruit growth. Fertilisation in seeded varieties stimulates gibberellin synthesis in the ovule, promoting cell division and causing fruit set (Mesejo et al. 2016). The rise in gibberellin levels activates cell division and expansion, resulting in fruit growth. Gibberellins also stimulate the transfer of carbohydrates to the developing fruit (Mesejo et al. 2013, Bermejo et al. 2015). In seeded varieties, the number of fruit, the size of fruit and final yield are to some degree controlled by the number of seeds per fruit as well as carbohydrate, water and mineral element supply and the external environmental factors described earlier.

Low levels of gibberellins are associated with a rise in abscisic acid (ABA) (Mesejo et al. 2013) and production of ethylene. Both of these are triggers for ovary and fruitlet abscission. The relative balance between growth-promoting gibberellins and the growth inhibiting effect of ABA play an important role in the regulation of fruit development in seedless mandarins (Vardi, Levin & Carmi 2008).

In seedless, strongly parthenocarpic varieties (e.g. Satsuma mandarin), increased levels of gibberellins found in the ovary or ovule during flowering trigger fruit development (Vardi, Levin & Carmi 2008, Bermejo et al. 2015). This contrasts with some self-incompatible varieties with low to moderate parthenocarpy in which gibberellin levels are not enhanced (e.g. Nules Clementine). For example, self-incompatible Marisol Clementine mandarins can set large numbers of seedless fruit and research has shown that this variety has higher levels of gibberellins in the ovary compared with Nules Clementine. Marisol also has greater carbohydrate mobilisation in the days following flowering which paralleled higher gibberellin levels (Mesejo et al. 2013).

In the absence of cross-pollination Nules Clementines show a low ability to set fruit (Bermejo et al. 2015). However, an exogenous supply of GA during flowering induces facultative parthenocarpy by enhancing ovule abortion or reducing pollen tube growth and improving fruit set (Mesejo et al. 2013, 2016). The application of GA replaces the need for pollination, which normally enhances gibberellin levels and so flowers are able to set seedless fruit even when they are not cross-pollinated.

### Carbohydrates

Whilst the initial drop of flowers is dominated by hormonal interactions, 'physiological or December' fruit drop is largely governed by metabolic factors, especially carbohydrate availability (Iglesias et al. 2003).

Carbohydrate reserves are relatively high at flowering, but decline quickly in the ovary as a result of rapid cell division associated with early fruit growth (Mesejo et al. 2013). During cell division fruit have a high demand for carbohydrates and rely mostly on stored reserves because the tree's capacity to synthesize carbohydrates at this time is insufficient to meet the fruits' requirements (Bustan & Goldschmidt 1998; García-Luis et al. 1988). By the end of cell division (Stage I of fruit development) carbohydrate levels are at their lowest during the natural fruit drop period. At this time there is a strong inverse relationship between carbohydrate availability and fruitlet abscission levels (Gomez-Cadenas et al. 2000). There is a high probability of abscission below a certain threshold carbohydrate content (Iglesias et al. 2003). Carbohydrate shortages trigger a hormonal sequence that triggers fruitlet abscission, increased ABA levels, followed by ethylene release.

An enhancement of carbohydrate availability during cell division is associated with an improvement in final fruit size and whole tree yield. Fruit largely become storage sinks for carbohydrates during the transition to Stage II (cell enlargement) and auxins play a key role during this stage.

### Nutrients

Tree nutrient status, particularly nitrogen (N), is also linked to flower bud differentiation. There is an increase in leaf ammonium content in buds and leaves prior to flowering. Trees need adequate nitrogen supply and nitrogen reserves to ensure that leaves and buds have adequate, but not excessive, levels in their cells. If tree reserves are not sufficient and root growth and the uptake and transfer of nitrogen and other mineral elements to the scion is limited by low soil temperatures (<18 °C) in late winter/early spring (Monselise 1947), floral bud initiation and differentiation may be adversely affected. Phosphorous (P) and potassium (K) also have a significant role in fruit set, fruit size and maturation (El-Otmani et al. 2000).

During late winter and early spring when soil temperatures are low (impeding nutrient uptake from the soil), foliar applied phloem-mobile nutrients such as ammonium and potassium from low-biuret urea and potassium phosphite respectively, are able to be translocated to all plant parts, providing the tree with a ready supply of nitrogen or potassium respectively.

For example a winter pre-bloom foliar application of low-biuret urea has been shown to increase flower numbers and total yield/tree in Valencia oranges and Washington navels (Ali & Lovatt 1994; Albrigo 1999). A single, 1% winter pre-bloom foliar application of low-biuret urea to alternate bearing Nules Clementine mandarins increased the two year cumulative yield of commercially sized fruit (Lovatt 2013). A single foliar application of potassium phosphite to Nour Clementine mandarins in Morocco at the early green flower bud stage increased fruit set (El-Otmani et al. 2000). Three foliar applications of potassium nitrate applied in winter, post bloom and mid-summer increased fruit size in Sunburst tangerines grown in Florida (Boman 2002).

## Manipulating fruit set

There are a number of techniques used to either reduce flower numbers in an expected heavy crop year or increase fruit set in weakly parthenocarpic varieties that have problems with setting fruit if fertilisation and seed production do not occur. These include:

## GA application before budbreak to reduce flower numbers

The application of GA (e.g. Ralex® – the only product registered in Australia for this purpose) at the flower bud initiation stage reduces flowering intensity (Martinez-Fuentes et al. 2004). GA works by modifying bud differentiation, promoting the development of more vegetative shoots and leafy inflorescences and reducing the number of leafless inflorescences. Leafy inflorescences have higher fruit set than leafless inflorescences. There are two periods in which GA can have an effect on flower bud formation; one at the bud initiation stage in early winter (usually mid- June to mid- July) and the second at bud swell (July). Research has shown that it is easier to manipulate the first sensitivity peak at the bud initiation stage.

In Australia the use of Ralex® for flower suppression is more commonly used on navel oranges because more research has been undertaken on how to use it for that purpose (Khurshid 2006). However, some unpublished research conducted in Queensland testing the effect of 200 mL Ralex®/100 L applied in the June/July period on Imperial mandarins and Murcott tangors found a 60–70% reduction in flower numbers when compared to unsprayed trees (T Khurshid 2016, pers. comm.).

The timing of application is critical and for mandarins the best time is about 4 to 6 weeks before bud break. In southern Australian regions (i.e. Riverland and Sunraysia) the approximate timing is July and slightly later for the Riverina (mid-July to early August). Exact timing of application is dependent on variety and region and it is recommended that the chemical manufacturer be consulted for the latest information on timings. Responses may vary and can be dependent on variety, application rate, timing and temperature.

## GA application at flowering to enhance fruit set in varieties with low natural parthenocarpy

Overseas research has demonstrated that GA applied during or shortly after flowering enhanced fruit set and yield in some seedless and self-incompatible mandarin varieties with low natural parthenocarpy, such as some Clementine mandarins (especially Nules), and Minneola, Nova and Orlando tangelos. However, results may be variable and fruit size may be small (in the absence of seeds), particularly if crop loads are heavy (Jackson & Futch 1997).

In Spain and South Africa a low concentration of GA (5–10 mg GA/L) is routinely applied to Clementine mandarins during flowering to improve fruit set. Mesejo et al. (2008, 2013) demonstrated that under cross-pollination conditions the application of 5–10 mg GA/L at flowering impaired fertilisation by either enhancing ovule abortion or reducing pollen tube growth in Nules Clementine mandarin. The intensity of response depended on the physiological stage of the flower at the time of application. The GA treatment increased fruit set by maintaining cell division in the developing fruitlets. A higher rate of GA (10–20 mg/L) is used in Morocco, where temperatures are higher during fruit set (Chao & Lovatt 2006).

However, work in California (Chao et al. 2011) on alternate bearing Nules Clementine has shown that the effect of GA applied at flowering on fruit set and final fruit size is modulated by the previous season's crop load. Multiple GA applications in a light 'off-crop' year increased fruit number, fruit weight and size, but application in a heavy 'on-crop' year did not increase yield or fruit size and some treatments had a negative impact. Crop load should be considered when determining whether to use GA to manage flower numbers for next season's crop. There is probably no benefit in applying it in an 'on-crop' year.

Chao and Lovatt (2006) also demonstrated that high rates of GA during flowering can have a negative effect on yield and fruit size distribution of Nules Clementine mandarins in California, which has warmer temperatures during the fruit set period compared to growing regions in Spain and South Africa. The total rate of GA applied per season was positively correlated with the yield of small fruit sizes and negatively correlated with the yield of larger fruit sizes. The reduction in the number of larger more valuable fruit sizes negatively affected grower returns.

There is currently no registration for the application of GA at flowering in Australia.

## Cross-pollination to enhance fruit set in self-incompatible or weakly parthenocarpic varieties

Cross pollination can improve fruit set in some varieties, but the fruit will be seedy.

Imperial mandarins are self-incompatible, and have poor fruit set if they are not cross-pollinated. Suitable pollen source varieties include Murcott and Ellendale tangors. Wallace et al. (2002) determined that for Imperial mandarins under Queensland conditions, one polliniser row should be planted every sixth row, so that each row is no more than three rows from a pollen source.

The genotype of the pollen may also have a strong influence on the number of fruit set, seed number and fruit size (Wallace, King & Lee 2002). Pollinizer varieties need to be carefully selected as some combinations result in very high seed numbers. For example, Mesejo et al. (2015) demonstrated that Nadorcott mandarin had fewer seeds when pollinated by Valencia late or Salustiana oranges, but more seeds resulted when flowers were pollinated by Nova tangelo, Ortanique or Fortune mandarin pollen. Nova tangelo is virtually seedless when pollinated by Salustiana orange, has more seeds when pollinated by Fortune mandarin and high numbers of seeds when pollinated by Afourer or Ortanique mandarins.

Varieties such as Minneola, Nova and Orlando tangelos benefit from cross-pollination with suitable pollen source varieties. Pollen source varieties need to be compatible, have an overlapping bloom period and produce consistently good crops of flowers. In the US recommended pollen source varieties for Minneola tangelo are Sunburst and Temple mandarins; Nova, Lee and Temple are suggested for Orlando tangelo and Orlando tangelo and Temple mandarin are suitable for Nova tangelo (Jackson & Futch 1997).

### Girdling or ringing to enhance fruit set

Girdling is the removal of a complete ring of bark from a branch using a sharp hooked-blade. Ringing is a single cut (about 1 mm in width) around the circumference of the branch without removing the bark (Agusti, Martinez-Feuntes & Mesejo 2002). This  can be done using a ringing tool (Figure 148 and Figure 149).

Both techniques result in the accumulation of carbohydrates in the tree organs above the girdling point due to the interruption of the downward transport of carbohydrates (Wallerstein, Goren & Monselise 1974). However, Li et al. (2003) showed that the carbohydrate accumulation effect only occurred during an 'off-year' when there was an excess of carbohydrates. Girdling also causes a decrease in the concentration of soluble sugars and starch in the organs below the girdle and trees can suffer serious root starvation (Li, Weiss & Goldschmidt 2003).

Depending on timing, the increased availability of carbohydrates to the flowers and fruitlets above the girdling point improves fruit set or fruit size. Rivas et al. (2006) found that the best time to girdle Fortune mandarins in Spain to increase final fruit set was either 15 days before flowering or 35 days after flowering. Rivas et al. (2007) showed that trunk girdling two mandarin varieties during flowering only increased final fruit set on leafy inflorescences. Girdling after physiological fruit drop at the onset of cell expansion (Stage II fruit growth) can also be used to increase fruit size, fruit colour and TSS levels (Peng & Rabe 1996). However, the use of girdling is usually not economically feasible for large commercial plantings in Australia.

Figure 148. Ringing tool.

Figure 149. Or mandarin tree showing ringing position. Ringing is undertaken at late petal fall (October) to improve fruit set.

## Crop load

Potential crop load is determined long before trees flower. Predicting how many flowers will set fruit and controlling crop load is not an exact science. The overall objective is to have trees producing a crop of good sized fruit every year and reduce the likelihood of an uneven cropping pattern developing (see Alternate bearing section). Less than 1000 fruit per tree are generally recommended for mandarin varieties in Israel to achieve marketable fruit size (Erner et al. 2004). Research in Australia by Bevington and Khurshid (2002) suggested that thinning should be carried out on Imperial mandarins if fruit counts are more than 8–10 fruit/frame (southern Australian growing regions) or 10–15 fruit/frame in Queensland (see the section on Measuring crop load).

## Alternate bearing

Many citrus cultivars, especially mandarins and their hybrids, have a strong tendency towards alternate bearing (also known as biennial or uneven bearing), producing a heavy crop ('on-crop') one year, followed by a lighter crop ('off-crop') the following year and so on. Crop load is the main cause of the alternate bearing behaviour of many mandarin varieties (Iglesias et al. 2007). Alternate bearing occurs more frequently on individual blocks, individual trees within a block or individual branches within a tree and its severity varies over time and among varieties (Wheaton 1997).

Alternate bearing is thought to be initially triggered by unfavourable weather, such as temperature extremes, frost or some form of stress (e.g. drought, waterlogging, salinity) that reduces flowering and/or fruit set, resulting in a light crop. A light crop leaves the tree with large carbohydrate reserves that can support a heavy crop the following season. Similarly, a heavy crop depletes the carbohydrate reserves in the tree which is then unable to support a big crop the following year. In some cases carbohydrate depletion is so severe it can cause tree death. (See Murcott collapse or mandarin scald in the chapter on Disorders).

The accumulation of carbohydrate reserves is a high priority for citrus trees and believed to be a survival strategy (Goldschmidt & Koch 1996). Once initiated, alternate bearing becomes entrenched through the effect of crop load and its impact on carbohydrate reserves. Tree nutrient status (especially nitrogen) and plant hormones also play roles not clearly understood. Delayed harvesting can also have a significant negative effect on next season's crop.

The incidence of alternate bearing in research trials is often assessed using an index by Pearce and Dobersek-Urbanc (1967) known as the alternate bearing index (ABI):

$$ABI = \frac{(\text{Year 2 yield}) - (\text{Year 1 yield})}{(\text{Year 1 yield}) + (\text{Year 2 yield})}$$

Yield is defined as the total number of fruit per tree. The ABI can range from 0 (no alternate bearing) to 1 (complete alternate bearing). Only when the ABI exceeds 0.5 for mandarins is alternate bearing considered a problem (Lovatt 2013). However the usefulness of the ABI has been questioned by Huff (2001) who argues that what may appear as an alternate bearing pattern may simply be a random pattern of yields which happens to be 'on-crop', 'off-crop', 'on-crop' and so on. El-Zeftawi and Thornton (1978) and Smith et al. (2004) found that the tendency towards alternate bearing in Ellendale tangors increased with tree age.

Research on the possible role of rootstocks in alternate bearing has produced conflicting results. Smith et al. (2004), in a long-term rootstock trial with Ellendale tangor, found no evidence of rootstock effects on alternate bearing patterns. They concluded that alternate bearing in this variety was a function of tree age combined with the influence of past cropping history. This is in contrast to El-Zeftawi and Thornton (1975), who found that Ellendale tangor on Emperor mandarin rootstock had a low biennial bearing index (<0.5), a high index (0.7) on Troyer and Carrizo citranges, and an intermediate index on Valencia orange. Georgiou (2002) found in a trial evaluating 12 rootstocks for Clementine mandarin trees that trees on all rootstocks exhibited a strong ABI in the early years of production.

## Measuring crop load

Crop load is normally assessed after natural physiological fruit drop has finished. The timing of this stage varies with region and from season to season, depending on climatic conditions, but is usually sometime between late November and early January (Table 66). The end of the physiological fruit drop period can be monitored by catching the fallen fruit (e.g. using a piece of shade cloth) under selected indicator trees every 2–3 days. The end is when the rate of fruit drop significantly declines.

Crop load can be measured using a counting frame (0.5 m x 0.5 m x 0.5 m). A light-weight frame can be made using aluminium tubing (Figure 150). Measure the crop load of at least 20 trees/ha by placing the frame at a height in the canopy which is representative of the average crop load of the tree (Figure 151). Count the number of fruit contained within the frame and do at least two frame counts per tree. The more fruit counts done, the more representative the results will be for that block. To get an average frame count, add all the individual frame counts together and divide by the total number of frame counts. For example, if a total of 500 fruit were counted in 40 separate frame counts then the average count would be:

$$500/40 = 12.5 \text{ fruit/frame}$$

As a guide, Imperial mandarin trees should be thinned if frame counts are more than 8–10 fruit (southern Australian growing regions) or 10–15 fruit in Queensland (Bevington & Khurshid 2002). For more information on assessing crop load refer to NSW DPI Primefact 787 *'Assessing citrus crop load'* (Falivene & Hardy 2008b).

Figure 150. Using a counting frame to measure crop load.

Figure 151. When measuring crop load take into account the variation in crop load across the canopy and place the counting frame in a part of the canopy that is representative of crop load. Note that most of the crop in this tree is in the lower two-thirds of the canopy.

## Managing crop load

The key to reducing or eliminating alternate bearing is to even out crop load across all seasons. Crop load can be increased in a predicted 'off-crop' year by increasing flowering and fruit set. Alternatively, crop load can be reduced in an 'on-crop' year by decreasing flower formation or reducing fruit numbers by thinning. Most orchardists manage crop load by using techniques that reduce crop load in a predicted heavy crop year. The appropriate crop load is dependent on variety, tree age, size and health, cultural practices and growing location.

Average fruit size is inversely proportional to the number of fruit on the tree and reducing the number of fruit on the tree improves overall fruit size. Fruit thinning reduces competition between fruitlets for carbohydrates and increases the leaf area supplying each fruit with carbohydrates. Thinning can be undertaken by hand, chemicals or pruning.

### *Hand thinning*

Hand thinning is the manual removal of fruit and is commonly used in some mandarin varieties (e.g. Imperial mandarin and Murcott tangor). Bevington et al. (1998) showed that hand thinning was a cost effective strategy for regulating cropping on Imperial mandarin trees. It is the most precise and least risky method of thinning, but is very labour intensive and costly as a result. Some varieties are thinned up to three times before harvest (Figure 153 and Figure 152). Thinning as early as possible will have the greatest effect on final fruit size.

Figure 152. A good crop load on a Murcott tangor tree after hand thinning multiple times.

Figure 153. A Murcott tangor tree that has been hand thinned three times to leave a well-balanced crop load with good fruit size.

When hand thinning the larger fruit are left and the small, clumped, blemished or damaged fruit are removed (Figure 154). For varieties prone to sunburn (e.g. Murcott tangor and Satsuma mandarin), remove fruit likely to suffer sunburn on the tops and outsides of trees. Strong branches will be able to support more fruit than weak spindly branches (Figure 155).

Hand thinning normally starts soon after natural fruit drop has finished; usually between November and January, depending on the region. A second thinning is undertaken 4–6 weeks later. A third thinning may be warranted on some varieties if the desired crop load has not yet been achieved. If possible excess fruit should be removed prior to the summer flush as the presence of fruit has been shown to inhibit summer and autumn budbreak, reducing the number of shoots and therefore nodes on which floral shoots are produced in the following spring (Verreynne & Lovatt 2009).

Stander and Cronje (2016) demonstrated that hand thinning Nadorcott mandarins in an 'on-crop' year in summer (≈ early-January) significantly increased the numbers of large-sized fruit (>60 mm) and reduced the number of small sized fruit at harvest, without significantly reducing total weight of fruit or fruit quality (Figure 156). The summer thinning treatment removed all fruit smaller than 20–25 mm. However, hand thinning in autumn (≈ mid-April) had no effect on fruit growth rate. The summer thinning in Year 1 also resulted in a higher fruit yield in Year 2 compared to the non-thinned (control) trees which maintained a typical alternate bearing pattern (Year 1 – 'on-crop'; Year 2 – 'off-crop', etc). The yield reduction on control trees in Year 2 was a result of the excessive number of fruit in Year 1 inhibiting the development of potential return bloom in Year 2.

For more information on hand thinning refer to the NSW DPI Primefact 789 *'Hand thinning citrus'* (Falivene & Hardy 2008a).

Figure 154. Hand thinning a Daisy mandarin tree – note the number of fruitlets removed on the ground.

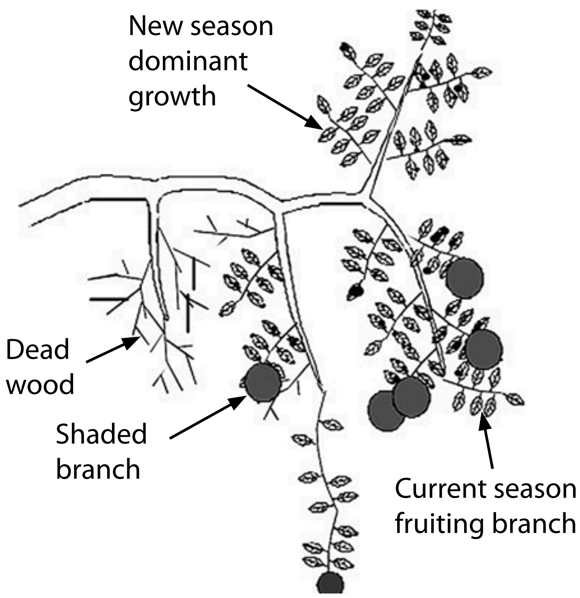


Figure 155. Diagrammatic representation of fruit bearing wood over time. Source: NSW DPI 2001.

Crop management

Figure 156. A crop of good sized Daisy mandarin fruit following hand thinning.

### *Chemical thinning*

Most chemical thinning agents used in citrus are synthetic auxins (Rabe 2000). Applied synthetic auxin can have a range of effects depending on the concentration of the natural auxin in the tree, the type of auxin applied, the concentration used, the time (development stage) of application, the carbohydrate status of the tree and the citrus cultivar (Guardiola 1988, Rabe 2000). Variability in the performance of chemical thinning agents is also influenced by weather conditions, especially temperature and humidity before and after application (Stover & Greene 2005). Some varieties (e.g. Murcott tangor) can be more sensitive than others to the effects of chemical thinning agents.

Most chemical thinning agents are applied at the end of the physiological (natural) fruit drop period. However, exact timing can vary from year to year depending on local weather conditions. Trees should be monitored to determine exactly when natural fruit drop has finished. Excessive crop and leaf drop may occur if applied too early, and if applied too late may be ineffective. Thinning agents should not be applied to unhealthy or stressedtrees or during adverse weather conditions. Carefully follow all label directions.

When using chemical thinning agents for the first time, it is recommended that they be trialled initially on a small plot of trees to become familiar with their use.

There are currently two products registered in Australia to thin mandarin fruit: ethephon (registered for Imperial mandarins only) and triclopyr (3,5,6 – TPA). Thinning agents used overseas include naphthalene acetic acid (NAA), 2,4-D (isopropyl ester of 2,4-dichlorophenoxyacetic acid) and 2,4-DP (2,4-dichlorophenoxy propionic acid, Corasil™) and ethychlorzate. None of these products are currently registered for this use in Australia.

**Caution – before using chemicals on fruit destined for export markets, check importing country permits and their MRLs.**

If fruit is to be exported, some overseas markets may not have established a maximum residue limit (MRL) for citrus fruit for certain chemicals, including plant growth regulators. Where an MRL has not been set, then residues must be zero (not measurable) at harvest. If there is concern or uncertainty about the use of any chemicals potentially resulting in residues in the fruit at harvest, it may be wise to consider having fruit tested by an analytical laboratory accredited by the National Association of Testing Authorities (NATA). For information on NATA-accredited laboratories that analyse fruit for residues refer to the *NATA* website. Citrus Australia Limited (CAL) also provides information on the MRLs for certain chemicals in various overseas markets. For more information refer to the *CAL* website.

### *Ethephon(trade names include Ethephon and Ethrel)*

The use of ethephon in combination with hand thinning and pruning can reduce a heavy crop load in Imperial mandarins. There are many products containing ethephon for thinning fruit, but all are registered for use ONLY on Imperial mandarins.

Ethephon breaks down to ethylene, which stimulates the development of the abscission layers on the stems of developing fruits, causing increased fruit drop. However, the amount of fruit removed can vary depending on crop load, application rate and weather conditions. Timing of application is critical. The correct time to apply ethephon is near the end of the natural fruit drop period when fruitlets are about 10–15 mm in size.

Some growers have reported mixed results using ethephon, possibly as a result of incorrect timing, over-application or unsuitable weather conditions; all of which can influence the degree of thinning. Temperatures too low or high may increase the number of fruit that drop. Ensure good soil moisture by irrigating two to three days prior to spraying. Water stressed trees may suffer excessive leaf or fruit drop. There are many precautions when using ethephon; a summary of the most important are covered in the best practice tips.

## Ethephon: best practice tips

- ☑ Carefully follow all label directions.
- ☑ Apply ethephon towards the end of the natural fruit drop period, when fruitlets are about 10–15 mm in size.
- ☑ Spray equipment must be correctly calibrated for each block of trees to be sprayed – apply between 13–15 L of diluted spray per 4–5 m high tree.
- ☑ Ensure even spray coverage of the canopy and only spray to the point of run-off (before spray begins to drip from leaves).
- ☑ Ensure trees are well watered before spraying, irrigating 2–3 days before spraying.
- ☒ Do not apply to stressed trees.
- ☒ Do not spray in cool weather (<18 °C) or in slow drying conditions.
- ☒ Do not spray in very hot conditions (>35 °C) or immediately after heat wave conditions.
- ☒ Do not exceed spray application volumes of 3500 L per hectare. Excessive spray volumes can cause heavy leaf and fruit drop.
- ☒ Do not spray if rain is predicted within 48 hours of application.
- ☒ Do not use alkaline water for application; if needed use a buffering agent to reduce water pH.
- ☒ Do not use surfactants or wetting agents.

### *Triclopyr or 3,5,6 – trichloro-2-pyridyloxyactetic acid or 3,5,6 – TPA (trade names: Tops® and Maxim®)*

Triclopyr, a synthetic auxin, is registered in Australia for both thinning and increasing fruit size in oranges and mandarins. For thinning, triclopyr should be applied during the natural fruit drop period (Figure 157), when fruit are between 9 and 15 mm in size (Figure 158). Do not apply to fruit smaller than 9 mm (Tops® product handbook, 2014). Excessive thinning and/or crop damage can result if applied before fruit have reached the correct growth stage.

Triclopyr is also used to enhance fruit size, but is applied later for that purpose, usually within two weeks of the end of natural fruit drop. For more information refer to the section on Improving fruit size. Triclopyr can only be used once per season – so it cannot be used for both fruit thinning and fruit size enhancement in the same season.

Figure 157. Nectar mandarin tree before thinning with triclopyr.

Figure 158. Nectar mandarin tree after thinning with triclopyr.

## Pruning

Light topping and/or hedging can be carried out prior to flowering to reduce the number of potential flowering sites, during flowering to reduce the number of flowers on which fruit could be set, and after natural fruit drop has finished to remove young fruitlets.

In a trial in Florida, topping 4.8 m high Murcott tangor trees by half a metre, in mid-summer (February) reduced the number of fruit/tree by 15%. This resulted in a 13% increase in mean fruit weight without an overall yield reduction (i.e. kg fruit/tree). The topping was undertaken quite late (≈ 4 months after bloom) and it has been suggested that the improvement in fruit weight was due to reduced water stress (lower transpiration from a smaller canopy) rather than reduced competition between fruit for photosynthates (Stover, Scott & Murphy 2003).

For more information on pruning refer to the chapter on Canopy management.

## Triclopyr: best practice tips

- ☑ Carefully follow all label directions.
- ☑ Apply only once per season.
- ☑ It is recommended that first time users of this product should only apply to a small test plot of trees to become familiar with its use and effects.
- ☑ Apply during the natural fruit drop period, when fruit are between 9–15 mm in size.
- ☑ Spray equipment must be correctly calibrated for each block of trees to be sprayed.
- ☑ Apply as a high volume spray to the point of run-off (before spray begins to drip from leaves).
- ☒ Do not apply to unhealthy or stressed trees.
- ☒ Do not apply to trees less than 5 years old.
- ☒ Do not apply when temperatures are >35 °C at time of spraying or for several days after application; or when wind speeds are <3 kph or >20 kph which could cause spray drift.
- ☒ Do not apply during surface temperature inversion conditions.
- ☒ Do not mix with anything other than a non-ionic wetter.
- ! Excessive spray volumes or application at the wrong growth stage can cause excessive leaf and fruit drop or fruit damage.

## Fruit growth and size

Fruit growth is largely a function of temperature, but there are many other factors, such as water availability and orchard management practices (e.g. nutrition), that also exert strong influences (Marsh 1973). Total heat units from bloom to maturity are strongly and positively correlated with fruit maturation rates (see the chapter on Climate and phenology). Warmer climates are associated with faster growth and earlier maturity.

Fruit go through three stages of development, Stage I – cell division, Stage II – cell expansion and Stage III – maturation. For more information on crop phenology see the chapter on Climate and phenology. Citrus fruit growth is generally linear or follows a single flattened 'S' shaped trajectory. There is a period of early slow growth followed by a rapid increase, after which growth slows down (Bain 1958; Figure 159). Imperial mandarin fruit growth in Queensland is linear, possibly due to warmer conditions (H Hofman, pers. comm.).

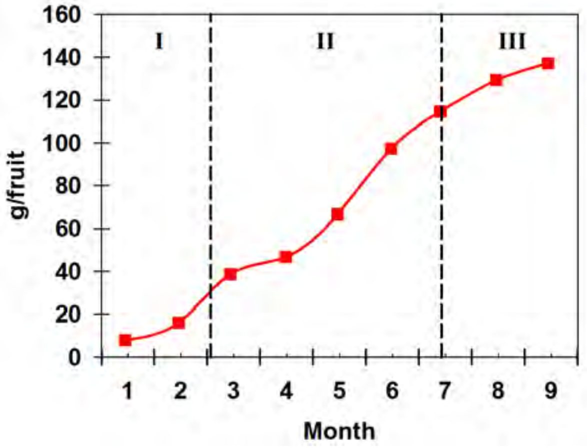


Figure 159. Growth of mandarin fruit. Source: Adapted from Ladaniya 2008.

The first stage of fruit growth is cell division which lasts about 30–40 days. During this stage all the cells that make up the mature fruit are defined and potential final fruit size is determined. This is the period most sensitive to adverse climatic conditions such as high temperatures (>35 °C) and water stress. In warm humid climates fruit size is often larger, (even with a heavy crop load) because higher temperatures increase the rate of fruit growth, compared with regions with a cooler spring. The optimum temperature range for fruit growth is widely believed to be between 20–30 °C, but a range of other factors such as water availability and mineral nutrition can moderate the expected benefits of favourable temperatures on fruit growth.

There are two natural fruit drop periods during Stage I fruit growth, one soon after the start of fruit set and a second towards the end of this stage. Levels of gibberellins in the ovary are important in controlling abscission at the start of fruit set and carbohydrate levels are more important at the end of Stage I during natural fruit drop. The loss of fruitlets during Stage I is also affected by temperature, humidity, soil moisture supply and competition between fruitlets for nutrients and carbohydrates. High temperatures and/or dry or windy conditions can cause excessive fruit shedding. Fruit are reasonably resistant to drop once they reach about 10–20 mm in size, but become more prone to dropping close to harvest.

Stage II, the cell expansion or enlargement phase, typically lasts between three to four months, depending on variety and climatic conditions. During this stage the juice sacs in the pulp take up water and enlarge, and the cells of the albedo expand and stretch to accommodate the expanding pulp. Very high or low temperatures and moisture stress during this stage can reduce fruit size and quality.

Fruit maturation or Stage III is characterised by the accumulation of sugars (measured as total soluble solids [TSS]), diminishing organic acids (measured as titratable acidity [TA]) and a change in rind colour. The length of the maturation period varies with variety and climate (predominately temperature). In warmer regions, fruit growth and maturation are faster and TSS accumulates more rapidly. Fruit growth and TSS accumulation are slower in cooler climates, and acidity levels at maturity are usually higher because organic acids are depleted more slowly.

Average fruit size in citrus is inversely related to the number of fruit carried by the tree (Guardiola 1988; Bevington et al. 2003). Fruit size can also be smaller in the absence of seeds. Non-parthenocarpic or weakly parthenocarpic varieties often have small fruit size if not cross-pollinated. There is a positive correlation between seed number per fruit and size and weight (Chao 2005).

Good fruit size is also dependent on an adequate supply of water, nutrients and carbohydrates from both stored reserves and manufactured by leaves during photosynthesis. Fruit are strong sinks for sugars, minerals and water. Water and minerals are supplied from the roots initially and later from the leaves. Carbohydrates are supplied from the reserves in the trunk, branches and roots initially, and from leaves later (Erner et al. 2004). The importance of the latter source is one reason why there needs to be sufficient leaf area per fruit to manufacture and supply sufficient carbohydrates for fruit growth and maturation. For fruit to be a strong sink for carbohydrates it has to be supported by a strong vascular system that can allow transport of sufficient carbohydrates into fruit during cell expansion.

## Improving fruit size

Increasing fruit size can be achieved by reducing crop load by thinning or pruning, which reduces competition between fruitlets for carbohydrates (as discussed previously) or by the application of a suitable plant growth regulator or a combination of both.

Auxins are plant hormones produced in the plant's meristematic tissue (growing points) and are responsible for increasing cell elongation. The auxins increase the elasticity of the vesicles (storage cells within fruit), allowing for a greater accumulation of juice (Agusti, Martinez-Feuntes & Mesejo 2002). Increasing the size of individual cells within the fruit results in an increase in the size of the locules (compartments within the fruit), which results in larger fruit (Figure 160).

Synthetic auxins have the most potential to increase fruit size and sink strength (Guardiola & Garcia-Luis 2000; Erner et al. 2004). When applied at the onset of cell expansion (Stage II), fruit sink strength is increased and carbohydrate accumulation is enhanced. The auxin stimulates cell expansion especially in the juice vesicles, which increases their capacity to accumulate juice and accelerates fruit growth (Agusti, Martinez-Feuntes & Mesejo 2002).

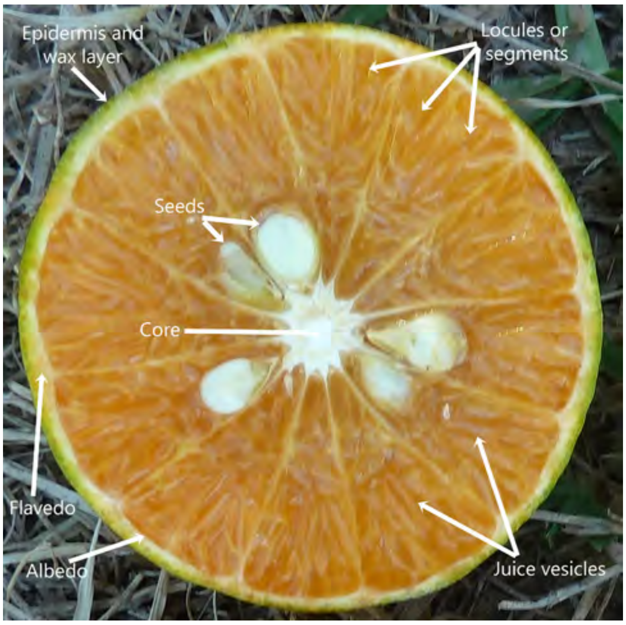


Figure 160. Transverse section of fruit showing various anatomical parts.

Synthetic auxins are widely used around the world as fruit size enhancers, shifting final fruit size distribution to larger sizes (Agusti et al. 1994, 1995 and 2002). The most common compounds used are dichlorprop-P (2,4 – DP) and triclopyr (3,5,6 – TPA), both of which are registered for mandarins in Australia. For example, in Clementine mandarins, dichlorprop-P increased fruit size by 3–4 mm and triclopyr by 4–6 mm (Agusti, Martinez-Feuntes & Mesejo 2002).

Foliar applications of potassium at key times in the fruit development cycle can also be effective in increasing fruit size. Boman (2002) demonstrated that three applications of potassium nitrate (winter, post bloom and summer) increased fruit size in Sunburst tangerines in Florida.

***Dichlorprop-P or 2,4-DP*** (trade name: Corasil™)

Dichlorprop-P is a synthetic plant growth regulator with auxin-like activity registered for use on mandarins to increase fruit size.

There is only a small window of opportunity for application. Dichlorprop-P is applied when fruit are between 8–20 mm in size, which approximately equates to the natural fruit drop period. Careful monitoring of fruit drop and fruit size during this period is critical to success. Trials conducted by the manufacturer have indicated that application at the smaller end of the fruit size range results in the best improvements in final fruit size. This is supported by the experience of Imperial mandarin growers in Queensland who reported that the best effect occurs if the formulation is applied when fruit are about the size of a shirt button (10 mm), and that earlier and later applications are less effective. Their experience supports the notion of a narrow window of opportunity for successful use of the chemical.

Dichlorprop-P: best practice tips

- ☑ Carefully follow all label directions.
- ☑ First time users of this product should consider only applying the formulation to a small plot of trees to become familiar with its use and effects.
- ☑ Apply around the time of the physiological fruit drop period, when fruit are between 8–20 mm in size.
- ☑ Spray equipment must be correctly calibrated for each block of trees to be sprayed. Apply in a spray volume of 2,500-3,000 L/ha for 4 m high trees and ensure thorough tree coverage.
- ☒ Do not apply to unhealthy, nutritionally deficient or stressed trees.
- ☒ Do not spray under adverse weather conditions.
- ☒ Do not mix with anything other than a non-ionic wetter.
- ☒ Excessive spray volumes or application at the wrong growth stage can cause excessive leaf and fruit drop or fruit damage.

***Triclopyr or 3,5,6–trichloro-2-pyridyloxyactetic acid or 3,5,6–TPA*** (trade names: Tops® and Maxim®)

Triclopyr is registered for use as a final fruit size enhancer of mandarin fruit, as well as a thinning agent (see the section on Chemical thinning). To increase final fruit size triclopyr should be applied within two weeks of the end of the natural fruit drop, usually when fruit are between 18–20 mm in size. Excessive thinning and/or crop damage can result if the formulation is applied before fruit have reached the correct growth stage. Triclopyr should only be used once per season, so cannot be used for both fruit thinning and size enhancement in the one year. For best practice tips on using triclopyr, refer to the Chemical thinning section of this chapter.

## Improving rind quality and slowing ageing

Gibberellins are naturally occurring plant growth regulators found in most plant tissues and are involved in physiological processes such as flowering, seed set and fruit development. Gibberellic acid (GA) (trade names such as Gala, Gibb Acid, Gibberellic Acid, Maxigibb and Progibb) is a commercially available form used in selected horticultural crops to manipulate flowering and fruit development, as well as to improve the external appearance and postharvest performance of fruit.

The effects of GA on citrus are dependent on both the timing of application and the concentration of GA applied. GA applied in summer and autumn improves rind quality and market out-turn. Autumn application of GA can delay fruit colouring, but does not affect internal fruit maturity. Chapman et al. (1979) showed that GA applied to Ellendale tangor mandarin trees 12 weeks before harvest reduced rind puffiness.

GA is only registered for use on mandarins as an autumn application to delay rind aging and reduce rind blemish. It can be used strategically to extend the harvest period. Application is recommended when fruit are between three quarters and fully coloured. Correct timing of sprays and good spray coverage of fruit are critical to achieving good results. GA application in autumn can delay fruit colouring, but the effects vary with variety, growing district and seasonal conditions. GA can also cause fruit spotting (Figure 161) in some mandarin varieties, particularly if applied before or during cold weather (i.e. 2–5 °C), frosts or unusually wet weather. The spotting is usually transitory and disappears within 10–21 days, but may reappear if fruit are placed into cold storage.

Figure 161. Spotting of Murcott tangor after the application of GA can occur under certain climatic conditions, but usually disappears within a few weeks.

### GA: best practice tips

- ☑ Carefully follow all label directions.
- ☑ Trees should be adequately watered before and after application.
- ☑ Spray equipment must be correctly calibrated for each block of trees to be sprayed.
- ☑ Ensure thorough spray coverage of the fruit surface – GA will only work where the spray makes contact with the rind.
- ☑ Spray to the point of run-off; typical water application rates are 5,000 L/ha for small trees, 7,500 L/ha for medium-sized trees and 10,000 L/ha for large trees.
- ☑ The pH of the water used for spraying should be between 4 and 6. For optimum results adjust the spray tank solution to pH 4.0 to 4.5 by adding an acidifying agent to reduce pH if the water is too alkaline.
- ☒ Do not apply in hot conditions when air temperatures are >35 °C.
- ☒ Do not use on unhealthy trees or trees suffering pest, nutritional or water stress.
- ☒ Do not apply to trees with heavily blemished fruit.
- ☒ Do not apply for 3–4 weeks after a copper or oil spray; some copper formulations can react with GA and oil restricts GA uptake.
- ☒ Avoid spraying in slow drying conditions, such as late in the day or in overcast or showery conditions. In winter, spray in the morning after dew has evaporated.
- ☒ Do not apply if rain is forecast within 6 hours of application.
- ! GA can delay fruit colouring by 1–2 weeks, but the effects can vary with application rates, variety, growing district and seasonal conditions.
- ! GA should be applied on its own, but can be mixed with Stop Drop sprays (see next section).

## Preventing pre-harvest fruit drop

Pre-harvest fruit drop can commence at colour change or soon after, and in some seasons may result in heavy crop losses. The application of selected synthetic auxins at low rates helps maintain the cells at the zone of abscission, reducing fruit drop. The only product registered in Australia for the prevention of fruit drop in mandarins is 2,4-D present as the dimethylamine salt. Another formulation called 2,4-D isopropylester (2,4-D IPE) sold as Alco® Citrus Fix™ is available in some overseas countries. 2,4-D is regarded as one of the most effective compounds in preventing fruit drop in citrus (Coggins & Hield 1968; Coggins & Lovatt 2004).

The amine or sodium salt of 2,4-D (trade names: 'Citrus Stop Drop' and 'Cling') applied pre-harvest is effective in delaying fruit drop and for retaining fruit on the tree to take advantage of later markets. Commercial 2,4-D formulations applied at less than 20 ppm delay the formation of the natural abscission layer at the junction of the fruit stem and the button. It is normally applied at early colour break, when the rind changes colour from dark to light green, sometime between March and June, depending on variety and growing region. There is an inverse relationship between the concentration of 2,4-D applied and the colouring of fruit; the higher the rate applied, the higher the number of green fruit (Modise et al. 2009). The recommended application rate for mandarins is 10 ppm. Most growers apply 2,4-D to selected blocks of mandarins, not every block.

2,4-D was initially developed as a herbicide and at higher rates (e.g. >30 ppm) it will increase fruit drop (Amiri, Kangarshahi & Arzani 2012). Leaf distortion, commonly referred to as 'boat shaped' or 'parrot beak' leaves (Figure 162), is sometimes seen on the youngest leaf flush after 2,4-D application. This condition is thought to be a result of using too high a rate, over-dosing trees when spraying or the result of climatic conditions at the time of application. It usually does not have any long term effects on the tree.

Some other crop plants are particularly sensitive to 2,4-D, and it is critical to avoid spray drift onto other plants, particularly tomatoes, grapevines, vegetables and ornamentals.

Recently, some overseas countries have shown concern over possible residues of 2,4-D in fruit at harvest. If fruit are destined for export markets check whether the importing country permits the use of the chemical and the MRL. In the absence of an MRL, residues should be zero (not measurable) in fruit at harvest. For more information refer to the *CAL* website.

Figure 162. 2,4-D sprays can sometimes cause a leaf distortion, commonly referred to as 'boat shaped' or 'parrot beak' leaves, that is usually seen in the youngest leaf flush. It is thought to be a result of over-dosing trees.

### Stop drop sprays: best practice tips

- ☑ Carefully follow all label directions.
- ☑ Sprays are normally applied at early colour break.
- ☑ Apply at recommended rates – the label rate for mandarins is 10 ppm.
- ☑ Good spray coverage of fruit is essential – spray to the point of run-off.
- ☑ Recommended water volumes are 2,000 L for small trees, 3,000–4,000 L for medium trees, 5,000 L for large trees and 7,500 L for very large trees (note that these water rates are slightly lower than those recommended for GA application to delay rind ageing).
- ☑ For export fruit – check if the importing country has an MRL set for 2,4-D.
- ☑ Prevent spray drift onto other crops.
- ☒ Do not apply to poor quality fruit.
- ☒ Do not apply on wet or damp days.

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# Canopy management

## Introduction

Mandarin orchards that consistently produce high yields of good quality fruit have a regular pruning program in place which generally consists of a combination of hand and mechanical pruning.

Pruning is used to:

- control tree height and width for ease of management
- manipulate crop load and reduce alternate bearing
- manipulate fruit size and improve fruit quality
- rejuvenate fruit bearing wood
- improve light and air penetration into the canopy
- remove dead and diseased branches, watershoots and unwanted growth
- reduce the tree canopy area to reduce water use in times of drought.

Mandarin trees have a range of growth habits from naturally weeping varieties, such as Clementines and Satsumas, to more upright varieties, such as Afourer mandarins.

Rootstocks also play an important part in tree vigour and growth. For more information see the chapter on Rootstocks.

In the last 20 years pruning has become an important part of the annual management program for citrus orchards, particularly mandarins. Once pruning is introduced on a regular basis orchardists aim to spend between 1–3 minutes/tree/year on selective hand pruning of bearing trees. Pruning is best done after harvest and before bud break and is typically undertaken between June and November, depending on purpose, variety and location.

Pruning can be done manually using secateurs, hand and chain saws, or mechanically using circular saws mounted onto self propelled machines or tractors.

Hand pruning allows for selective branch removal and is used to open up the tree canopy, rejuvenate fruit bearing wood, remove diseased, dead or unwanted growth and manage tree structure.

Mechanical pruning is non-selective and is typically used for managing tree height and spread and to manipulate cropping and fruit size. It is used when skirting, topping and hedging trees.

## Tree growth

Mandarin trees, like other citrus species, typically have three growth flushes per year, depending on local climatic conditions. Citrus flowers are typically borne on one year old wood or on the leafy shoots arising from one year old wood. As each new growth flush is added on to the previous growth flush, the fruit bearing wood is more likely to be found on the outside of the tree canopy (Figure 163). Over time this produces larger trees with increased shading inside the canopy, resulting in most of the fruit being carried on the tops and outsides of trees, where they are more prone to wind damage and sunburn.

Light is critical to tree and fruit growth and development. The leaves harvest the sunlight through the process of photosynthesis to produce carbohydrates and sugars which are then transported to the sites where they are needed, such as the developing buds, flowers and fruit.

Improving light penetration into the tree canopy improves tree productivity and fruit quality. In some varieties, such as Murcott tangor, better quality fruit are produced on the insides of trees where they are also protected from sunburn.

The density and orientation of plantings also affects light penetration into the orchard. Generally, the closer the planting the quicker shading will become a problem. Ideally tree rows should be orientated to run north–south to obtain maximum sunlight throughout the day. Light distribution in east–west rows is poorer with low light levels, particularly on the southern side of trees.

Citrus trees exhibit apical dominance, meaning that the top bud suppresses the shooting of buds below it. One way to stop apical dominance is to prune off the shoot tips (tip pruning). If trees are left unpruned branches naturally bend under the weight of the foliage and fruit, forcing the tip downwards and allowing the lateral buds to shoot (Figure 164). Bending or topping strong vigorous shoots can induce lateral shoot growth.

Strong bearing branches tend to produce larger fruit. They also transport water and nutrients more efficiently throughout the tree. Fruit situated closer to a strong bearing branch that can deliver water and nutrients more efficiently will have a better chance of reaching a good size than fruit situated at the end of a long trailing branch (Figure 165). Pruning aims to encourage this strong new growth.

Medium or large pruning cuts usually result in strong vigorous regrowth that needs to be managed. This regrowth needs to be thinned out (space shoots about 15–20 cm apart) 6–8 weeks later (Figure 166). Any unwanted shoots can easily and quickly be snapped off by hand if done when the shoots are still soft and green. Reducing fertiliser, especially nitrogen, and irrigation applications can also be used to reduce excessive vigorous growth.

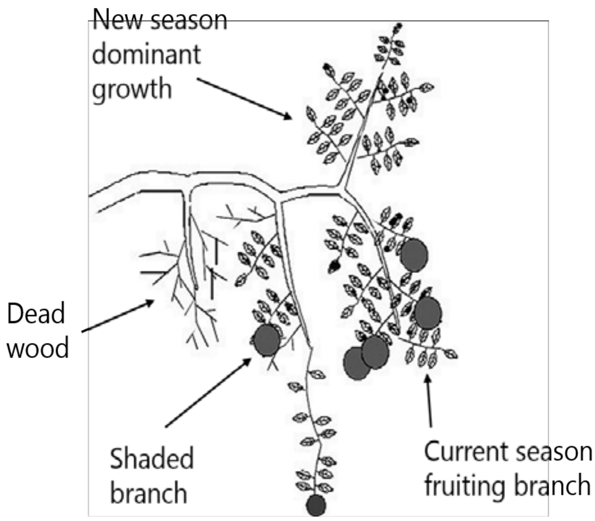


Figure 163. Diagrammatic representation of fruit bearing wood over time. Source: NSW DPI 2001.

Figure 164. A citrus branch naturally bent under the weight of foliage and fruit forces the branch tip downwards, allowing the lateral buds to shoot.

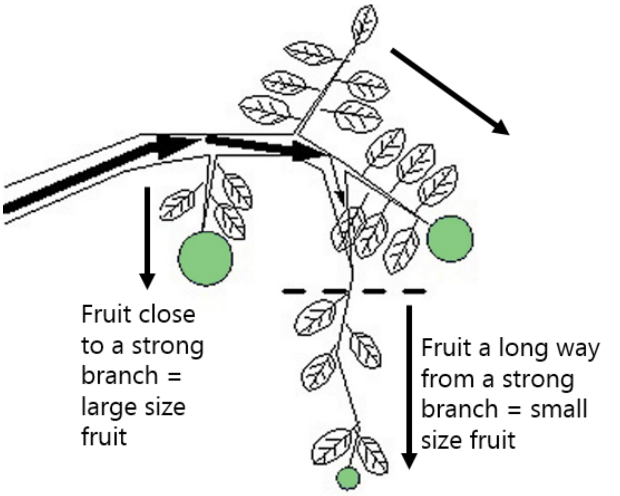


Figure 165. Diagrammatic representation of the flow of nutrients and water through branches to fruit. Source: NSW DPI 2001.

Figure 166. Strong regrowth following pruning must be thinned out 6–8 weeks later.

## Hand pruning

### Young trees

Pruning starts when trees are about 12 months old. Hand pruning is used to develop the tree's structural framework. Aim for 3–6 well spaced main limbs, with the lowest limb between 45–65 cm above ground level.

### Bearing trees

Hand pruning is normally carried out after harvest and is used to maintain good cropping potential.

If pruning is done annually, as little as 1–5 cuts are made, requiring only 1–3 minutes on each tree. Medium or heavy pruning, which allows a lot more light into the canopy can produce an excess of new shoots. It is important to thin out this regrowth, by coming back when shoots are about 10–15 cm long and quickly snapping off any unwanted shoots by hand.

The structural framework of the tree needs to be managed as trees mature (Figure 167). This requires the periodic removal of some major limbs in order to maintain 5–8 good strong structural limbs (Figure 168). Major limbs are removed when there are too many, they cross over or they have become diseased or unproductive.

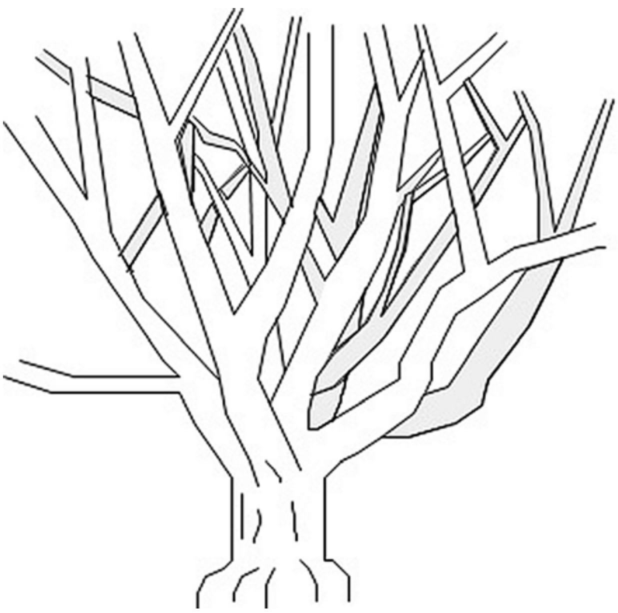

Figure 167. Tree structure before pruning. Source: NSW DPI 2001.

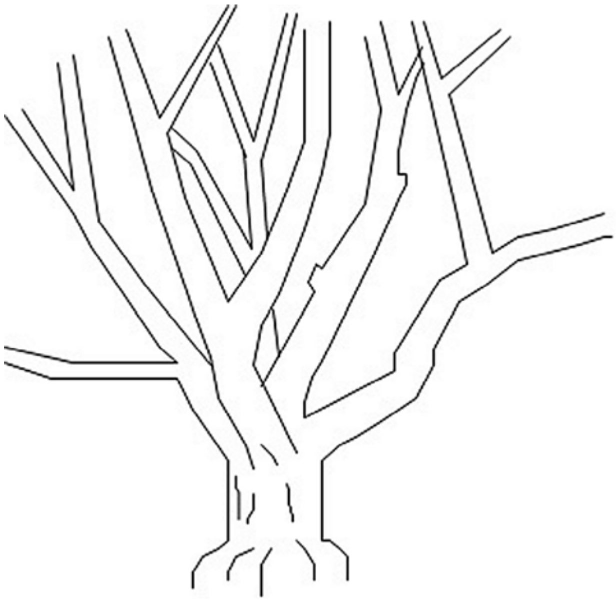

Figure 168. For a good structural framework aim to leave 5–8 limbs when pruning. Source: NSW DPI 2001.

## Rejuvenating older trees

There are several types of pruning styles used on mature trees to help improve air and light penetration into a dense canopy and generate new fruit bearing wood inside the tree.

### Window or chunk pruning

Window pruning involves taking out a chunk of the canopy removing one large or a few smaller branches to create a window into the canopy to let in more light (Figure 169).

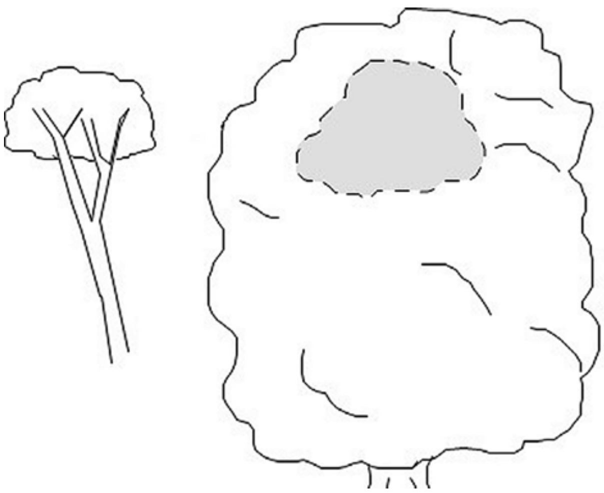

Figure 169. Window or chunk pruning. Source: NSW DPI 2001.

## Canopy thinning

Canopy thinning involves the removal of selected smaller branches throughout the canopy to improve light and air penetration (Figure 170).

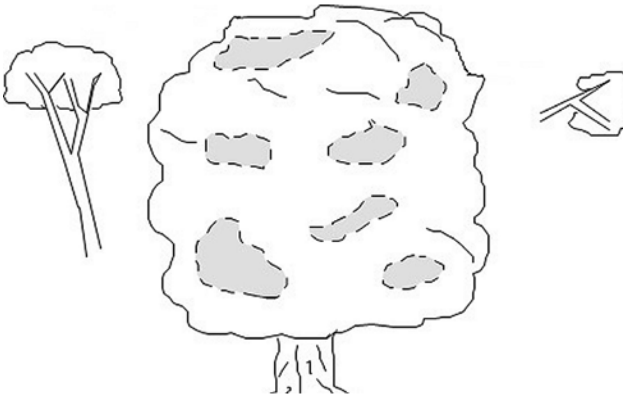

Figure 170. Canopy thinning. Source: NSW DPI 2001.

## Open centre pruning

This type of pruning involves removing the centre of the tree to create a 'vase' shaped tree, similar to that used on deciduous fruit trees (Figure 171 and Figure 172).

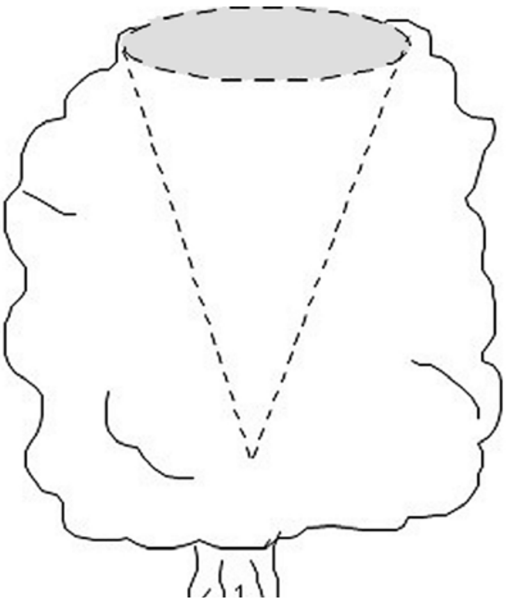

Figure 171. Open centre pruning. Source: NSW DPI 2001.

Figure 172. Opening up the centre of trees allows more light into the canopy.

## Skeletonising

This type of pruning is very severe and normally undertaken only on very old, but healthy trees whose yields have become uneconomical. It is more commonly done on longer living orange trees rather than on mandarins. It is sometimes used to reduce tree water use during severe droughts.

Trees are heavily pruned in order to create a new structural framework and a whole new canopy. Skeletonising trees will put them out of production for at least 2 years. Because of this, skeletonising is sometimes carried out only on one side of the tree, with the other side being pruned 1–2 years later. Alternatively, only every second row is skeletonised to retain some income from the block. The other row is then pruned 1–2 years later.

After skeletonising, the tree should be protected from sunburn by whitewashing with water based paint (Figure 173). Irrigation and fertiliser applications will also need to be reduced to match canopy loss. This type of pruning requires significant follow-up work to select out and manage the regrowth.

Figure 173. Recently skeletonised trees showing regrowth (which has been thinned out) and whitewashing for sunburn protection.

## Mechanical pruning

### Hedging

Hedging removes only the outer canopy (Figure 174). It is used to:

- maintain access in the inter-row space
- reduce shading
- rejuvenate fruit bearing wood
- reduce crop load.

Depending on the purpose, most hedging is undertaken after harvest up until the end of spring. Light hedging is preferred and removes wood no thicker than about 10–12 mm in diameter. Only about 5–10% of the canopy is removed, which should not have a major impact on tree yield. Medium (10–20% removal) and heavy (20–30% removal) hedging will affect crop production and can promote excessive regrowth. Saw blades are set at an angle of 20° to the vertical allowing light to reach the tree skirts. The hedging site on trees should be varied to avoid a 'witches broom' effect developing in the canopy.

Some mandarin varieties have a tendency to enter into a cycle of alternate bearing – producing a heavy crop one year, followed by a lighter crop the next. Hedging is one crop management strategy used to even out crop load. However, it is important to remember that hedging is a non-selective form of pruning.

Light to medium hedging is used in a predicted heavy crop or 'on' year to reduce:

- the number of potential flowering sites by hedging after harvest and before flowering
- the number of flowers by hedging during flowering
- crop load by hedging after fruit set and the natural fruit drop period.

Figure 174. Hedging mandarin trees.

### Topping

Topping is generally used to reduce tree height and improve light penetration into the canopy and the orchard floor. It can also be used to reduce crop load. As the height of trees increase, the lower parts of the canopy become shaded. Lower tree heights of 3–4 m are now common in citrus orchards, improving access to the canopy, particularly for spraying and harvesting activities.

Topping is normally done after harvest, up until early spring. Topping in late spring or summer can result in excessive vigorous upright growth. Trees can be topped flat or more commonly cut at an angle of up to 30° (Figure 175). Topping is typically carried out every 2–3 years depending on tree vigour.

Topping, like hedging, if done at the same height each time will cause trees to develop a 'witches broom' effect – so topping height should be varied.

Figure 175. Topping of mandarin trees.

### Skirting

Skirting refers to the removal of the lower branches or skirt of the tree, usually up to a height of at least 0.5 m from ground level (Figure 176).

Skirting is used to:

- prevent fruit from touching the ground and reducing the risk of soil borne disease spores, such as sour and brown rots, coming into contact with the fruit
- prevent the movement of pests, such as Fuller's rose weevil and snails, into the tree canopy
- facilitate monitoring and undertree management operations, such as weed control, irrigation and fertiliser application.

Figure 176. A well maintained orchard with a regular skirting program.

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NSW DPI 2001, *Canopy management for bigger and cleaner fruit*, Module 3 Certificate III in Citrus Production, NSW Department of Primary Industries, Orange.


### Pruning: best practice tips

- Pruning should be an annual part of tree management.
- The best time to prune is after harvest and before bud break.
- After medium or heavy pruning, management of the regrowth is critical.
- After pruning adjust fertiliser and irrigation applications to match canopy loss.
- When hand pruning sterilise your pruning equipment after each tree to reduce the spread of disease. When using mechanical pruning machinery, the blades should be sterilised after each block or variety.
- All pruning and grafting equipment should be sterilised with at least a 1% sodium hypochlorite (NaOCl) solution. For household bleach (5.25% NaOCl), mix 1 part with 4.25 parts water and for commercial products (12.5% NaOCl) mix 1 part with 11.5 parts water.
- Dilution rate = (% NaOCl of bleach product ÷ by % NaOCl of solution required) – 1 = parts of water required. For example: (12.5 ÷ 1) – 1 = 11.5 parts water. So, 100 mls of bleach (12.5% NaOCl) should be mixed with 1150 mls of water to make a 1% solution.
  **Note: Chlorine products are corrosive to metals.**
- Heavy pruning should not be carried out in hot weather as branches or fruit can be sunburnt.
- In areas where there is the potential for frost, pruning should not be carried out when the resulting young flush growth is likely to be exposed to frost.
- Heavy pruning at the wrong time can result in excessive vegetative growth.
- Pruning during budbreak or flowering can significantly impact crop load.
- The more drastic the pruning the longer it takes for the tree to recover and produce fruit.

# Diseases

## Introduction

Mandarins are susceptible to a range of diseases in Australia, particularly in regions with wet springs and summers. Coastal areas and regions with high rainfall and humidity tend to have a higher incidence of fungal diseases. The most common diseases in these areas are black and brown spot, melanose, sooty blotch, Armillaria and Phytophthora brown, root and collar rots. In these regions trees require regular applications of protectant copper and other fungicide sprays in order to keep fruit free of blemish.

In Australia most fungal pathogens in citrus are controlled using applications of protectant copper based sprays. At present there are few other fungicides registered for use in citrus. For more information on using copper sprays to control diseases in citrus refer to *NSW DPI Primefact 757*.

The most important cultural methods used to control disease inoculum are focused on removing or reducing the source. Trees should be kept free of dead wood with regular pruning. This also opens up the tree canopy for better air circulation and easier penetration of fungicide sprays. Skirting trees will also help air circulation and reduce the likelihood of pathogens being carried from the soil onto the tree in rain splash.

For information on the pesticides currently registered for use on citrus refer to the Australian Pesticide & Veterinary Medicines Authority, *APVMA PubCRIS* website.

## Armillaria

Armillaria causes root death in susceptible hosts, particularly in coastal areas. It is caused by the fungus *Armillaria luteobubalina*, which is native to Australia and common in coastal eucalypt forests, including bloodwoods. Armillaria occurs only occasionally in inland orchards. There are other fungal diseases that cause root rot in citrus, most commonly Phytophthora.

### Cause

The fungus survives for years in woody debris such as stumps and dead tree roots. The fungus spreads from tree to tree by fungal strands (rhizomorphs) that grow out from the roots of infected trees. Infection occurs when the root of the tree comes into contact with an Armillaria infected root or a rhizomorph reaches a newly planted tree.

### Symptoms

Armillaria damages the root system of the tree initially causing leaf fall and twig dieback, and eventually tree death. In citrus this above ground deterioration of the tree is not usually seen until the disease is well established in the root system and trunk (Figure 177).

Infected roots are often spongy and if the bark is removed a thin, white, fan-like growth can be seen on the wood surface (Figure 178). Freshly infected tissue has a strong mushroom smell. Clusters of toadstools are produced around the tree trunk during autumn (Figure 179).

### Control

- Trees in the early stages of infection can be treated by exposing the butt and main roots to air. This slows down fungal growth.
- Badly infected trees should be carefully removed and burnt. Unless all infected root debris that harbours the fungus is removed, it is pointless planting another citrus tree because it will also succumb to the disease.
- Deep ripping to remove old roots or stumps of previous fruit trees or native vegetation, spelling the soil and cover cropping are essential in treating infected sites.

Figure 177. Armillaria affected trees – the disease spreads along the tree row as infected roots reach adjoining trees.

Figure 178. White fan-like growth under the bark, indicative of Armillaria root rot.

Figure 179. Clusters of toadstools of the Armillaria fungus form at the base of the tree trunk in autumn.

## Black spot

Black spot is common in the humid, citrus growing regions of Queensland and coastal NSW with summer rainfall. It is not found in southern citrus growing regions, central NSW or Western Australia. Although black spot can affect most citrus varieties, it is a major problem in Valencia oranges where mature fruit are often present on the tree alongside next season's crop. Mandarin varieties affected include Imperial and Murcott tangor.

### Cause

Citrus black spot is caused by the fungus *Phyllosticta* (syn. *Guignardia*) *citricarpa*. Spores are produced on dead leaf litter on the orchard floor. The spores are ejected into the air and land on immature fruit and leaves during rain or in irrigation water. The fungus then remains dormant until the onset of warm weather in late summer/autumn when fruits begin to ripen and the symptoms are expressed. Infection mostly occurs in late spring and summer.

### Symptoms

Black spot causes unsightly lesions on the rind of fruit but does not affect internal fruit quality (Figure 180). Fruit symptoms can vary from a hard spot to a speckle. Black spot first appears as small red/orange spots which develop black margins and then enlarge to become necrotic lesions, typically with a light coloured centre. Black pycnidia (secondary fruiting bodies) can sometimes be seen in the centre of the spots. Occasionally symptoms appear on older, senescing leaves as small, dark, sunken spots with a light coloured centre.

Figure 180. Black spot symptoms on Murcott mandarin. Photo: Andrew Miles.

### Control

Spray programs to control black spot rely on the use of protectant copper and mancozeb fungicides and the strategic use of the newly registered fungicide Amistar® (active ingredient azoxystrobin). Azoxystrobin is a broad spectrum fungicide that acts by inhibiting the mitochondrial respiration in fungi, stopping their energy supply. Amistar® can only be applied twice per season to reduce the likelihood of resistant strains of the fungus developing. Carefully follow all label directions.

For more information on the latest spray program for black spot control contact your state's primary industry agency or horticultural consultant.

- ☑ Apply protectant copper and other fungicides as part of a black spot management program.
- ☑ Cover or remove leaf litter to reduce the source of inoculum.
- ☑ Harvest fruit as soon as possible before symptoms develop.
- ☑ Keep harvested fruit cool (<20 °C) to prevent symptom expression.

## Blight

Citrus blight is a major problem in the hot, humid citrus production areas of Florida, South America and South Africa. In Australia citrus blight has been confirmed in orchards in the Gayndah/Mundubbera region (Queensland) and in the Riverina (NSW) [Chapman & Hutton 1988, Broadbent et al. 1996]. Blight is often difficult to diagnose because of the similarity of symptoms to other diseases. Diagnostics for citrus blight include assays for zinc accumulation in bark, reduced water flow into the trunk by a syringe injection technique, the presence of amorphous plugs in the xylem vessels and the presence of a unique protein.

Blight causes gradual tree decline with symptoms not usually appearing until trees are bearing, most commonly between 6–10 years of age. Once trees are affected they do not recover and must be removed. Trees on rough lemon, Rangpur lime, *C. trifoliata* and the citranges are especially susceptible, while trees on Cleopatra and Emperor mandarin rootstocks and Swingle citrumelo are more tolerant. Sweet orange rootstock is highly resistant. In the USA significant tree losses have been recorded with Cleopatra mandarin when trees reach 12–15 years of age (Castle et al. 2006).

### Cause

The exact cause of citrus blight is currently unknown. The disease can be transmitted from tree to tree through natural root grafting, which suggests the presence of some type of transmissible agent.

### Symptoms

Symptoms of blight begin in one sector of the tree canopy (Figure 181) and gradually spread to include a general tree decline with permanent wilting (Figure 182), followed by leaf fall, dull green foliage with shortened internodes, twig dieback and poor growth. Trees may survive in this condition for a long time showing little vigour. As the disease progresses, fruits become small and trees produce out of season leaf flushes and flowers. Trees often show symptoms of transient zinc-like deficiency patterns. Elevated zinc levels are found in the tree bark. Water shoots arising from the trunk, large scaffold branches and rootstock may give the impression of tree recovery, but this is only temporary.

The wilting is a result of the water conducting vessels (xylem) becoming blocked, reducing water uptake and transport throughout the tree. The xylem vessels in the trunk, large branches and roots become blocked with light yellow or dark brown amorphous plugs best viewed under a scanning electron microscope.

Figure 181. Blight symptoms on citrus.

Figure 182. Blight symptoms showing as wilting and thinning of the tree canopy.

### Control

- ☑ Remove affected trees and replace using less susceptible rootstocks.

## Botrytis (grey mould)

Botrytis is sometimes a problem in the wet, humid tropical or subtropical regions, reducing fruit set and damaging young fruitlets.

### Cause

This disease is caused by the fungus *Botrytis cinerea,* known as grey mould, because of its typical grey to greenish-grey spores. The fungus lives on decaying organic matter and its spores are carried by wind, water and insects. The fungus is favoured by prolonged damp, wet and cool conditions at petal fall. Temperatures around 18 °C are optimal for its growth.

### Symptoms

The fungus most commonly develops in blossoms, decaying petals or very young shoots that become covered in the grey mould. Botrytis can reduce fruit set and cause ridges or raised areas on young fruitlets, similar to that caused by wind injury.

### Control

- ☑ Apply protectant copper fungicides in early spring if persistent damp weather is likely.

## Brown rot

### Cause

Brown rot is a fungal-like disease that can invade maturing fruits. Brown rot is caused by species of *Phytophthora*, including *P. citrophthora* and *P. nicotianae*, which also cause collar and root rots in citrus.

### Symptoms

The decay is firm and light brown in colour with a distinctive smell (Figure 183). Fruit near the ground become infected first, after being splashed with soil or water containing the fungus. If wet conditions which favour infection continue, the disease can spread to fruit throughout the canopy. Snails can also carry the spores throughout the canopy.

### Control

- ☑ Copper sprays, particularly applied to the skirt and the under-tree area, help reduce brown rot.
- ☑ Prevent fruit and foliage from coming into contact with soil and water splash by skirting trees. This also helps to improve air circulation and dry out foliage and soil.
- ☑ Ensure snail population is low.

Figure 183. Symptoms of brown rot on fruit showing white fungal mycelium.

## Brown spot

Brown spot is a serious disease of some mandarin varieties in coastal, subtropical and tropical regions with high rainfall and humidity, predominantly during periods of mild temperatures (≈25 °C) and prolonged leaf wetness. Not all mandarin varieties are susceptible to brown spot and the known susceptibility of some varieties is outlined in Table 67.

Table 67. Susceptibility of mandarin and tangelo cultivars to brown spot.

| Cultivar | Susceptible |
|---|---|
| Afourer (W. Murcott) | No |
| Clementine | No |
| Daisy | Yes |
| Dancy | Yes |
| Ellendale | No |
| Emperor | Yes |
| Fortune | Yes |
| Fremont | No |
| Hickson | No |
| Imperial | No |
| Kara | No |
| Minneola | Yes |
| Murcott | Yes |
| Nova | Yes |
| Ortanique | No |
| Page | Yes |
| Seminole | Yes |
| Sunburst | Yes |

Adapted from Hutton and Mayers (1988); Kohmoto, et al. (1991).

## Cause

Brown spot is caused by the fungus *Alternaria alternata*. Spores are produced on mature leaves, dead twigs and recently fallen leaf litter. Spores are spread by wind and water. The fungus is favoured by damp weather in early spring, late summer and early autumn. Heavy dews are sufficient for infection. Ideal conditions for infection are 12–14 hours of leaf wetness and air temperatures of 20–27 °C. Brown spot is more severe on trees carrying lush shoot growth and on trees with dense canopies that prevent good air circulation where foliage remains wet for long periods.

## Symptoms

Symptoms occur on leaves(Figure 184), young stems (Figure 185) and fruit (Figure 186). On leaves, brown to black spots often develop on the margin (Figure 187). A toxin produced by the fungus causes the veins on young leaves to darken, especially along the leaf midrib, with yellowing and death of the adjacent tissue. Infected young shoots can become blighted and blackened. Small, black, slightly sunken spots appear on fruit 1–2 days after infection (Figure 188). Newly set fruit often falls. On green fruit the spots may be surrounded by a yellow halo. Some spots will increase in size changing to light brown as the fruit ripens. Some spots dry out and become corky and leave pockmarks if dislodged.

## Control

Avoid planting very susceptible varieties such as Daisy and Emperor mandarins and Murcott tangor in areas where brown spot is prevalent. If this is not possible, a disease management program involving the application of registered fungicide sprays will need to be implemented.

Protective fungicide sprays such as copper, and other registered fungicides, such as Amistar®, captan (currently under an APVMA permit until 31 July 2022, PER82043) and iprodione (currently under an APVMA permit until 30 September 2019, PER14772) can be applied throughout the growing season to protect fruit. Only 2 applications of Amistar® are permitted per season to avoid resistance developing. Only 4 applications of captan are permitted per season, with a minimal interval of 28 days between applications. Only 3 applications of iprodione are permitted per season, with a minimal interval of 60 days between applications. Refer to the *APVMA PubCris* website for more information.

Fungicide sprays are usually applied at petal fall, early December and early March. However, additional sprays may be required if conditions are wet. For more information on the latest spray program for brown spot control contact your local primary industry agency.

- ☑ Choose resistant varieties in regions where conditions favour disease development.
- ☑ Plant trees in areas of the orchard with good air flow.
- ☑ Prune trees to improve air circulation to reduce the length of time that leaves are wet.
- ☑ Remove dead and diseased wood and burn if possible.
- ☑ Source new trees from nurseries that are free of the fungus.
- ☑ Apply protectant and other registered fungicides as part of a brown spot management program.
- ☒ Do not overfertilise trees with nitrogen which promotes excessive production of susceptible lush new growth.
- ☒ Avoid overhead irrigation.

Figure 184. Brown spot symptoms on leaves.

Figure 185. Brown spot symptoms on young shoots.

Figure 186. Brown spot lesions on fruit.

Figure 187. Leaf infected with brown spot showing blackening of the leaf margin.

Figure 188. Brown spot lesions on fruit.

## Cachexia (xyloporosis)

Cachexia affects some mandarin varieties and tangelos as well as Rangpur lime and *Citrus macrophylla* rootstocks. Symptoms are severe in Orlando, Seminole and Wekiwa tangelos, Clementine mandarin and Ellendale tangor (Figure 189). Cachexia is rarely seen in Australia, especially with the availability of healthy budwood from the Australian Citrus Propagation Association Inc. (Auscitrus).

### Cause

Citrus cachexia viroid (CVd-IIb), synonymous with hop stunt viroid, is latent in some old citrus varieties. The viroid is carried in the plant sap and can be transmitted from tree to tree by budding or grafting, and mechanically by pruning and hedging activities. Natural grafting of tree roots can also transmit the viroid between trees. It is not transmitted by sap sucking insects.

### Symptoms

The disease is characterised by inverse pitting of the bark with associated gumming (Figure 190). In order to detect these symptoms in a symptomatic scion the bark must be removed just above the bud union. Affected trees are stunted with yellowing of the canopy and general tree decline. Rootstock sprouting at the bud union is also common.

Figure 189. Symptoms of cachexia on Ellendale tangor showing as stunted trees with yellowing of the canopy.

Figure 190. Inverse pitting and gumming of the bark of Ellendale tangor caused by the citrus cachexia viroid. (Note rootstock sprouting on left tree stump).

### Control

- ☑ Any trees showing symptoms of cachexia should be tested by Auscitrus or NSW Department of Primary Industries (DPI) to verify the presence of the viroid. Infected trees must be removed.
- ☑ Only purchase nursery trees that have been propagated with budwood from Auscitrus.
- ☑ Always sterilise pruning and hedging equipment between trees and blocks. Use a 1% sodium hypochlorite (NaOCl) solution to sterilise all pruning and grafting equipment. If using household bleach (5.25% NaOCl), mix 1 part with 4.25 parts water and if using commercial products (12.5% NaOCl) mix 1 part with 11.5 parts water.

  Dilution rate = (% NaOCl of bleach product ÷ by % NaOCl of solution required) – 1 = parts of water required. For example: (12.5 ÷ 1) – 1 = 11.5 parts water. So, 100 mls of bleach (12.5% NaOCl) should be mixed with 1150 mls of water to make a 1% solution. **Note: Chlorine products are corrosive to metals.**

## Citrus tristeza virus (CTV)

Different strains of the virus cause various diseases including grapefruit stem pitting, orange stem pitting and quick decline of orange and mandarin varieties on sour orange rootstock. CTV is the reason that sour orange and smooth seville are not used as rootstocks for these scions in Australia. Orange stem pitting (OSP) only occurs in Queensland and it is illegal to move citrus budwood or trees from Queensland interstate.

Grapefruit stem pitting affects mainly grapefruit scions and OSP strains of CTV cause symptoms in Ortanique, Sunburst, Osceola, Nova, Malvasio and Page mandarins. Although other mandarins can be infected by OSP they are highly tolerant.

There are also other mandarin stem pitting strains that are exotic to Australia. If any stem pitting symptoms are seen on mandarins they should be immediately reported to the primary industry agency in your state or the Exotic Plant Pest Hotline (1800 084 881) for further investigation.

### Cause

The virus is spread in infected budwood and by the brown citrus aphid (*Toxoptera citricida*).

### Symptoms

Stem pitting (Figure 191) causes a range of symptoms including tree stunting, twig dieback, leaf yellowing and curling and lopsided or small fruit. If the bark is removed fine furrowing or pitting of the wood can be seen. In mandarins on *C. macrophylla* pitting would be seen in the rootstock. Quick decline causes rapid decline of mature trees or slower decline of young trees, but it is not seen in Australia because smooth seville and sour orange are not used as rootstocks for mandarins. Other commonly used rootstocks in Australia are tolerant to CTV. For more information on CTV tolerance see the Rootstocks chapter.

Figure 191. Stem pitting in mandarin in SE Asia.

### Control

- ☑ Remove and destroy infected trees.
- ☑ Only buy nursery trees produced using budwood from Auscitrus.
- ☑ Report any stem pitting symptoms on mandarins to your state's primary industry agency.
- ☒ Do not use *C. macrophylla,* smooth seville, sour orange or Savage citrange rootstocks for mandarins.
- ☒ Do not take citrus budwood or trees from Queensland into other states.

## Collar rot

Collar rot is a fungal-like disease caused by *Phytophthora citrophthora* (more common in the cooler southern regions) and *P. nicotianae* (more common in warmer climates). These pathogens also cause root and brown rots of citrus. Spores of the fungus in the soil are splashed onto the trunk in soil and water and can be carried up the trunk by snails. As the rootstock is usually more resistant than the scion, ensure the bud union is well above soil level. Rootstocks vary in their tolerance to infection (see Phytophthora root rot for rootstock susceptibility). Mandarin scions are more tolerant of collar rot than sweet oranges or lemons.

### Symptoms

Affected bark is wet, soft and discoloured and gum is often exuded. Later the bark dries and cracks (Figure 192). Yellowing and dieback of limbs does not occur until the disease is advanced. Collar rot often follows a period of damp or wet weather.

### Control

Protectant copper products and phosphorous acid are registered for control of the disease in citrus. For more information on phosphorous acid refer to Phytophthora root rot.

- ☑ Select nursery trees that are budded high.
- ☑ Keep the bud union well above soil level.
- ☑ Avoid wounds to the tree trunk.
- ☑ Ensure tree trunks are not standing in water for long periods of time and microsprinklers are not placed close to the tree trunk.
- ☑ On trees with trunk guards ensure soil does not build up around trunk from ant activity. (Figure 193)
- ☑ Apply protectant copper sprays to tree skirts before rain in autumn.
- ☑ Apply foliar sprays of phosphorous acid in autumn or late winter. Take care when applying to young mandarin trees as it can cause leaf burn.
- ☑ When collar rot occurs, pare away the infected bark from healthy tissue and paint with a copper based paint.

Figure 192. Old symptoms of collar rot typically occurring just above soil level, showing callous formed on the edge of the wound sealing off the infected area.

Figure 193. Collar rot caused by soil build up within the tree guard from ant activity at the base of the tree.

## Crotch rot and other wood rots

The melanose fungus *Diaporthe citri* (*Phomopsis citri*) causes various wood rots in citrus, including crotch rot in Hickson mandarins (Figure 194).

Generally the fungus only invades the wood after it has been damaged or weakened by other causes, such as drought or water stress. The fungus enters healthy tissue through wounds or dead twigs. The fungus causes a cinnamon brown discolouration of the bark with a well-defined margin between healthy and diseased tissue, often with streaks of yellow gum.

Crotch rot of Hickson mandarins is a serious disease in coastal areas identified by a rotting of wood in the tree crotch. The forking of trees and the weight of fruit on branches causes cracking, traps moisture and infection occurs in the freshly exposed tissue. Once infected the fungus grows through the trunk or limbs, eventually girdling the tree, causing death.

### Control

- ☑ Avoid moisture stress.
- ☑ Prune branches and stems off below the infected wood. Large pruning cuts should be painted with a copper paste.
- ☑ Keep trees free of dead wood.
- ☑ Protectant copper sprays used for disease control can help reduce infection.

Figure 194. Crotch rot symptoms on Hickson mandarin caused by wood invasion by *Diaporthe citri*.

## Diplodia wood rot

The Diplodia fungus causes wood rot with copious amounts of gum exuded on the surface (Figure 195). It most commonly appears in summer or autumn and when trees have been subject to moisture stress. *Diplodia gummosis* has been associated with Hickson, Fallglo and Robinson mandarins. *Diplodia citricola* has been identified in Daisy mandarin.

### Control

- ☑ Avoid wounds to the trunk of trees and take care when pruning off side shoots.
- ☑ Avoid moisture stress.
- ☑ Remove affected bark and the discoloured wood beneath it. This may require limb removal. Paint the wood with a copper paste.

Figure 195. Gumming associated with the Diplodia fungus on Daisy mandarin.

## Dry rot

### Cause

Dry rot is caused by the yeast *Nematospora coryli* which sometimes infects mandarins. *Nematospora coryli* commonly infects the seeds of tropical and subtropical fruits. The yeast is spread to fruit by the feeding activity of certain insects, such as the spined citrus bug and the green vegetable bug.

### Symptoms

Affected fruit usually have no obvious external symptoms so detection is difficult without cutting the fruit. Internally the fruit flesh is dry and brittle. Sometimes not all the juice sacs are affected. The albedo develops a brown, gummy discolouration and the seeds of the fruit are shrivelled and brown (Figure 196). Symptoms can often be confused with those of boron deficiency, endoxerosis or damage from spined citrus bug.

### Control

Control is limited to managing the insect vectors.

Figure 196. Symptoms of dry rot in mandarin fruit.

## Exocortis

Exocortis or scaly butt was a major disease in the 1940–50s. The disease is rarely seen now because of the widespread use of pathogen-free budwood from the Auscitrus budwood scheme. The disease can still occur if nurserymen or orchardists use their own budwood.

### Cause

Citrus exocortis viroid (CEVd) can infect all citrus varieties but its presence is symptomless in most. Symptoms develop when infected budwood is grown on susceptible rootstocks such as *C.*

*trifoliata* and Rangpur lime. It is not usually seen in Swingle citrumelo or the citranges in Australia. No symptoms are seen on rough lemon, sweet orange and mandarin rootstocks.

The viroid is carried in the plant tissue and can be spread from tree to tree by budding or grafting, pruning and hedging activities. Natural grafting of tree roots can also transmit the viroid between trees. Ease of mechanical transmission varies with the scion. Exocortis is not transmitted by sap sucking insects and seed transmission is unknown.

The exocortis viroid is extremely resistant to both high temperatures and dry conditions and can remain infective on propagation and pruning equipment for long periods of time.

### Symptoms

On *C. trifoliata*, the most severely affected rootstock, symptoms of bark scaling (cracking and bark peeling; Figure 197) and stunting (Figure 198) first appear below the bud union when trees are about 4 years old.

Other symptoms include yellowing of the canopy and general tree decline. Exocortis has no affect on fruit quality, but because it stunts trees the viroid severely reduces yield.

Figure 197. Stunted tree growth caused by infection by exocortis.

### Control

Any trees showing symptoms of exocortis need to be tested by Auscitrus or NSW DPI to verify the presence of the viroid. All infected trees need to be removed.

- ☑ Only purchase nursery trees that have been propagated with budwood from Auscitrus.
- ☑ Always sterilise pruning or hedging equipment between trees and blocks, particularly those on susceptible rootstocks such as *C. trifoliata* and Rangpur lime. Use a 1% sodium hypochlorite (NaOCl) solution to sterilise all pruning and grafting equipment. **Note: Chlorine products are corrosive to metals.**

  Dilution rate = (% NaOCl of bleach product ÷ by % NaOCl of solution required) – 1 = parts of water required. For example: (12.5 ÷ 1) – 1 = 11.5 parts water. So, 100 mls of bleach (12.5% NaOCl) should be mixed with 1150 mls of water to make a 1% solution.

Figure 198. Late stage symptom of exocortis showing bark peeling on *C. trifoliata* rootstock.

## Greasy spot

Greasy spot affects all citrus varieties and is common in coastal areas with wet conditions during spring or autumn or in inland areas in autumn when rainfall is more frequent or overnight dews occur.

### Cause

The fungus *Mycosphaerella* sp. present on decomposing citrus leaf litter causes greasy spot. Rainfall is necessary for spore release and infection occurs through the leaf stomata.

### Symptoms

Leaves are mostly affected and symptoms rarely occur on fruit. Greasy spot first appears as yellow spots on the upper leaf surface (Figure 199) with corresponding raised yellow blisters on the underside of leaves (Figure 200). Over time the spots become darker (Figure 201) with an oily or greasy appearance. Severe infections can lead to defoliation, especially if trees are stressed or in poor health.

Figure 199. Yellow spots on the leaf surface.

Figure 200. Yellow blisters on the underside of leaves.

Figure 201. Spots become darker over time.

## Control

- Apply protectant copper fungicides in spring and autumn, particularly if conditions are damp, showery or wet.
- The use of horticultural spray oils can hinder and delay symptom development.
- Keep trees healthy.
- Remove or cover the fallen leaf litter with mulch (e.g. straw).

## Lemon or citrus scab

In Australia citrus scab is commonly called lemon scab because it is mainly a disease of lemons. However, it can also affect some mandarins, tangelos, grapefruit, Rangpur lime and rough lemon rootstocks. It does not affect oranges or Tahitian limes in Australia. Rough lemon rootstock can act as a source of the inoculum. Lemon scab is a problem in the humid citrus growing regions of Qld, NT, coastal NSW and WA.

Lemon scab is rarely seen on mandarins in Australia as the pathotypes of the fungus present here do not readily infect mandarins. Fungicides used to control other diseases also prevent infection. Mandarin varieties such as Afourer, Emperor, Fremont, Kara and tangelos are susceptible to scab, while Imperial mandarin is resistant. Scab is common on Murcott tangors in the USA. Any scab symptoms on any citrus variety other than lemons should be reported to your state's primary industry agency or the Exotic Plant Pest Hotline (1800 084 881) as the symptoms may be the result of an exotic pathotype.

### Cause

Lemon scab is caused by the fungus *Elsinoë fawcettii* var. *scabiosa*, but many pathotypes exist. Moist conditions favour disease development. Spores of the fungus are readily produced on scab lesions on leaves and fruit and are dispersed in the orchard by rain, overhead sprinkler irrigation and during spraying operations. Dry spores can also be spread by winds in greater than 2 m/s.

Recently a new pathotype of *Elsinoë australis* was found on the fruit of finger limes (*C. australasica*) at a site in Queensland. The lesions were slightly raised, corky scabs and light brown to grey. The pathotype was used to artificially infect Murcott tangors, but did not produce symptoms in mandarin, orange, lemon or grapefruit cultivars tested.

### Symptoms

Lemon scab infects fruit, young leaves and twigs, producing slightly raised, irregular scabby or wart-like lesions (Figure 202). At first these lesions are grey or pinkish, but darken with age, and tend to be corky on top. On lemons the lesions are more common on fruits than leaves (Figure 203). Leaf growth is often distorted and lesions appear as wart-like structures on one side and as a depression on the other side of the leaf. The raised lumps associated with lemon scab can sometimes be confused with symptoms caused by the grey mould fungus (*Botrytis*) or wind rub abrasions on young fruit.

Lemon scab should not be confused with the symptoms of citrus canker, sweet orange scab or other forms of citrus scab not present in Australia. Symptoms of these two exotic diseases are provided here for your information. Citrus canker, caused by the bacterium *Xanthomonas citri* subsp. *citri*, is not present in Australia. Outbreaks have occurred in Australia but have been eradicated. The most recent outbreak was in 2005 at Emerald; the area was declared free of the disease in 2009.

Figure 202. Lemon scab lesions on mandarin leaves. Photo: Malcolm Smith.

Figure 203. Lemon scab lesions on Eureka lemon fruit and leaves.

Citrus canker lesions are usually raised, coloured tan to brown and surrounded by an oily water soaked margin and a yellow ring or halo (Figure 204). Large or old lesions may have a crater like appearance. Leaves, fruit and stems may be infected (Figure 205).

On leaves the growth is usually not distorted and the raised scabby lesions appear on both sides of the leaf. Lesions are crater like, with a corky texture and have a water soaked margin. They may be surrounded by a yellow halo, or have a 'shot hole' appearance if the centre of the lesion has dropped out. The size of the lesion depends on the age of tissue at the time of infection and the mandarin cultivar. Lesions often follow the feeding galleries of citrus leaf miner.

Lesions on the fruit are always raised and have a cracked circular appearance. The lesions may have a water soaked margin or yellow halo. It is unusual to see multiple lesions on fruit or stems without lesions being present on leaves.

Sweet orange scab (Figure 206), a fungal disease caused by *Elsinoë australis*, and many other exotic forms of citrus scab are not present in Australia. These exotic forms of citrus scab have a much wider host range than lemon scab, in some cases affecting oranges, mandarins, grapefruit, limes, lemons and kumquats. These exotic forms occur in South America, Korea and the USA. Symptoms occur mainly on fruit. The corky, scab like lesions are grey to very light brown. The lesions can be scattered or coalesce to form large scabby patches. Sweet orange scab lesions are usually smoother in appearance than lemon scab or citrus canker lesions.

If unusual scab-like symptoms appear on sweet oranges or mandarins (Figure 207), expert advice is needed to confirm that the trees or fruit are not affected by one of these two exotic diseases. Contact your state's primary industry agency or the Exotic Plant Pest Hotline (1800 084 881).

Figure 204. Citrus canker lesions on Minneola tangelo fruit.

Figure 205. Citrus canker lesions on Imperial mandarin leaves.

Figure 206. Sweet orange scab symptoms on orange fruit.

Figure 207. Scab lesions on Afourer mandarin fruit and leaves in New Zealand. Photo: Malcolm Smith.

### Control

Only copper fungicide sprays are currently registered to control scab. Susceptible young leaves and fruit need to have a protective covering of copper when moist conditions are prevalent. As the fruit grow and the protective copper coating is stretched and removed by wind and rain it may need to be re-applied.

Fruit are susceptible to infection for 6–8 weeks after petal fall. Leaves are most susceptible just after emergence and are tolerant to infection by the time they are half to fully expanded.

- ☑ Moist cool weather favours disease development.
- ☑ Apply a protectant copper spray when conditions are conducive to disease development.
- ☒ Some copper sprays can darken skin blemishes.

## Melanose

In coastal, subtropical and tropical regions of Australia, melanose is one of the most important diseases causing fruit to be downgraded, especially in older trees. The incidence of melanose usually increases as trees age and the amount of dead wood in the canopy increases.

### Cause

Melanose is caused by the fungus *Diaporthe citri*. Spores of the fungus arise from fruiting structures (pycnidia) that develop in dead citrus tissue, particularly small twigs that have died within the previous few months. The spores are released by rainfall and splash onto fruit, particularly those situated near the source of inoculum. At 25 °C, periods of continuous wetness exceeding 9–12 hours are required for spore germination and penetration of host tissue. Much longer periods of wetting are required for infection if the temperature drops below 20 °C.

### Symptoms

Melanose attacks foliage, fruit and twigs in the very immature stage. As these tissues mature they become resistant to infection, so that by eight or nine weeks after petal fall no further infection of fruit can occur. Damage is superficial and does not affect internal fruit quality. On the fruit, leaves and small twigs, small, dark brown to black spots are produced that are raised and rough to touch. The melanose lesions on fruit vary in size and appearance depending on the age of the fruit at the time of infection and the number of spores. 'Mudcake' melanose develops when the rind is heavily infected with numerous spores soon after petal fall (Figure 208). 'Flyspeck' melanose develops when fruit are either infected early with a few spores or with numerous spores when the fruit is more mature (Figure 209). 'Tearstain' melanose forms when spore laden water drips over fruit during rain. The melanose fungus also causes wood rot and phomopsis stem-end rot of fruit (see Crotch rot and other wood rots).

### Control

Timing of protectant copper sprays is very important. The initial application should be made at petal fall. This gives about 4–6 weeks protection, depending on weather conditions. In wet weather another copper application may be needed, especially if melanose is a serious problem. The melanose fungus harboured in dead wood throughout the framework of the tree is little affected by the copper sprays.

- ☑ Keep trees free of dead wood.
- ☑ Apply copper fungicides to prevent infection.

Figure 208. Mudcake melanose on fruit.

Figure 209. Flyspeck melanose on fruit.

## Phytophthora root rot

*Phytophthora* is a fungal-like disease organism commonly found in Australian soils. It causes collar rot, root rot and brown rot in citrus. *Phytophthora* is active in wet conditions and is a problem in poorly drained soils. Citrus rootstocks have varying tolerances to root rot (Figure 210 and Figure 211). *C. trifoliata* is highly resistant to the fungus; the citrange rootstocks (Troyer, Carrizo and Benton) and Swingle citrumelo have good tolerance; Cleopatra mandarin has intermediate tolerance, while rough lemon, *C. volkameriana*, and particularly sweet orange, are the most susceptible to infection.

### Cause

Phytophthora root rot is a fungal-like disease caused by *Phytophthora citrophthora* and *P. nicotianae,* which are common in Australian citrus growing regions. *P. citrophthora* is more common in the cooler southern regions and *P. nicotianae* is more common in warmer climates.

*Phytophthora* requires moisture for spore production, dispersal and germination. However, the fungus can remain dormant in the soil during unfavourable dry conditions. Temperature and soil pH can also influence activity. *Phytophthora* thrive in warm, moist soils with a pH between 5.5 and 7.5. The fungus enters the tree through wounds or directly into the growing tip of the feeder roots.

Figure 210. Rough lemon (left) and *C. trifoliata* (right) rootstocks artificially innoculated with *Phytophthora citrophthora,* showing death of roots only on rough lemon.

Figure 211. Phytophthora root rot symptoms on a tree on rough lemon rootstock (left) compared to healthy trees on *C. trifoliata* rootstock.

### Symptoms

Affected trees show symptoms including thinning of the foliage, sparse new growth and reduced tree vigour, yellowing, dull or bronzed foliage, yellow veins and dieback of twigs and branches.

Inspection of the tree roots is required to identify the extent of the root rotting. Affected feeder roots are colourless or tan to dark brown and decayed. In feeder roots the outer covering of the root (cortex) can be sloughed off leaving only the central core (stele). Infection can also extend into the larger roots, causing root lesions and extensive discoloration and death.

### Control

Use tolerant rootstocks in regions with high rainfall, areas with shallow or heavy soils or those with impeded drainage, or in re-plant situations. Monitor soil moisture levels in the orchard to avoid over-irrigation.

The only chemical registered for the control of Phytophthora root rot in citrus is phosphorous acid applied as a foliar spray. Phosphorous acid (also referred to as phosphonic acid or phosphonate) protects roots against the *Phytophthora* fungus, so trees need to have some healthy roots for it to be effective. Phosphorous acid does not reduce populations of *Phytophthora* in the soil, but has a dual action in the plant: it directly inhibits the growth of the fungus and indirectly stimulates the plant's natural defence mechanism.

Phosphorous acid is highly systemic and mobile, but regardless of application method it moves with the sap flow to that part of the plant most actively growing. Therefore timing of application is very important and needs to occur when there will be effective translocation from the leaves to the roots. Based on this information, application would be best targeted in autumn or late winter, prior to flowering and fruiting or onto spring growth after leaf flushing has finished.

Follow all label directions carefully as phosphorous acid can cause leaf burn in young mandarin trees. Do not apply to moisture stressed trees or in high temperatures (>35 °C), particularly if humidity is low.

- ☑ Select soils suitable for citrus. Soils should have good drainage. In shallow or heavy soils mound the tree row to improve soil depth and drainage.
- ☑ Choose the best Phytophthora-tolerant rootstock for the soil conditions.
- ☑ Purchase new trees from Phytophthora-free nurseries.
- ☑ Monitor soil moisture to avoid over-irrigation.
- ☑ Choose nursery trees that have been budded high.
- ☑ Apply foliar sprays of phosphorous acid in autumn or late winter, prior to flowering. Take care when applying to young mandarin trees as it can cause leaf burn.

## Pink disease

Pink disease is common in wet humid tropical or subtropical areas close to remnant rainforest. It affects many woody plant species.

### Cause

The disease is caused by the fungus *Erythricium salmonicolor*. Spores of the fungus are carried by wind or rain onto the tree where it can penetrate the woody tissue under suitable conditions.

### Symptoms

The fungus forms a pink, smooth, velvety crust over trunks and branches (Figure 212). Over time the fungus will penetrate and kill the bark, often ringbarking the branch. Infected branches may produce gum, which is dry and hard and adheres closely to the wood.

Figure 212. Branch showing symptoms of pink disease.

### Control

- ☑ Prune out diseased branches and burn. Apply copper based paints to pruning cuts.
- ☑ Apply protectant copper fungicides during the rainy season.
- ☑ Prune trees to improve air and light penetration into canopies.

## Septoria spot

Septoria spot can be an important disease in inland areas if protective copper sprays are not applied. Symptoms usually appear in winter with the onset of cold conditions, particularly frost, or after harvest when fruit are put in cold storage. Usually only late maturing varieties will be affected.

### Cause

Septoria spot is caused by the fungus *Septoria citri*. The fungus occurs saprophytically on infected twigs, dead wood and leaf litter. The water-borne spores are dispersed by rain and irrigation water. Fruit must be continuously moist over several days for infection to occur. Infection commonly occurs in late summer and autumn after damp weather and while fruit are still green. The fungus remains latent in the fruit until cold weather (especially frost) allows it to develop in late winter–early spring.

### Symptoms

Small, round (1–2 mm), sunken pits first appear on the fruit surface (Figure 213). Initially the pits are light tan becoming reddish brown to pale brown as fruit mature. The pits may enlarge and coalesce to form deeply sunken, dark brown or black blotches across the fruit surface (Figure 214). Small black dots (pycnidia – fruiting bodies) may be produced in the lesions. Symptoms can occur on fruit on the tree, often resulting in fruit fall, but more commonly appear after harvest in cool storage.

Figure 213. Symptoms of septoria spot on citrus fruit.

Figure 214. Various symptoms of septoria spot on citrus fruit.

### Control

- ☑ Apply a protective copper spray in mid-February to March before autumn rain. A second spray may be required if wet conditions persist.
- ☑ Keep trees free of dead wood.
- ☑ Skirt trees to reduce water splash from the soil onto low hanging fruit.
- ☑ Remove leaf litter and fallen fruit.
- ☑ Use frost prevention measures.

## Sooty blotch

Sooty blotch (*Gloeodes pomigena*) occurs as a superficial black coating on the rind of fruit. The black colouring is due to the growth of fine fungal threads that live on the surface tissue of the fruit (Figure 215).

Sooty blotch is common in coastal, subtropical and tropical regions after a wet autumn or winter. Both shade and high humidity are conducive to the development of sooty blotch, with fruit on the southern sides and inside of trees most affected.

Although causing only superficial damage sooty blotch makes the fruit unsightly. It can be difficult to remove on the packing line, especially from cultivars with a rough rind.

Figure 215. Sooty blotch on fruit.

### Control

- ☑ Copper sprays used for the control of other diseases will provide some protection.
- ☑ Prune trees to improve light and air penetration.

## Sooty mould

Sooty mould is a black, superficial fungal growth that appears on the surface of leaves (Figure 216), stems and fruit (Figure 217) after trees become infected with honeydew excreting insects. Although sooty mould does not penetrate the tissue, it may affect tree performance by reducing photosynthesis. The mould deposits may delay fruit colouring. Good packing line procedures will normally remove the blemish from smooth skinned varieties, but it may be difficult to completely remove from rough skinned varieties.

### Control

Sooty mould is prevented by controlling the honeydew excreting insects such as aphids, soft scales and mealybugs, and also the ants that protect them. The use of horticultural mineral oils for pest control can also dislodge the mould from plant surfaces.

Figure 216. Sooty mould on leaves.

Figure 217. Sooty mould on fruit.

## Sudden death

Sudden death affects all citrus varieties, predominately those on *C. trifoliata* and Carrizo or Troyer citrange rootstocks. Trees of all ages can be affected but the incidence of sudden death is greatest in trees that are 7–15 years of age.

### Cause

No definitive pathogen has been identified as the cause, but sudden death is associated with poorly aerated and/or poorly drained soil. It most commonly occurs on heavier soils, or where drainage problems occur such as perched water tables and layers of compacted soil, leading to temporary waterlogging.

### Symptoms

Affected trees wilt and die rapidly, often with a good crop of fruit still on the tree (Figure 218). If the tree roots are inspected, one or more of the structural roots will be blackened or dead, with a brown discolouration extending from the dead root into and across the tree butt, stopping at the bud union (Figure 219). The discoloured wood smells of rancid coconut oil.

Figure 218. A mature tree that dies suddenly with fruit still attached – typical of sudden death.

### Control

- ☑ Plant citrus on suitable soils that are well drained.
- ☑ Monitor soil moisture to prevent over-watering.

Figure 219. Roots of *C. trifoliata* affected by sudden death showing wood discolouration stopping at the bud union.

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Diseases

# Disorders

## Introduction

There are a number of physiological disorders that affect mandarins. These disorders are not caused by a pest or disease, but can occur as a result of climatic conditions, variety and/or management practices.

## Albedo breakdown or creasing

Albedo breakdown or creasing is a physiological disorder caused when the cells in the albedo, (white internal rind) separate from the flavedo (external rind; Figure 220). The actual cells remain intact, but when the cells separate at the cell wall junction a crack forms in the albedo (Figure 221) and this can then spread. These underlying cracks in the albedo cause the surface of the fruit to become creased.

Creases appear irregularly on the fruit surface (Figure 222), ranging from just a few to severe cases where the whole fruit is covered (Figure 223). Severely affected fruit are soft and lumpy and may be prone to splitting when packed. Research has shown that fruit with albedo breakdown have lower calcium levels in the albedo. In oranges both variety and rootstock can affect the incidence of albedo breakdown. The incidence of albedo breakdown can be sporadic and varies with season and growing location.

Mandarin varieties affected include Taylor Lee, Hickson, Nova, Daisy, Ellendale and Murcott tangors.

Maintaining adequate calcium levels in the tree and the application of foliar calcium sprays in January/February to increase levels in the fruit rind are recommended management strategies.

Gibberellic acid (GA) sprays are also used to reduce the incidence of albedo breakdown by delaying rind maturation. The application of GA on mandarins at the wrong time can prevent fruit from colouring. It can also cause rind staining on some varieties (see the Crop management chapter).

For more information on GA refer to *'Using gibberellic acid sprays on navel oranges'* (Lindhout et al. 2008), or contact the product manufacturer.

Figure 220. Outer layers of mandarin fruit.

Figure 221. Cracks in the albedo of a mandarin fruit.

Figure 222. Creases on the fruit surface.

Figure 223. Mandarin fruits with symptoms of creasing.

## Frost damage

The sensitivity of trees to frost damage is dependent on a range of factors, including variety, rootstock, tree size, foliage and fruit maturity, tree conditioning to cold temperatures and tree health. Mandarin trees vary in their cold tolerance with Satsuma mandarin trees being the most tolerant.

Damage is caused by ice formation inside the plant cells. Fleshy plant parts, such as leaves, shoots and fruit, are damaged by ice forming inside the tissues. Ice crystals grow in the space between the cells and draw water out of the cells (Figure 224), leading to dehydration of the cells. As the ice melts it ruptures the cell walls and damages the cell. The amount of damage caused by frost is largely dependent on the temperature and the length of time trees are exposed. Generally the lower the temperature and longer the duration of exposure, the greater the damage (O'Connell et al. 2011).

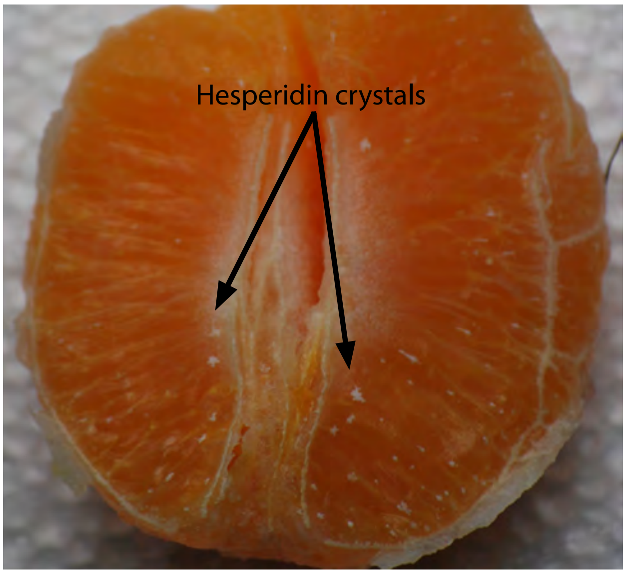



Figure 224. Hesperidin crystals inside fruit following frost injury.

Critical damage temperatures for citrus are related to scion and rootstock variety as well as the maturity of foliage and fruit. *Citrus trifoliata* is the most cold tolerant rootstock.

Although mandarin trees are quite frost hardy, the fruit are more susceptible to frost damage than other citrus varieties due to their thin skins and small size. Mature citrus leaves can tolerate −6.1 °C to −1.7 °C and dormant wood −6.7 °C for up to four hours, while soft leaf flush can be damaged by temperatures of only −1.1 °C (O'Connell et al. 2011). Critical damage temperatures are listed in Table 68.

Table 68. Fruit temperatures at which freezing begins.

| Development stage | Temperature |
|---|---|
| Half ripe mandarin fruit | −2.2 °C to −1.7 °C |
| Ripe mandarin fruit | −2.8 °C to −2.2 °C |
| Buds and blossoms | −2.8 °C |

Source: O'Connell, Connell and Snyder 2011.

### Tree damage

Young trees and the youngest leaves and shoots are the most susceptible to damage. (Figure 225) In cold conditions citrus leaves naturally droop or roll, regaining their turgidity when temperatures rise. When leaves roll, sunlight hits the moisture on the leaf causing the surface to turn pale brown and blacken with age, appearing as tar spotting on the underside of leaves (Figure 226). Mild frost damage causes the leaves to be quickly shed, so extensive leaf fall shortly after a frost is an indication that damage was mild. Severe frost damage where the leaf petiole (stalk) has been killed, results in the leaves becoming dry and brittle and remaining attached to the tree for several weeks (Figure 227).

Where trees have lost all their leaves, the trunk and branches may be susceptible to sunburn, so trees should be whitewashed for protection.

Frost damage may cause blackening and dieback of shoots and twigs, and in severe cases bark splitting and lifting on the trunk and branches. The full extent of frost damage to trees can take many months to become obvious as twig and branch dieback continues. The best thing to do immediately after a frost is nothing. Pruning out dead wood should be carried out in mid to late spring in the following season.

Fertiliser and irrigation applications to frost affected trees should be managed to take any damage into consideration.

Figure 225. Frost damage to a newly planted orchard. Photo: Malcolm Smith.

Figure 226. Tar spotting on the underside of leaves caused by cold damage.

Figure 227. Frost damage to a mature tree. Photo: Malcolm Smith.

## Fruit damage

Fruit damage can occur to the peel or the pulp. Immature fruit are more susceptible to damage than mature fruit, which have a higher sugar content. High total soluble solids (TSS) in fruit at the time of a frost can help reduce dehydration and subsequent freeze damage. Small mature fruit are more susceptible than larger mature fruit, which can store more heat.

External fruit damage usually appears within a few days, but can take as long as two weeks to develop. Damage is quite variable and can appear as watersoaked areas on the rind; as a tan to brown mottling (Figure 228) with pitting similar to oleocellosis damage or as extensive blackened areas often invaded by saprophytic fungi.

Internal fruit damage cannot be assessed unless the fruit are cut. There may be no external symptoms. It can take between five to ten days for the damage to be well expressed so fruit assessments should be carried out about 10 days after the frost.

Initially the fruit segments have a watersoaked appearance. As the juice freezes its volume increases, rupturing the juice sacs. Crystals of hesperidin (a flavonoid) may be formed. The crystals can sometimes be seen as white flecks in the flesh and give the fruit an off-flavour. The juice leaks out of the ruptured juice sacs and seeps out through the rind. The empty juice sacs collapse and dry out, leaving behind hollow gaps in the flesh.

If fruit are suspected of having frost damage they should not be harvested until the damage is assessed about 10 days after the frost.

For information on frost protection measures refer to the Orchard basics chapter.

Figure 228. Frost damage to mandarin fruit.

## Fruit splitting

In mandarins fruit splitting develops at the stylar or blossom end of the fruit, which is the weakest point on the rind (Figure 229). Fruit splitting is common in some genetically thin-skinned mandarin varieties. Varieties susceptible to splitting include Ellendale and Murcott tangors, Mor, Nova, Orri, Orlando and Ortanique mandarins and the Clementine varieties Fino, Marisol, Nules and Orogrande (Stander 2013).

Split fruit may drop or remain on the tree. The split may be short and shallow or deep and wide, exposing the fruit segments (Figure 230). The severity of the disorder can vary considerably between seasons.

Split fruit can also be invaded by fungal pathogens, such as *Alternaria alternata*, which causes black centre or core rot. See the Postharvest diseases and disorders chapter.

It is thought that fruit split as a result of the excessive pressure exerted by the expanding pulp on the thin over-stretched rind, particularly during Stage II of fruit development. The flavedo stretches and becomes thinner, but splits because it cannot accommodate the increase in pulp volume. However, the potential for fruit to split is largely a result of any stress to the tree or fruitlets during Stage I of fruit growth (Rabe & Van Rensburg 1996).

Mesejo et al. (2016) demonstrated that, regardless of the citrus species, fruit splitting was a result of unstable tree water status, due to the interaction between soil moisture, rootstock and climatic conditions, causing sharp changes in the growth rate of fruit. For more information on rootstock effects refer to the Rootstocks chapter.

A wide variety of cultural and environmental factors can influence rind quality characteristics and therefore contribute to the occurrence and severity of fruit splitting. These include:

- an irregular or fluctuating water supply
- nutrient imbalances (especially phosphorus and potassium) which affect rind thickness
- warm and humid climatic conditions which can reduce rind thickness
- a heavy crop load.

Research in South Africa has shown that a foliar application of 2,4-D directly after physiological fruit drop to Marisol and Mor mandarins decreased splitting by up to 50% (Stander, Theron & Cronje 2014). The application of 2,4-D at this time increased rind strength and rind thickness at the stylar end.


Figure 229. Basal (stylar) cracking of mandarin.

Figure 230. Severe splitting of Nova mandarins.

## Hail damage

Hail storms can cause significant damage to trees and fruit (Figure 231). The wounds caused by the hail can be invaded by pests such as fruit fly and many fungal disease pathogens.

Depending on the severity of the storm, damage can include:

- leaves, stems and branches broken, bruised or pitted (Figure 232)
- fruit bruised, pitted or missing chunks of flesh (Figure 233)
- leaves and fruit stripped from trees.

Broken or severely damaged branches should be pruned as soon as possible. Severely damaged and fallen fruit should be collected or raked into the inter-row area and mulched.

Trees should be sprayed with a protectant copper fungicide to help prevent fungal diseases from invading any wounds.

Figure 231. Hail damage on Imperial mandarins.

Figure 232. Hail damage to stems. Photo: Malcolm Smith.

Figure 233. Hail damage to a young fruitlet. Photo: Malcolm Smith.

## Internal dryness (granulation)

Internal dryness or granulation is a disorder commonly affecting Imperial mandarins. Fruit show no obvious external symptoms, but when cut the fruit segments appear to be dry, white or colourless and are relatively tasteless (Figure 234 and Figure 235). Fruit have a lower extractable juice percentage, decreased soluble solids and decreased sugar and acid levels.

Although there has been extensive research on granulation and several studies in Australia on the cause of internal dryness in Imperial mandarins no single definitive cause has been identified.

The most recent research undertaken in Australia is published in the HAL project report CT 04002 '*Management of internal dryness of Imperial mandarin*' (Hofman 2013). The following information is from that report.

The main theories on the cause of granulation include:

- sink competition between different plant organs for carbohydrates
- inefficient transport of carbohydrates, water or mineral nutrients into the fruit
- temperature and/or moisture stress
- too rapid growth
- an abnormal maturation process.

Figure 234. A mandarin fruit showing symptoms of internal dryness.

Of these it is the 'sink competition' theory which has the most research support. The most actively growing plant part at the time is normally the strongest 'sink', attracting the most carbohydrates.

The findings from that report identified that:

- granulation is triggered early in fruit development when competition for carbohydrates between young fruit, flowers and the expanding leaf flush may be intense
- seasonal conditions such as warm winters and warmer than average temperatures and/or higher than average rainfall during the early fruit development period may exacerbate competition for carbohydrates between flowers, fruit and leaves
- low crop loads exacerbate the problem.

The following management strategies were suggested to reduce the incidence of internal dryness:

- crop thinning and pruning to reduce biennial (alternate) bearing patterns
- supply additional nitrogen to trees during the Stage I (cell division) period.

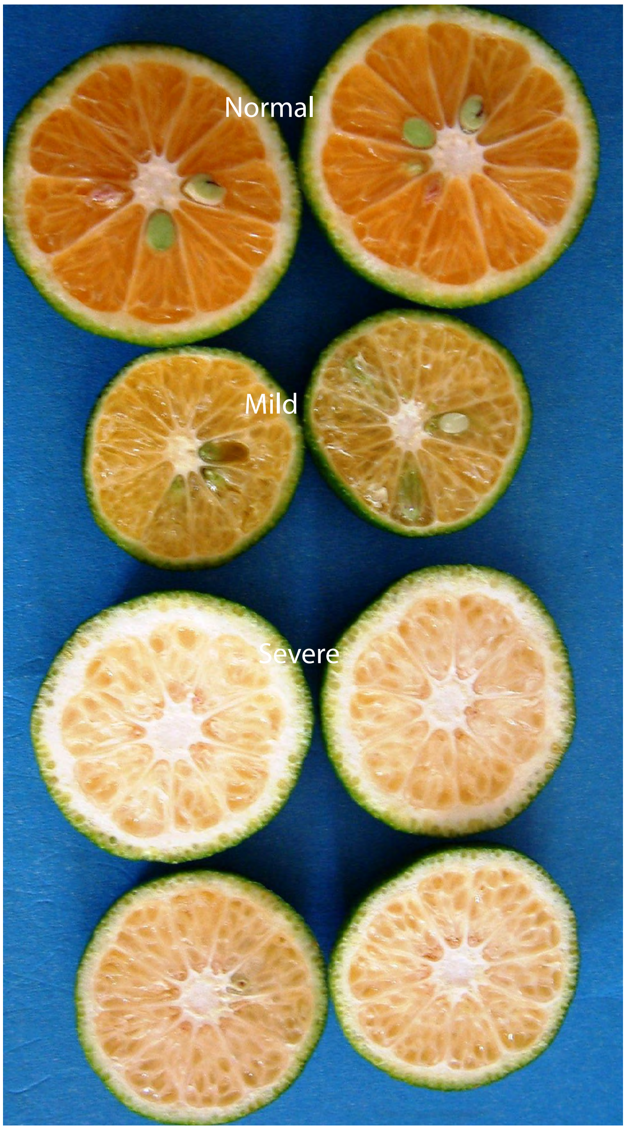



Figure 235. Symptoms of internal dryness from mild to severe compared with a normal fruit.

Because internal dryness is impossible to detect visually, there is much interest in trying to develop a non-destructive method to identify affected fruit on the packing line. Various in-line technologies are currently being assessed.

A recent Australian study to assess the response of consumers to Imperial mandarin fruit with different levels of granulation found that fruit with granulation levels > 55% were not acceptable (Prakash 2016). In this study 154 consumers rated their preference for fruit with three levels of granulation (35, 45 and 55%). The consumers rated attributes which included fruit flavour, sweetness, sourness, juiciness and chewiness.

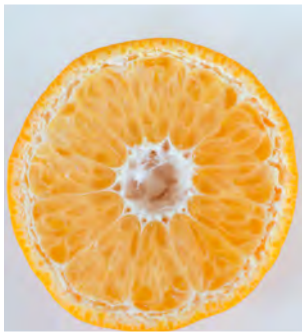
The results of this study suggest that Imperial mandarins with granulation levels of up to 35% were acceptable by consumers on all attributes tested, while fruit with 55% or more granulation were not acceptable. However, the fruit samples in this study had higher average levels of juice (% by weight) than that found by Hofmann (2013) in another study on granulation. The Prakash (2016) study included fruit with average juice levels of 44% (for 35% granulation), 39% (for 45% granulation) and 30% (for 55% granulation). This suggests that the sample fruit used were not particularly 'dry' despite appearing visually granulated. Additionally, consumers were not given a full range of fruit samples to compare and they were not presented with fruit having little or no granulation.

In Spring 2016 Citrus Australia Limited (CAL) released a new sampling method for assessing granulation, as well as a maximum standard for granulation in Imperial mandarins. The standard allows for no more than 3 fruit with > 55% granulation in a 30 piece sample/consignment. Examples of different levels of granulation are depicted in Figure 236. For more information about the sampling method refer to the Harvesting chapter.

< 5% granulation

Up to 35% granulation

35–45% granulation



>55% granulation

Figure 236. Examples of fruit with different levels of granulation. Source: Citrus Australia Limited.

Disorders

## Mandarin scald

Mandarin scald is a rapid decline of trees during a heavy crop or 'on' year, appearing when fruit reach maturity. It is thought that root carbohydrate starvation is the triggering mechanism. All varieties can be affected if crop thinning is not undertaken. Symptoms include leaf wilting, yellowing or defoliation, fruit drop and an excessively large crop of small fruit. Branch dieback and root death may also occur. Depending on the severity of the dieback, the trees may recover in 1–2 years, but usually remain weak and unproductive. This condition is similar to that observed in Murcott collapse.

## Murcott collapse

Some citrus cultivars, particularly mandarins, are prone to alternate bearing. Murcott mandarin can be affected to the point where trees suddenly collapse under a heavy crop in an 'on' year. First symptoms include wilting and yellowing of leaves, followed by defoliation and shrivelling of fruit. Fruit then fall and twigs and branches can die back. Trees appear as if they will die, however most will generally recover. It is believed that as a result of the heavy crop demands, the tree roots are starved of carbohydrates (starch), which is the primary cause of the collapse. To reduce the likelihood of this condition it is recommended that in heavy crop years, crop load is reduced by at least 30–40%, by thinning or pruning. For more information refer to the Crop management chapter.

## Necking

Mandarin fruit shape can be affected by climatic conditions. In cool, humid conditions fruit tend to be flatter and smaller, whilst fruit in hotter, drier regions tend to be rounder, larger and have more prominent necks (Figure 237). Varieties vary in their tolerance to different climatic conditions. See the Varieties chapter and the Climate and phenology chapter.

Figure 237. Necking on Amigo mandarin grown in the Murray Valley, South Australia, which has a dry Mediterranean type climate.

## Papillae (raised pimples or velcro fruit)

This condition is sometimes seen on mandarins, including Imperial and Amigo. The pimples are caused when the oil glands in the fruit peel are modified to produce juice vesicles. Initially they are raised and pimple-like (Figure 238), but as the fruit matures they die, leaving a rough surface blemish (Figure 239). What triggers the oil glands to be modified is unknown. Originally it was thought that it was a genetic based trait, but it is more likely to be induced by certain climatic conditions.

Figure 238. Papillae on a mandarin fruit. Photo: Malcolm Smith.

Figure 239. Rough surface blemish left after the papillae die on an Imperial mandarin fruit.

## Puffiness

Puffiness occurs when the rind separates from the fruit segments causing the rind to become puffy and loose (Figure 240). When this occurs the pulp quickly dries out and becomes woody. It is commonly associated with over-maturity. During fruit maturation (Stage III) pulp growth almost stops in some varieties leading to the formation of cracks between the pulp and the peel. When combined with loosening and degradation of the albedo, these cracks develop into large, hollow air spaces (Figure 241).

Varieties such as Ellendale tangor, Imperial, Hickson and Satsuma mandarins are particularly susceptible. To avoid fruit becoming puffy, they should be harvested at peak maturity and not left to become over-mature. An application of gibberellic acid at three quarters to full colour will delay rind ageing for late marketing. Carefully follow all label directions. For more information refer to the Crop management chapter.

Figure 240. Puffy Imperial mandarin fruit.

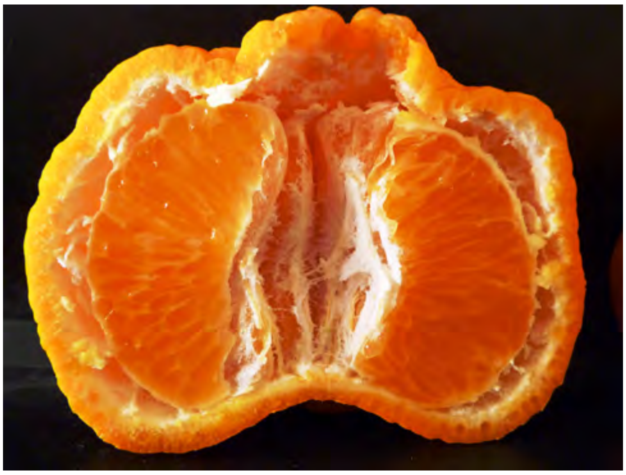


Figure 241. A cross section of a puffy Imperial mandarin fruit.

## Rind staining

Stains on the rind of mandarin fruit can be caused by various foliar sprays. Damage can be caused by applying chemicals:

- at inappropriate rates
- during unfavourable climatic conditions, such as hot weather or under slow drying conditions (Figure 242)
- in mixtures containing several products
- too close in time to other chemical products, such as oil or copper.

Sprays including horticultural mineral oils, wetters, fungicides, insecticides and gibberellic acid (Figure 243) can damage some varieties. Carefully follow all the manufacturer's directions when applying sprays (Figure 244).

Figure 242. Spray injury to seedless Murcott tangor, probably made worse by overcast, showery weather conditions during the growing season. Photo: Malcolm Smith.

Figure 243. Spotting of Murcott tangor caused by the application of gibberellic acid (GA). Spotting can occur in some varieties if GA is applied during, or followed by, cold weather, frosts or unusually wet weather and usually disappears within 10–21 days.

Figure 244. Rind staining on Hickson mandarin (cause unclear).

## Rough/pebbly skin

Some varieties of mandarin, such as Murcott, develop a rough/pebbly rind on the exposed surface, especially on fruit hanging on the outside and tops of trees (Figure 245). In susceptible varieties pruning is used to encourage fruit production inside the canopy and hand thinning is used to selectively remove any fruit likely to be affected.

A rough skin texture can also be a consequence of climatic conditions at the time of fruit set and development. In more humid climates with smaller seasonal diurnal changes in temperature fruit tend to have a smoother skin texture.

The immature fruit of some varieties tend to have rough skin which becomes smoother as fruit mature. Over-mature fruit left on the tree can also develop rough skins.

Rough skin can also be due to an excess of potassium or nitrogen, or a phosphorus deficiency. Nitrogen, phosphorus and potassium levels and their relative ratios can have a major impact on fruit quality characteristics, including skin quality and colour, rind thickness and juice content. For more information refer to the Nutrition chapter.

Figure 245. A Murcott tangor fruit with roughened skin. This fruit was set at a later time (a second crop) to the main crop and developed under different climatic conditions.

## Sunburn

Some mandarin varieties are susceptible to sunburn, including Murcott tangor, Tango, Afourer and Satsuma mandarins. Sunburn appears on the exposed fruit surface, usually on the tops of trees as a circular yellow/white blotch (Figure 246). Over time the damaged area can darken and become rough (Figure 247). Sunburnt fruit tend to be dry inside. Sunburnt fruit are usually removed when fruit are hand thinned. Selective pruning is also used on susceptible varieties to encourage fruit to grow on the inside of trees.

There are several sunscreen products that can be sprayed on trees to prevent sunburn (Figure 248). However, some of these products have been reported to exacerbate scale (especially red scale) and mite populations. Some products can be difficult to remove from the fruit surface during postharvest handling procedures.

Figure 246. Sunburn on exposed fruit surface.

Figure 247. Symptoms of sunburn on mandarin fruit.

Figure 248. Mandarin fruit treated with a commercial sunscreen product.

## Tree splitting

Some varieties such as Ellendale tangor and Hickson mandarins are particularly susceptible to splitting at the fork. Heavy crop loads can also cause the branches of trees to split and break. Limbs carrying heavy crop loads can be supported by timber scaffolds. Ensure that any support structures do not cut into the wood causing the branches to be ringbarked. An old method of trying to save split trees is to bolt the limbs together. A hole is drilled through the branches and a threaded rod is inserted through the holes (Figure 249). Nuts and washers are used to hold the rod and branches in place.

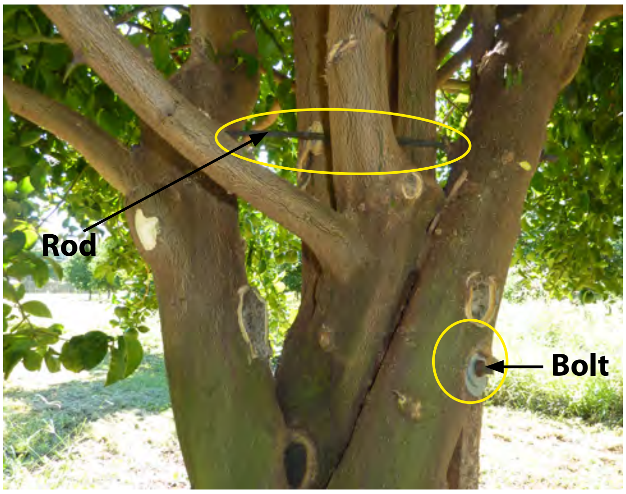



Figure 249. Using a threaded rod and bolt to save a tree that split at the fork. Photo: Malcolm Smith.

## Watermark (water burn)

This problem occurs mainly on mature Imperial mandarins during wet, humid conditions when water collects on the bottom of fruit for extended periods. Watermark first appears as a water soaked area on the base of fruit, developing into a brownish stain, which is somewhat sunken and pitted (Figure 250). The application of gibberellic acid or an autumn copper spray may assist in reducing the severity of this problem by making the rind more resistant to damage.

Figure 250. Water damage to Imperial mandarin.

## Wind blemish

Wind blemish has a silvery grey appearance which darkens as the fruit age (Figure 251). Wind can also cause raised ridges on young fruit, that enlarge as the fruit grow (Figure 252). The use of some copper sprays can also darken the blemish (Figure 253).

Wind blemish on fruit is one of the most important factors reducing fruit quality and accounts for most fruit downgraded in packing sheds. Additionally, wind damage can reduce tree growth rates and yields, damage limbs and cause root damage in young trees. Wind protection is essential in mandarin orchards. For more information refer to the Orchard basics chapter.

Fruit are most susceptible to damage in the first 12 weeks after petal fall. As soon as the petals fall and the small immature fruit are exposed, wind blemish to the rind can occur with any movement of leaves, branches, twigs and dead wood, thorns and other fruit. For more information on windbreaks refer to *'Windbreaks for citrus'* (Owen-Turner & Hardy 2006).

Figure 251. Symptoms of wind damage on fruit.

Figure 252. Wind scarring can also appear as raised ridges on fruit.

Disorders

Figure 253. Wind scars can be darkened by copper sprays.

## Winter yellows

Winter yellows occurs sporadically across different regions and is triggered by unseasonal climatic conditions. Widespread outbreaks of winter yellows in southern Australia have generally occurred when there was unseasonally high rainfall between January and March, promoting a good late summer/early autumn leaf flush, followed by an unseasonal and sudden cold snap. Following the cold snap the youngest shoots turn yellow prior to winter (Figure 254). This condition is known as winter yellows because affected trees are particularly conspicuous during the winter months.

The incidence of winter yellows in an orchard varies from whole blocks of younger trees to individual trees scattered randomly across a block. It most commonly affects younger trees (2–5 years) with little or no crop that have made vigorous shoot growth in late summer–early autumn. Yellowing is less common and less severe on trees carrying a good crop of fruit, because vigorous shoot growth has been somewhat limited.

Leaf yellowing starts adjacent to the leaf midrib, then spreads out along the lateral veins until most of the leaf blade is affected. The amount of growth affected by yellowing varies from just part of a branch to all of the most recent leaf flush. In young trees sometimes the whole tree can turn yellow. In severe cases leaf drop and out-of-season flowering occurs.

The yellowing of the foliage and shoots is thought to be a consequence of the interruption of carbohydrate transport from the leaves to the tree roots, resulting in an accumulation of starch (the main carbohydrate) in the leaves (Figure 254).

Leaf age affects carbohydrate storage and export. No carbohydrates are exported out of the leaves until they are fully expanded (1–2 months), nor during the colder winter months. With the sudden onset of cooler temperatures the leaves and shoots turn yellow because the leaves are too young to export the carbohydrates to other parts of the plant, so carbohydrates are accumulated in the leaves. The leaves stay yellow until the following spring when the starch is able to be transported to other parts of the tree. Sometimes the amount of starch in the leaves will actually rupture the cells, causing permanent damage to the leaves. Because very little or no carbohydrates move into the tree roots, the roots can actually starve and die. Young trees with substantial root death may not recover.

Figure 254. Symptoms of winter yellows showing the autumn leaf flush affected by yellowing.

Figure 255. Leaves become loaded with starch – a symptom of winter yellows.

To reduce the impact of winter yellows:

- ☑ Avoid management practices that encourage a vigorous autumn flush, such as applying excessive amounts of nitrogen, particularly on young trees.
- ☑ Leave some fruit on trees (especially young trees).
- ☑ Reduce irrigation and fertiliser applications to severely affected trees where substantial root death has occurred.

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# Pests

## Introduction

Mandarins, like other citrus varieties, are susceptible to a wide range of pests. The incidence and importance of these pests varies with growing region and seasonal conditions. Pest activity and life cycles are closely related to local weather conditions, which will influence timing of pest management decisions. In warmer regions there are usually a greater number of pests and pest generations per year than in cooler areas.

This chapter outlines the main pests affecting citrus and provides detailed information on some of the more common and economically damaging pests in commercial orchards.

The most comprehensive book on citrus pests in Australia is '*Citrus pests and their natural enemies*', (Smith, Beattie, & Broadley) which was published in 1997. A field guide was also published, but both are now out of print.

Orchards should be regularly monitored throughout the year so that pest problems are identified and managed as early as possible to avoid crop and tree damage and to make control easier.

Pest management should involve a combination of control methods, including cultural and biological control and, if necessary, the targeted use of selective pesticides. Horticultural mineral oil sprays are commonly used to control a wide range of pests in citrus.

Any pesticides used must be registered for use on citrus. Follow all label directions carefully. To check on registered products go to the Australian Pesticides & Veterinary Medicines Authority *(APVMA) PubCRIS* website.

For any fruit destined for overseas markets it is critical to check if maximum residue limits (MRLs) are set in the destination country for any pesticides used. The *Citrus Australia* website has a list of the MRLs for the most common export markets.

## Horticultural mineral oils

Horticultural mineral oils (HMO) are a by-product of the lubricating fraction of petroleum oils. HMO sprays control pests either by suffocation or by altering their behaviour (such as reducing feeding and egg-laying).

HMO are generally applied at high volumes so that the oil forms a thin, even coating over all surfaces. Oils are not poisons and have limited residual activity.

The volume and dose of HMO sprays depends on the type of pest, level of infestation, citrus variety, tree height, canopy density, planting density and proximity to harvest.

The loss of HMO from the tree is more rapid in tropical and subtropical climates than in temperate regions: the higher the temperature, the more rapidly the HMO disappear.

HMO sprays can sometimes damage plants – this is referred to as phytotoxicity. It can occur if HMO are not applied correctly or under the right conditions. Damage can include leaf burning and oil soaking (of leaves and fruit), and in severe cases, leaf drop and reduced yields.

The risk of phytotoxicity is higher if HMO sprays are applied:

- excessively
- at temperatures above 35 °C
- in high humidity (>90%)
- during prolonged cold weather
- within one month of a sulphur spray
- to trees in poor health, water stressed or waterlogged.

### Using HMO sprays

- it is better to apply a higher volume of spray mix than to use a higher concentration of oil in the mix.
- timing is critical: apply HMO when the numbers of the target pest exceed acceptable levels and they are at their most susceptible stage, or when susceptible new growth on trees starts to appear.
- for most pests all plant surfaces need to be thoroughly coated: the upper and lower

leaf surfaces, fruit, twigs, branches and the insides of trees.

- the residual activity of HMO (how long they last) is less in hotter tropical conditions than in cooler temperate climates (oil molecules evaporate quicker in warmer climates).
- where multiple low concentration (<0.5%) HMO sprays are used annually (e.g. for control of pests such as citrus leafminer), apply sprays just to the point of run-off (which is when the spray just starts to drip off leaves). Recommendations need to carefully consider variety, dose (volumes and concentration) and proximity of spray to harvest.
- where only one or two applications of a higher concentration (1%) HMO spray are used annually (e.g. for control of pests such as scales), apply at volumes which exceed the point of run-off (which is when the spray is continuously dripping off leaves).

For more information on HMO see NSW DPI Agfact H2 AE.5 *'Using petroleum-based spray oils in citrus'* (Beattie & Hardy 2005).

**HMO sprays: best practice tips**

- ☑ HMO spray mixtures need to be continuously agitated.
- ☑ Aim to have the HMO spray dry on the tree within 1 to 2 hours of application.
- ☒ Do not apply HMO sprays in temperatures higher than 35 °C, or when relative humidity exceeds 90%, or the ambient shade temperature is more than 32 °C.
- ☒ Do not apply HMO sprays to moisture-stressed trees or waterlogged trees.
- ☒ Do not add additional emulsifiers or surfactants to the HMO spray.
- ☒ Do not mix HMO with incompatible chemicals.
- ☒ Do not apply HMO spray within one month of a sulfur spray.
- ☒ Do not use more than 0.5% concentration HMO with a copper spray.
- ☒ Do not use more than a total (i.e. %HMO × # applications) oil concentration of 3% in tropical and subtropical climates and 2.5% in temperate climates, annually.
- ! To reduce the likelihood of oil 'soaking' on fruit, do not apply oil sprays within eight weeks of harvest (especially in cool conditions, when the HMO takes longer to dissipate from and within the tree).
- ! Excessive use of oil sprays (high doses) can reduce yields by clogging up the water and food transport systems in the tree.
- ! Avoid spraying trees during flowering.

## Citrus gall wasp

The native citrus gall wasp (CGW – *Bruchophagus fellis*) is a serious pest in Queensland and northern coastal NSW. It has more recently become a problem in the southern inland growing areas of NSW, Victoria and South Australia.

CGW can exhibit strong varietal preferences. In Queensland it prefers oranges, grapefruit and lemons rather than most mandarin varieties. In the Central Burnett, Sunburst, Nova and Hickson mandarins seem more prone to CGW damage compared to Murcott tangor and Imperial mandarin.

### Damage

CGW infests young shoots, causing woody galls to form around the developing larvae (Figure 256). The woody galls can reduce tree growth and productivity (Figure 257). All varieties can be attacked, but lemons, grapefruit and some rootstocks are most susceptible.

Figure 256. Galls showing the exit holes of adult citrus gall wasps.

Figure 257. Heavy infestations of citrus gall wasp can significantly reduce tree growth and productivity.

Pests

### Life cycle

The wasp has a single generation per year. Adult wasps emerge in spring and the timing of the emergence is influenced by temperature (Figure 258). Peak emergence in southern Australia is between mid-October and mid-November.

Figure 258. Recently emerged citrus gall wasp. Photo: Dan Papacek.

### Management

There are two parasitic wasps (*Megastigmus brevivalvus* and *M. trisulcus)* that are important natural enemies of CGW. The parasitic wasps lay their eggs into the eggs of CGW and the larvae feed on the developing CGW larvae (Figure 259). The parasitic wasps can be introduced into newly infected areas of an orchard, but may take several years to become established and require repeated releases for 3–5 years. Parasitic wasps should be introduced towards the end of CGW emergence.

A recent research project on the control of the CGW found that three sprays of HMO (0.5%) 10–14 days apart prior to peak emergence of CGW provided good control. The oil sprayed on leaves deters the wasps from laying eggs. However, recent reports suggest that this control is not as effective in blocks where all trees are sprayed – leaving the wasp no choice but to lay eggs on the sprayed trees.

Monitoring is required to determine the timing of the first spray. Monitor galls twice weekly from late September. The first spray should be applied when CGW adults are visible. Avoid spraying trees with HMO during flowering.

**CGW: best practice tips**

- ☑ Monitor galls twice weekly from late September for wasp emergence.
- ☑ Introduce parasitic wasps towards the end of CGW emergence.
- ☑ Use HMO sprays when CGW adults are visible.

Figure 259. Female citrus gall wasp laying its eggs into a young citrus shoot. Photo: Dan Papacek.

## Citrus leafminer

Citrus leafminer (CLM – *Phyllocnistis citrella*) is a small moth whose larvae damage immature foliage. Trees are usually only infested in late summer and autumn. CLM rarely occurs in spring because populations are very low following the cooler months of winter. Also, the production of new growth is more synchronised and quickly becomes immune to attack.

### Damage

Twisted and curled leaves are generally the first noticeable symptoms. Severe infestations (an average of two or more mines per leaf) can retard the growth and yield of nursery and young trees, but their effect on mature trees is almost insignificant.

### Life cycle

Adult moths lay their eggs at night on the undersides of leaves. The peak egg laying period occurs between mid-February and mid-March. The larva hatch and burrow into the leaf causing silvery serpentine mines (Figure 260). The larva pupates on the edge of the leaf before emerging as an adult moth.


Figure 260. Citrus leafminer damage showing moth and mining by the larva.

### Management

Natural enemies include small parasitic wasps and predators, such as lacewings. Predators are generally only associated with heavy infestations.

Minimising infestations using chemicals is difficult because larvae are protected by their mines and pupae are protected by their pupal chambers. Sprays are usually only required for moderate and severe infestations on young or vigorous trees (e.g. recently hedged trees) in summer and autumn. Spraying of mature trees specifically for leafminer should only be considered if severe infestations are anticipated or when they may be an important source of infestation to adjacent immature trees.

HMO sometimes provide good control of CLM, particularly in nursery situations and in young trees. Early application of HMO to the youngest leaves (<20 mm long) on flushes between late summer and mid autumn prevents rapid growth of CLM populations and reduces the risk of heavy infestations later in the season. Female moths lay fewer eggs on oil sprayed leaves and the HMO deposits also influence moth movement between and within trees. It is too late to spray with HMO when most leaves are longer than 20 mm.

HMO must be applied thoroughly to the upper and lower surfaces of susceptible leaves. Trees should be sprayed to the point where the spray just starts to drip off the leaves. Two or more sprays may be needed, particularly in summer and autumn when flushes are produced over a long interval. Young and vigorous trees will need to be sprayed more frequently than mature trees or trees with low vigour. Spray moderate to severe infestations every 5–14 days during each growth flush. The interval between sprays will be shorter during summer and early autumn than in mid or late autumn.

For control of leafminer only, thoroughly and evenly spray flush growth using a low HMO concentration (0.25–0.5%) at volumes equivalent to 3,500 L/ha to 4 m high trees. The total amount of oil used in one season should not exceed 2.5% in temperate climates. Do not apply HMO in high temperatures (>35 °C) or high humidity (>90%). Do not use sulfur within one month of HMO spray. Do not apply to moisture-stressed trees.

For more information on using HMO refer to the NSW DPI Agfact H2 AE.5 *'Using petroleum-based spray oils in citrus'* (Beattie & Hardy 2005).

**CLM: best practice tips**

- ☑ CLM infests the summer/autumn flush.
- ☑ Sprays are normally only required for moderate to severe infestations on young trees.
- ☑ Use HMO and thoroughly apply to new growth <20 mm long.
- ☑ Early application (mid-late January) prevents rapid growth of CLM populations.

## Fruit flies

Fruit flies are a serious pest of many horticultural crops. Fruit flies sting fruit and lay eggs in the fruit, then developing larvae feed inside the fruit. In addition to the direct damage fruit flies cause to fruit, an infestation can have serious implications for movement of fruit beyond a production region within states, between states and especially for export. For current management information contact your local primary industry agency or check their website.

The two main pest fruit flies affecting citrus are the Mediterranean fruit fly and the Queensland fruit fly:

### Mediterranean fruit fly

Mediterranean fruit fly (Medfly – *Ceratitis capitata*) is currently only present in Western Australia (mostly in the south-west). Quarantine restrictions apply to the entry of fruit that host Medfly from WA into other states of Australia. Medfly will attack most citrus varieties, especially mandarins. Citrus are a good host of Medfly during the cooler months when other deciduous fruit trees such as stonefruit are dormant.

#### Damage

Medfly attacks fruit as it begins to colour. The fly punctures the rind during egg laying and the larva feed on the pulp. Stung fruit may fall. Damaged fruit can be invaded by fungal diseases such as moulds and rots, the spores of which can be carried by the flies.

#### Description and life cycle

The adult fly is 3–5 mm long with a tan abdomen which is encircled by two lighter colour rings (Figure 261). It is smaller than the Queensland fruit fly (QFF). The thorax has irregular patches of black and silver. The wings are mottled with distinct brown bands extending to the wing tips.

Medfly overwinters in the fruit as eggs and larvae and sometimes pupae, in the ground as pupae, and in very green trees and weeds as adults. These insects become active as temperatures rise in spring.

### Management

There are a number of chemicals registered for control of Medfly in citrus. For more information on registered chemicals or chemical permits visit the *APVMA PubCRIS* website or contact your local primary industry agency or horticultural advisor.

Management of Medfly relies on a combination of trapping, application of baits to foliage and orchard hygiene.

Monitoring fruit fly presence is essential in any management program. There are male and female traps. At least 2 traps (1 male and 1 female) should be used per hectare. Traps should be checked weekly.

Bait sprays should be used when fruit are about half size, but can be used earlier in high pressure situations. Foliage baits are a mixture of an insecticide (maldison) and a source of protein that the female fly requires for maturation of her eggs. The baits are an attractive food source for both the male and female flies. The baits are eaten by the flies as they forage over the leaves for food. Baits are applied as a coarse spray to the foliage in the middle of the tree canopy. Avoid contacting the fruit with the bait mixture as it can burn fruit. Baits should be applied weekly and more often during periods of high fruit fly pressure or wet weather.

Cover sprays are not usually necessary and should only be used as a last resort when monitoring indicates damage is occurring or is imminent. Most cover sprays will only kill adult flies on contact and do not stop the female fly from stinging the fruit.

Figure 261. Mediterranean fruit fly (*Ceratitis capitata*). Photo: Andrew Jessup.

**Mediterranean fruit fly: best practice tips**

- ☑ Good orchard hygiene is critical.
- ☑ Use male and female traps to monitor fruit fly presence in the orchard.
- ☑ Apply bait sprays as directed.
- ☑ Remove or treat other host plants.
- ☑ Remove and destroy infested or fallen fruit.
- ☑ Remove all fruit from trees during harvest operations.

## Queensland fruit fly (QFF)

Queensland fruit fly (*Bactrocera tryroni;* Figure 262) is a serious pest of most fruit in Queensland and parts of NSW and Victoria. It is most prevalent from October to May. Queensland fruit fly prefers humid conditions, but can also survive in the drier urban and irrigated areas in the south and southwestern regions of NSW and northern Victoria.

Figure 262. Queensland fruit fly (*Bactrocera tryroni*). Photo: Max Hill.

QFF can also enter a region via transport of infested fruit from areas where it is endemic. Regions and states free of QFF have strict legislative controls on the movement of QFF host fruit and vegetables in order to keep them free of QFF. QFF host fruit and vegetables cannot be transported into the Greater Sunraysia Pest Free Area (PFA; Figure 263), or across some state borders (e.g. South Australia), unless the consignment is accompanied by a permit from a state authority or industry certification scheme.

Most citrus varieties can be attacked by QFF, but some varieties such as mandarins are more attractive than others. Varieties reported to be attacked include Ellendale and Murcott tangors and Imperial, Hickson and Clementine mandarins.

Citrus fruit are usually stung when they are silver green, changing colour or fully coloured. Fruit damage can be high in situations when there are no other suitable hosts, there are high numbers of flies, fruit have thin skins or are already damaged (e.g. splitting or hail damage).

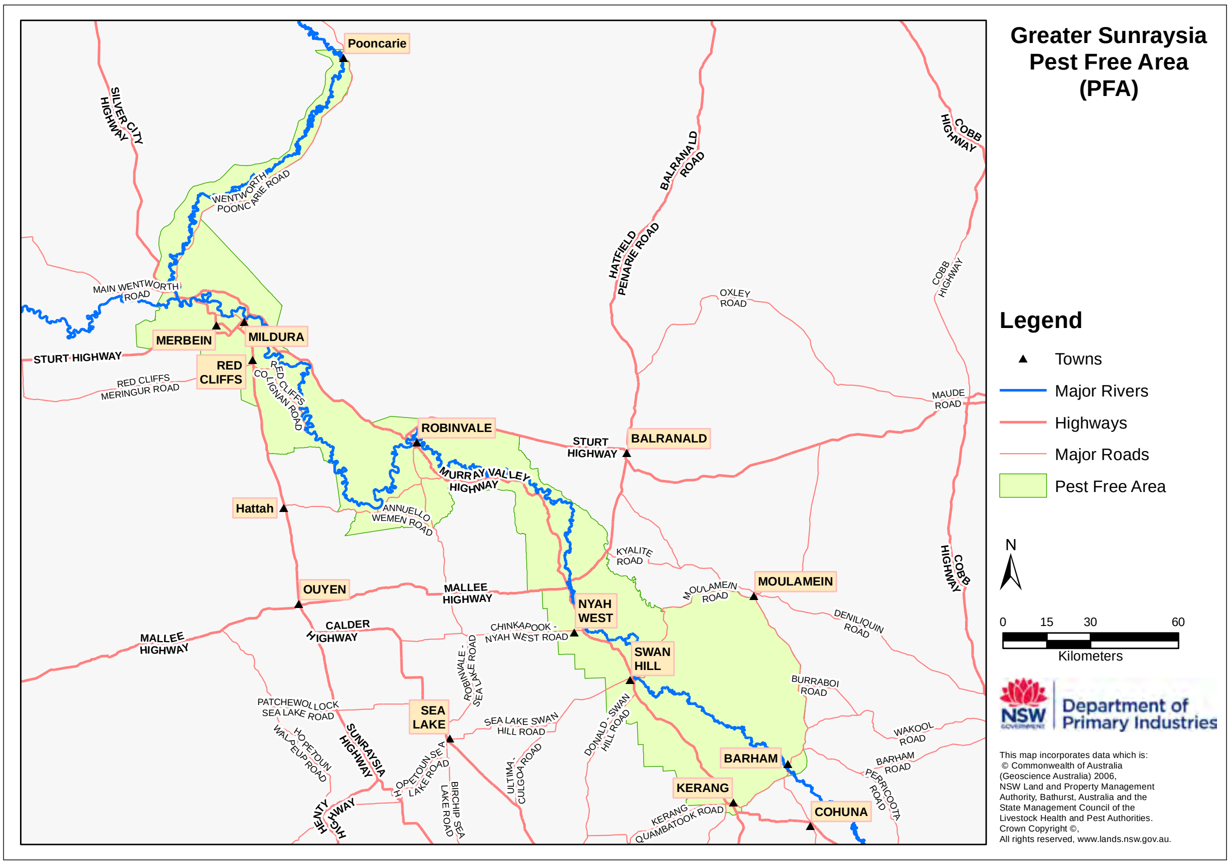


Figure 263. Greater Sunraysia pest free area.

## Damage

Damage by larvae tunnelling in the fruit varies with the type and maturity of the fruit, the number of larvae in it and the weather. Fruit infested with QFF larvae usually fall from the tree. Frequently citrus fruits, although stung, do not develop larvae, but sometimes fall. Stung or damaged fruit will also be invaded by fungal diseases such as brown rot, sour rot and blue and green moulds, the spores of which can be carried by the flies (Figure 264).

Figure 264. Fruit stung by QFF often get fungal infections such as sour rot, brown rot or blue and green moulds, the spores of which can be carried by the flies.

## Description and life cycle

The adult QFF body is about 6–8 mm long and is reddish brown with yellow markings. In early spring, over-wintering adult flies become active and the females lay eggs in fruit. Larvae develop in these fruit (Figure 265) and from then on the fruit fly population builds up as successions of suitable fruit become available for infestation. By late summer–autumn there can be numerous flies ready to infest any suitable unprotected fruit until the onset of cold weather in late autumn. The flies are most active in the early morning and late afternoon, resting in shaded spots during the hottest part of the day.

QFF overwinter mostly as adults that shelter in protected locations and are difficult to find. Evergreen trees in house yards adjacent to orchards can serve as overwintering refuges for QFF. Lemon trees are often quoted as harboring QFF in the winter in some areas. Placing traps in these trees is a good way of reducing the survival of overwintering flies.

In cold climates flies will die out in winter unless they can move from the orchard to warmer positions. This is not sufficient for maintenance of a population suitable for causing problems next season if the previous fruit fly population is small.

However, as has been the case in southern NSW and northern Victoria recently, previous season populations have been very large. Their chances of survival over the winter and, consequently, their potential to damage next season's crops increase dramatically.

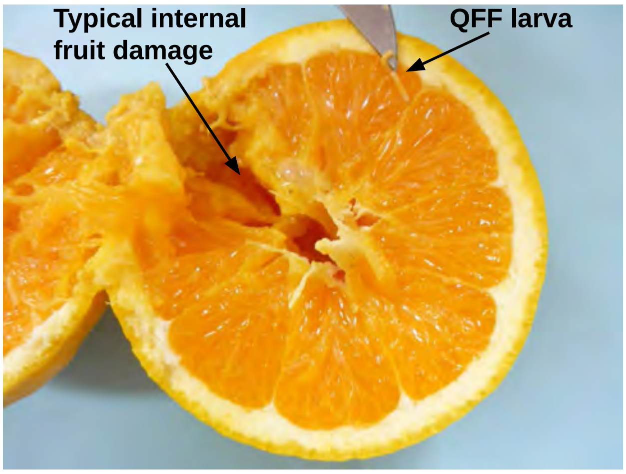


Figure 265. An orange attacked by QFF – showing damage around the site of the sting and developing larvae.

## Management

In districts where QFF occurs, harvest fruit as early as possible. Fruit fly populations increase as the season advances and temperatures become warmer. As the fruit ripens it becomes more attractive to the egg-laying females. Do not send damaged or fallen fruit to the packing shed and dispose of any reject fruit. All fallen or reject fruit should be collected and well mulched or buried to a depth of at least 300 mm.

There are a number of chemicals registered for control of QFF in citrus. These chemicals are described according to how they are used in controlling QFF. For more information on registered chemicals or chemical permits visit the *APVMA PubCRIS website* or contact your local primary industry agency or horticultural advisor.

### *Traps*

Parapheromone traps are used to monitor male QFF populations in orchards. The traps are effective and convenient for detection of QFF, but do not control them. The traps are an important tool for monitoring the efficacy of bait and spray programs. Monitor traps weekly in spring, summer and autumn and fortnightly in winter.

Currently there is one commercially available female fruit fly trap and attractant that has been shown to be effective. However, at present the cost/unit is quite high, so using it as a control method in commercial orchards may not be economically feasible.

New female traps and lures, currently not on the market, are being field tested in various locations around Australia. These trap/lure combinations are also based on protein, but are in gel formulations.

Fruit fly traps contain a lure, a pesticide and something that holds the lure and/or pesticide. Malathion is the pesticide that is most often used. For malathion to be effective the insect must come into contact with it directly or via contamination on the inside surfaces of the trap caused by other flies spreading it around. Malathion has no fumigant properties. Another pesticide approved for use in traps is dichlorvos (DDVP), which does have fumigant properties.

The lures in the traps attract only the male fruit fly, which is then killed by the pesticide. Traps are hung in trees and are best placed in the east or north-east side of the tree, out of direct sunlight. The lures are effective for about 3 months. There are a number of other fruit flies that are often captured in these traps, such as Island fly (Figure 266) and Callantra, but these are not pest fruit flies.

Figure 266. Island flies are commonly caught in traps, but are not considered pest fruit flies.

### *Lure stations*

Some products are used as lure stations and not actually placed in traps. Lure stations are not used to monitor fruit fly populations. The lures are hung in trees and can attract and kill male fruit flies, but the flies are not captured.

### *Baits*

Bait mixtures should be used according to label directions. Bait sprays are usually applied as a band or spot spray to the lower foliage or skirts of trees. Baiting should commence at least 6 weeks prior to fruit ripening. Apply weekly or after heavy rain when fruit flies are active. Baiting is more effective when carried out in the morning when the fruit flies are most active.

The bait mixture is prepared using an attractant (protein source) and an insecticide. Flies are attracted to the protein which they require for egg maturation. As they feed they are killed by the insecticide. The insecticides used in bait sprays include maldison, chlorpyrifos, spinosad and trichlorfon. The protein source is either yeast autolysate or hydrolysate. Bait sprays kill both female and male fruit flies.

**Traps: best practice tips**

- ☑ Lures and pesticides in traps should be handled and replaced according to label directions.
- ☑ The best traps retain all flies attracted into them. Generally a coloured base with a clear lid achieves this. Yellow is the most attractive colour for QFF, so the trap base should predominantly be this colour.
- ☑ Fly entry holes should be located away from the top of the trap as flies will be attracted to the light and may simply walk out of the trap through the entry holes.
- ☑ The trap should be robust and be able to withstand high winds and orchard operations.
- ☑ Keep twigs and leaves away from the traps as they allow in ants. Ants destroy the flies which is not good for monitoring purposes.
- ☑ The trap should not be able to fill up with rain or water from irrigation. If water does get in it should be able to drain away. Drainage holes should be small enough to prevent trapped flies escaping.
- ☑ Water should not be able to come into contact with the lure and/or pesticide as it will absorb some, diluting its effectiveness in the trap and contaminating the ground beneath the trap.
- ☑ Traditionally, traps have been placed out in the orchard at about 1.2 m or higher from the ground. The higher the trap is placed in the canopy the more effective it is.
- ☑ The best aspect for traps is the east/north-eastern side of the tree. Traps become very hot inside if placed in the sun. This deters flies from entering and causes damage to the attractant lure.

**Orchard hygiene: best practice tips**

- ☑ Good orchard hygiene is an important part of QFF management.
- ☑ Remove unwanted fruit trees from around sheds, houses and along boundary fences.
- ☑ Pick up and properly dispose of fallen fruit.
- ☑ Control QFF in all other host plants.
- ☑ Remove all late hanging fruit missed during harvest.
- ☒ Do not send damaged or fallen fruit to the packing shed.

For more information refer to the states' primary industry websites and NSW DPI Primefact 752 *'Managing Queensland fruit fly in citrus'* (Hardy & Jessup 2012).

## Fruit piercing moths

Fruit piercing moths (*Eudocima* species) can be a problem in early season mandarin varieties in Queensland (particularly northern Queensland) and the Northern Territory. In wet years they can also be a problem in the drier central growing districts around Emerald and Mundubbera. Most damage is done between February and April.

### Damage

The moths pierce the fruit rind and suck out the juice, leaving a large feeding hole (2 mm). Juice leaks from the hole and burns the fruit rind. Secondary rots usually invade the fruit and the fruit then drop.

### Description and life cycle

There are three species of moths that attack fruit. The moths are large (100 mm wingspan) and colourful with brown, cream on green forewings and yellow and black hindwings.

The adult moths rest in the surrounding bush during the day and fly into orchards around dusk to feed on ripening fruit at night. The larvae feed on native vines and pupate between leaves.

### Management

Orchard hygiene is important. Damaged, rotten and fallen fruit should be removed from the orchard as they attract the moths.

Chemical control is difficult. Monitor the edge rows of the orchard alongside any nearby native vegetation prior to dusk.

Netting of trees and bagging of fruit is effective but costly.

## Fuller's rose weevil

Fuller's rose weevil (FRW – *Naupactus godmanni*) is a serious quarantine pest, especially in southern citrus growing regions.

### Damage

FWR does not cause significant damage to trees or fruit, but its presence as eggs or adults on fruit destined for certain export markets can result in the rejection of the fruit shipment.

### Description and life cycle

The adult weevils are around 8 mm long, grey-brown and cannot fly (Figure 267). Adults lay their eggs under the fruit calyx, in splits in the bark and in microsprinklers. Most FRW adults emerge from the soil in late summer between February and May. After emergence the weevils climb trees via the trunk, low hanging foliage or weeds to feed and lay eggs.

Figure 267. Fuller's rose weevil. Photo: Andrew Creek.

### Management

Citrus blocks should be monitored monthly from December to harvest for the presence of weevils. Trees should be skirted and weeds controlled around trees to prevent movement into trees. Recent Australian research has found trunk band spraying with a registered insecticide is the most effective method for controlling FRW. Commercial spray arms are available that can be mounted to a tractor to apply the trunk sprays. Remember, many insecticides also disrupt or kill natural enemies. For information on registered chemicals visit the *APVMA PubCRIS website.*

For more management information refer to the *'Fuller's rose weevil in-field management guide'* (Crisp & Baker 2012).

**FRW: best practice tips**

- ☑ Monitor orchards for weevil presence monthly between December and harvest.
- ☑ Keep trees skirted to prevent low hanging branches.
- ☑ Keep tree rows free of tall weeds.

## Mealybugs

Five species of mealybugs occur on citrus in Australia. Mealybugs are an important quarantine pest and their presence can have serious implications for export. They prefer warm, humid conditions. Mealybugs tend to hide underneath or around the calyx of fruit (Figure 268). The presence of mealybugs leads to the accumulation of sticky honeydew and sooty mould on fruit surfaces. Feeding can also cause distortion of leaves and young shoots. The main species of mealybug that attack citrus are outlined in Table 69.

Figure 268. Mealybugs on Fremont mandarin.

### Damage

Mealybugs feed on the plant sap and excrete honeydew on which the sooty mould fungus grows. Ants feed on the honeydew and protect the mealybug from any natural predators.

### Description

Mealybugs are slow moving, soft bodied, oval shaped insects around 3–4 mm in length. They are covered with a coating of white mealy wax that extends into fine filaments around the edge of the body. They tend to crowd together in sheltered sites between touching fruit and leaves (Figure 269) or under the fruit calyx.

Figure 269. Mealybugs feeding on a flush of new growth.

**Mealybugs: best practice tips**

- ☑ Monitor leaves, twigs and fruit from late spring to late autumn.
- ☑ Control ants.

Table 69. Summary of the main mealybug species that attack citrus.

| Pest | Region | Description and location | Occurrence, conditions and monitoring |
|---|---|---|---|
| **Citrophilus** *Pseudococcus calceolariae* | NSW, VIC, SA | Oval, white and waxy. Fruit and leaves. | 3–4 generations/year. Monitor November–June. |
| **Citrus** *Planococcus citri* | QLD, NT, WA, coastal NSW | Oval, white and waxy. Flowers, fruit, leaves and twigs. | 3–5 generations/year. Monitor November–May. |
| **Longtailed** *Pseudococcus longispinus* | QLD, NT, NSW, VIC, SA | Oval, white and waxy with a long tail. Fruit and leaves. | 3–4 generations/year. Monitor November–May. |
| **Spherical** *Nipaecoccus viridis* | QLD, coastal NSW | Spherical and white. Twigs, shoots, leaves, flower buds and fruit. | At least 6 generations/yr. Monitor from October–harvest. |
| *Rastrococcus runcatispinus* | QLD, coastal NSW | Large, oval shaped, red, grey and orange with long filaments. Mostly on leaves. | Several generations/year. Monitor from late summer–early autumn. |

## Mites

Mites damage fruit and foliage by their feeding which causes surface scarring and russetting. Most mites have a broad host range infesting weeds, other fruit and vegetable crops and ornamentals, so it is important that the orchard is kept free of other host plants. The main mite species affecting citrus are listed in Table 70.

### Description and life cycle

Mites are very small and not readily seen with the naked eye. A ×10 hand lens (at least) is needed to see mites. Most mites have a life cycle that has 4 stages: egg → larvae → nymph → adult. The life cycle of most mites is completed in 3–4 weeks in summer and 2 weeks for the eriophyid mites (i.e. rust mites and bud mite). During winter the mites are generally dormant, over-wintering as either adult females or eggs. Mites prefer warm humid conditions, and infestations are reduced or killed by very hot, dry conditions.

### Management

In some areas plant feeding mites are controlled by natural predators and pathogenic fungi and usually do not cause enough damage to warrant spraying. However, mites can be a problem if the right weather conditions occur and there are few natural predators present.

Some pesticides, especially the organophosphates and synthetic pyrethroids, severely disrupt natural predators. Mite problems can occur as a direct consequence of those pesticides being used in the orchard. Additionally, fungicides such as copper sprays reduce the natural pathogenic fungi living on the tree branches and twigs and also impede predation by ladybird beetles.

There are a range of control measures. Regularly monitor young citrus fruit and foliage between November and May for both pest mites and predatory mites. Target this period using a combination of the available control measures. Pay special attention if relative humidity in late summer and early autumn is above average, as rust mites and broad mite populations can increase rapidly in warm humid weather.

If chemical control is required it is important to get good spray coverage of the plant parts where the mites are feeding. This is especially important for bud, broad and rust mites which prefer protected sites (in flower buds, between fruit, under leaves and inside the trees).

Mites can be difficult to control because:

- they are small and difficult to see
- infestations can develop very quickly during ideal weather conditions; so regular monitoring is essential in order to identify a mite problem early and apply suitable control measures
- there can be many overlapping generations of mites per year, so damage can extend over a long period, especially if weather conditions are right
- most of the pesticides registered for mite control in citrus do not kill eggs; so one spray on its own will not usually be effective. A combination of control measures needs to be used to control the nymphs that hatch from the eggs. Most pesticide products will also harm beneficial predatory mites.

### *Predatory mites*

There are a range of predatory mite species that feed on plant feeding mites. Predatory mites naturally occur in citrus orchards, but their presence can be severely affected by pesticide usage. For best results predatory mites need to be introduced early in the season when the pest mite first appears and numbers are low, well before the main population peaks. Several releases of predatory mites a couple of weeks apart may be required. In some areas releases may need to be made each year. In Queensland, pollen from Rhodes grass sown in the inter-row area provides food for the predatory Phytoseiid mites. Growers leave every second row unslashed. Effective use of natural predators requires careful selection of pesticides in the orchard. Aim to use pesticides, such as horticultural mineral oils (HMO), that have minimal impact on beneficial insects.

Some species of predatory mites are commercially available. Companies that breed and supply beneficial insects for citrus orchards include Bugs for Bugs in Mundubbera, Qld (*www.bugsforbugs.com.au/*) and Biological Services at Loxton, SA (*www.biologicalservices.com.au/*).

Information on the toxicity of chemicals to various beneficial insects is available from insect suppliers or at the *Biobest* or *Koppert Biological Systems* websites.

### *Pesticides*

There are a range of pesticides specifically registered for mite control on citrus. Most miticides need to be applied at the first sign of mite activity. As not all products are registered for all mites, check product labels for full registration details, including precautions for use.

Some miticides can only be used once per season to reduce the chance of mites developing resistance to the chemical. It is important to check what stage of the mite's life cycle these products control.

Most of the current registered products do not kill all stages – so their use must be carefully targeted and combined with other management strategies.

There are also various fungicides that have a suppression effect on some mite species. Mancozeb, zineb and sulfur are all registered for control of mites in citrus. However, most will also have an impact on the beneficial predatory mites. These products only affect the juvenile and adult stages; mite eggs are not affected.

Table 71 lists the miticides currently registered for use in citrus and the mite stage controlled.

### *Horticultural mineral oils (HMO)*

HMO sprays have been shown to reduce feeding and laying eggs (oviposition) by mites. HMO will also suffocate adults and juveniles. Use high volume, low dose sprays (i.e. 0.3–0.5%). Depending on mite numbers, several sprays 2 weeks apart may be required. It is essential to get good coverage of plant parts where the mites are feeding. More information on using HMO is outlined at the start of this chapter.

Figure 270. Brown citrus rust mite damage to oranges.

Figure 271. Two spotted mite damage to leaves.

Table 70. Major mite pests of citrus.

| Mite | Region | Pest location and damage | Monitoring and major natural predators | Other information |
|---|---|---|---|---|
| **Broad mite** *Polyphagotarsonemus latus* | QLD, coastal NSW, WA | Young foliage and newly set fruit in spring-summer. Thin silver-grey 'sharkskin' scarring, that can be scratched off. | November to May. Phytoseiid mites: *Euseius victoriensis*, *Euseius elinae* and *Amblyseius herbicolus*. | Prefers protected sites. Lemons and limes most susceptible – especially fruit set during summer/ autumn. Most damage done to young fruit. Prefers high humidity and populations often increase following rain. 20–30 generations/year. |
| **Brown citrus rust mite** (**Figure 270**) *Tegolophus australis* | All areas | Young green fruit and mature leaves, in exposed positions. Smooth dark brown blemish on exposed fruit surfaces and leaves. Blemish cannot be scratched off. | November to May. Phytoseiid mites: *E. elinae; E. victoriensis, A. herbicolus* and *A. lentiginosus*. | Is a native pest. Prefers warm-humid conditions. Damage more common on oranges and mandarins. 20–30 generations/year. |
| **Citrus bud mite** *Eriophyes sheldoni* | QLD, NSW, WA | Leaf buds and blossoms. Twisting and distortion of fruit and young leaves. | November to May. Phytoseiid mites: *E. victoriensis* and *E. elinae*. | Most susceptible varieties are Lisbon lemon, navel oranges and grapefruit. 20 generations/year. |
| **Citrus flat mite** *Brevipalpus lewisi* | QLD, NSW, VIC, SA | Exposed surfaces of fruit near stem end or under calyx. Undersides of leaves and green twigs. Grey spotting and scarring on fruit rind. Yellow spotting on mature leaves. | November to May. Phytoseiid mite – *E. victoriensis* and Stigmaeid mites. | Mite prefers green fruit or those beginning to colour.Movement of mites on to fruit occurs late from February to May. 6–8 generations/year. |
| **Citrus red mite** *Panonychus citri* NB Citrus red mite is a quarantine pest, only present in the Sydney and central Coast regions. Nursery trees and other plant material need to be treated before sending to other regions. Contact your local regulatory inspector for more information. | Gosford and Sydney | Leaves, twigs and fruit. Straw coloured stippling of fruit and leaves. | November to May. Phytoseiid mites: *E. elinae* and *A. lengtiginosus*. Predatory lady beetle: *Stethorus nigripes*. | Oranges are preferred host. Does not like hot dry conditions or prolonged periods of high humidity. Not a major pest in commercial orchards on Central Coast as natural predators keep in check. 8–10 generations/year. |
| **Citrus rust mite** *Phyllocoptruta oleivora* | All areas | Young green fruit, leaves (undersides) and twigs, in sheltered positions inside the tree. Slightly rough brown blemish on protected (inside facing) fruit surfaces and leaves. Blemish cannot be scratched off. | November to May. Predatory mites: *E. victoriensis**, *E. elinae*, *A. herbicolus* and *A. lentiginosus*. | Prefers warm humid conditions. Damage more common on grapefruit and lemons. 20–30 generations/year. |
| **Oriental spider mite** *Eutetranycus orientalis* | QLD, northern NSW | Upper leaf surfaces and fruit (outward facing surfaces). | Predatory lady beetle: *Stethorus fenestralis*. | Major pest of Murcott tangor and Imperial mandarin. 10–20 generations/year. |
| **Two spotted mite** *Tetranychus urticae* (Figure 271) | All areas | Young shoots, mature leaves and fruit. | Predatory mites: *Phytoseiulus persimilis* and *Typhlodromus occidentalis*. Phytoseiid mites: *Euseius victoriensis*, *Euseius elinae*. Predatory lady beetles: *Stethorus nigripes* and other species. | Meyer lemons especially. 10–20 generations/year. |

Source: Information extracted from '*Citrus pests and their natural enemies*', Smith et al. 1997*.

Pests

Table 71. Miticide products currently registered for use in citrus, their mode of action, mite life cycle stage controlled and their toxicity to predatory mites.
Note: Check the APVMA PubCRIS website to confirm products are currently registered for use on citrus.

| Active ingredient | Trade name®, chemical group | Mode of action | Mite life cycle stages controlled | Toxicity to predatory mites |
|---|---|---|---|---|
| Abamectin *only 1 application/ yr permitted | Vertimec (6A) | Contact, limited systemic activity but some translaminar movement | Juveniles and adults | Medium |
| Dicofol | Kelthane (2B) | Contact, not systemic | Juveniles and adults | High |
| Etoxazole *only 1 application/ yr permitted | Paramite (10B) | Growth regulator, inhibits moulting | Eggs and juveniles | High |
| Fenbutatin oxide | Torque Vendex (12B) | Contact, not systemic | Juveniles and adults | Low |
| Mancozeb and zineb | Various | Contact | Juveniles and adults | Low |
| Horticultural mineral oils | Various | Contact – smothering action. Oil deposits reduce egg laying and feeding | All stages | Medium |
| Sulfur | Various | Contact | Juveniles and adults | Medium |

### Mites: best practice tips

- ☑ Use a ×10 hand lens to regularly check young developing fruit and foliage for mites between November and March.
- ☑ When a heavy mite infestation is identified, immediate control is often necessary to prevent damage to developing fruit, especially if climatic conditions in late summer and early autumn favour rapid mite development.
- ☑ Release predatory mites early in the season when pest numbers are low. In some regions predators may need to be released every year.
- ☑ Encourage a good population of beneficial insects in the orchard by selecting pesticides that have minimal impact, such as HMO.
- ☑ Encourage grasses in the inter-row sod (e.g. Rhodes grass) that produce pollen. In Queensland this has been shown to help increase predatory mite populations.
- ☑ Control broadleaf weeds.
- ☑ If chemical control is required, more than one chemical application will normally be required because most of the registered pesticides do not kill all stages.

## Nematodes

Nematodes are small microscopic worms, some of which are parasites of citrus roots. The most important is the citrus nematode (*Tylenchulus semipenetrans*) which affects citrus, grapes and olives. There are also several new biotypes of citrus nematodes that have been identified overseas that can infect resistant rootstocks, but their presence in Australia is unknown. Other nematode species which cause damage are the root lesion and stubby root nematodes.

Nematodes prefer light sandy soils rather than heavy clay soils and higher populations of citrus nematode are often found in alkaline soils. Citrus rootstocks vary in their tolerance to citrus nematode (see the Management section).

### Damage

Mature citrus trees can tolerate large numbers of nematodes before exhibiting symptoms of decline, but young trees will grow poorly in infested soil. Above ground symptoms include leaf yellowing, sparse foliage, poor growth, stunting and reduced fruit size and yield. Such symptoms are not readily distinguishable from other production problems without sampling and testing root and soil for nematodes. Damage to trees depends on a range of factors including:

the number of nematodes, soil characteristics, health and condition of tree roots, susceptibility of the rootstock, presence of other soil pathogens and orchard management practices.

Nematode larvae pierce tree roots, releasing saliva which causes the roots to swell, impeding the uptake of water and nutrients and reducing tree growth. Yield losses from citrus nematode can be in the range of 10–30%, depending on the level of infection (Verdejo-Lucas & McKenry 2004). Feeder roots heavily infested by the citrus nematode are slightly thicker than healthy roots and have a dirty appearance because of the adhesion of soil particles to the gelatinous matrix deposited by the female nematode on the root surface.

### Management

Nematodes can survive in the soil in old infested roots for long periods of time. There are many natural enemies that feed on pest nematodes including parasitic fungi, bacteria, other nematodes and mites, but little is known about the activity of these predators.

Once tree roots are infected there are few chemical controls available. In the past soil fumigants and nematicides were used, but most of these products are now unavailable. Several methods of soil sterilisation such as soil solarisation and steam are used in small areas, seed beds or nurseries, but are not usually feasible in orchard situations.

Solarisation involves covering the moistened soil with clear plastic sheeting for between 40 to 60 days. Soil solarisation is used in some regions with hot dry summers, but the depth of penetration into the soil is usually limited to the top 20 cm.

Rootstocks have differing tolerances to citrus nematode. Rootstocks are classified as being resistant if they greatly inhibit nematode reproduction. The only source of genetic resistance against citrus nematode is found in *C. trifoliata* (Verdejo-Lucas & McKenry 2004). Swingle citrumelo is also highly resistant, whilst Troyer and Carrizo citranges have moderate resistance in some regions.

Continuous cultivation of resistant rootstocks has led to the emergence of new biotypes of citrus nematode which are more virulent and can infect these resistant rootstocks. At present three biotypes have been identified around the world:

1. citrus – found in California and Italy, infecting Troyer and Carrizo citranges, other citrus species, olives, grapes and persimmons.
2. Mediterranean – found in countries around the Mediterranean basin and South Africa; infecting Troyer and Carrizo citranges, other citrus species, grapes and persimmons.
3. poncirus – found in California, Israel and Japan; infecting *C. trifoliata* and its hybrids, other citrus species and grapes.

The biotypes of citrus nematode in Australia are currently unknown.

Soil and root samples can be used to detect the presence and number of nematodes. Take samples from depths of 30–45 cm from around 20 sites (with a similar soil texture) to form a composite sample. The sample size for soil is 500 grams and about 100 grams of tree roots are needed. Send samples to a diagnostic laboratory for examination. If planting into old citrus, grape or olive ground, it is wise to collect soil and root samples to determine whether nematodes are present.

In re-plant sites cultivate the soil to remove as many old roots as possible, then leave fallow for several years and plant green manure crops. Brassica crops such as Indian and White mustard, radish and canola suppress nematodes in a process called biofumigation. Organic matter and soil amendments high in carbon can reduce nematode populations. In trials in South Australia self-seeded weed residues were just as effective as brassica cultivars in reducing citrus nematode (Walker & Morey 1999).

### Nematodes: best practice tips

- ☑ Before planting test the soil for the presence of nematodes. This is especially important in re-plant ground that has previously been planted with citrus, grapes or olives.
- ☑ Use resistant or tolerant rootstocks.
- ☑ In old citrus, grape or olive ground, cultivate the soil to remove as many old tree roots as possible, plant green manure crops and spell the ground for several years before re-planting.
- ☑ Be careful not to bring nematodes into new areas on the roots or soil of nursery trees. On arrival inspect the roots of all bare-rooted nursery trees that have been grown in-ground for signs of nematode infection.
- ☑ Green manure crops and organic matter can suppress nematode populations and improve natural biological control organisms in the soil.

## Scale insects

Scale insects are one of the main pests of citrus. They are sap-sucking insects. There are two types – hard (armoured) and soft scales. The life cycle of these insects involves a number of different stages: eggs, then several nymph stages (including crawlers) and finally adults (Figure 272).

### Damage

Scale insects can blemish fruit and be difficult to remove on the packing line. Soft scales produce honeydew on which sooty mould fungi grow. This fungi blemishes fruit. Sooty mould can also be difficult to remove on the packing line, particularly on rough skinned varieties.

### Hard scales

Hard (armoured) scales have a thin hard, waxy protective cover that, depending on the stage of the life cycle, is either attached to, or separated from, the body of the insect. Except for the first crawler stage, the immature stages and the adult females do not move.

At high levels of infestation they cause severe blemishing of fruit and can cause twig and branch dieback and even kill trees. The timing of control measures for hard scales is not as critical as that for soft scales infestations. Examples of the main hard scales affecting citrus are listed in Table 72.

Hard scales:

- prefer to settle on fruit, twigs and branches
- do not produce honeydew, but can occur in association with soft scales, honeydew and sooty mould
- should be monitored from October to May (most species)
- reduce tree vigour and productivity
- blemish fruit, reducing fruit quality.

### Soft scales

Soft scales are soft bodied and have no separate protective cover. However, in adults the upper surface is hard and leathery or has a protective waxy or mealy secretion. Movement is usually possible, though limited after the first crawler stage. The timing of control measures for soft scales is critical and is targeted after egg hatch, when the young crawlers have emerged.

Soft scales are not as damaging to trees as hard scales but they produce a sugary secretion called honeydew on which the sooty mould fungi grow. Sooty mould can cover the fruit and leaves, reducing photosynthesis. Fruit quality can be reduced if the mould is not removed on the packing line. The honeydew also attracts ants, which protect the scale insects and disrupt the activity of natural enemies of soft and hard scales. Examples of the main soft scales affecting citrus are listed in Table 73.

Soft scales:

- prefer to settle on leaves and twigs
- produce honeydew that promotes presence of sooty mould, which reduces photosynthesis and tree vigour
- ants feed on honeydew and protect scale insects from natural enemies
- make ant control important
- result in reduced fruit quality if sooty mould not removed on the packing line
- need correct timing of sprays – wait for egg hatch to be completed and the young crawlers to emerge.

### Management

Scale insects have many natural enemies. Small wasps, both native and introduced, parasitise scale insects. Ladybird larvae and adults, lacewing larvae, predatory mites and several caterpillars are also predators. Some fungi also attack scale insects (Figure 273).

Natural enemies help reduce scale infestations, but this natural balance can be upset by factors such as the use of broad spectrum insecticide sprays, very hot weather, ant infestations and dust from nearby roads or cultivation.

Hard scale infestations such as red scale can become a serious problem in dusty or hot dry conditions, following the use of broad-spectrum pesticides, and with ant activity associated with soft scales, mealy bugs and aphids.

Soft scale infestations on newly planted or young trees are usually more significant than on older, full-bearing trees. Young trees should be carefully monitored for infestation.

Only use sprays where necessary. Biological control is effective in most orchards. If chemical control is needed, HMO are commonly used. Thorough spraying is essential because HMO sprays work by smothering the scale insects. HMO sprays need to be applied at high volume, 3,000–12,000 L/ha depending on tree height and density. Consider spraying heavily infested trees rather than whole blocks.

Spray timing is critical for some scale types (e.g. soft scales), and is often carried out after egg hatch when the young crawlers have emerged. The main target period for control of most soft scales using HMO is November in Queensland and February–March in mid-coastal NSW and December for white wax and pink wax scales. Most hard scales have two target periods for control using HMO, November–December and February–March. For more detailed information on monitoring and control of scale insects, refer to '*Citrus Pests and their Natural Enemies*' (Smith et al. 1997).

There are a number of precautions when using oil sprays. For more information on HMO sprays see the beginning of this chapter. For other chemicals registered for scale control refer to the *APVMA PubCRIS* website.

Figure 272. Adult black scale with scale mummies (white) that have been killed by a fungus.

Figure 273. Red-headed fungi attacking hard scale.

Table 72. Main species of hard scales affecting citrus.

| **Hard Scales** | | | |
|---|---|---|---|
| **Pest** | **Region** | **Appearance and location** | **Occurrence, conditions and monitoring** |
| **Chaff** | Coastal Qld and NSW | Grey brown and oval. Leaves, fruit, twigs and branches. | 5–6 generations/year. Monitor from fruit set to harvest (October–May). |
| **Circular black** | Qld, coastal NSW and NT | Black to dark red and circular. Leaves and fruit. | 2–6 generations/year. Monitor from fruit set to harvest (October–May). |
| **Glover** | Qld, coastal NSW | Light brown long and slender. Fruit, leaves and twigs. | 2–6 generations/year. Monitor from fruit set to harvest (October–May). |
| **Mussel (purple)** | NT, Qld, coastal NSW | Light brown and mussel shaped. Fruit, leaves, twigs and branches. | Prefer warm moist conditions. 2–6 generations/year. Monitor from fruit set to harvest (October–May). |
| **Red** | All areas | Red brown and circular. Fruit, leaves, twigs and branches. | Prefers exposed sites on outsides of fruit (Figure 274) and trees (Figure 275 and Figure 276). Prefers temperatures of 30–38 °C. Good autumn rainfall followed by a dry summer increases populations. 2–6 generations/year. Monitor from fruit set to harvest (October–May). |
| **White louse** | Qld, coastal NSW | Thin long and white (Figure 277). Branches, trunk, twigs, fruit and leaves. | Prefers dry conditions. 3–6 generations/year. Monitor all year. |
| **Yellow** | NSW, Vic, SA | Yellowish and circular. Fruit and leaves. | Prefers temperate shady conditions on inside parts of tree and undersides of leaves. 2–4 generations/year. Monitor from fruit set to harvest (October–May). |

Source: Information extracted from '*Citrus pests and their natural enemies*', Smith et al. 1997.

Pests

Table 73. Main species of soft scales affecting citrus.

| Soft Scales | | | |
|---|---|---|---|
| **Pest** | **Region** | **Appearance and location** | **Occurrence, conditions and monitoring** |
| **Black** (Figure 278 and Figure 279) | All areas | Black dome shaped with 'H' on back. Twigs and leaves. | Prefer moderate conditions with high humidity. 2–4 generations/year. Monitor November–December and February–March. |
| **Citricola** (Figure 280) | WA, SA, VIC, inland NSW | Grey brown mottled and flattened. Young leaves and twigs. | 1–2 generations/year. Monitor October–November and March–April. |
| **Cottony citrus** | QLD | Long yellow-brown with a cottony egg mass. Leaves and twigs. | 2–3 generations/year. Monitor October–December. |
| **Cottony cushion** | QLD, NSW, VIC, SA | Red brown with a white mealy secretion and fluted egg sac. Twigs, branches and trunks. | 2 generations/year. Monitor October–December and February–March. |
| **Florida wax** | QLD | Whitish, waxy and globular (2–4 mm). Twigs and leaves. | 2 generations/year. Monitor October–December. |
| **Green coffee** | QLD | Pale yellow green, oval and flattened. Young leaves, twigs and fruit. | 3–4 generations/year. Monitor October–December. |
| **Hard wax** (Chinese) | Coastal NSW and WA | Hard dry dirty white waxy and globular. Leaves and twigs. | Prefer warm humid conditions. 1 generation/year. Monitor in February. |
| **Hemispherical** | QLD | Glossy light to dark brown, dome shaped. Leaves, twigs and fruit stalks. | 4–6 generations/year. Monitor October–December. |
| **Long soft** | QLD, coastal NSW | Grey-brown and flattened. Twigs and leaves. | 4–6 generations/year. Monitor in October. |
| **Nigra** | QLD | Shiny dark and oval. Leaves, twigs and fruit stalks | 4–6 generations/year. Monitor October-December. |
| **Pink wax** | QLD, coastal NSW and WA | Pink waxy and globular. Leaves and twigs. | Prefer humid conditions. 1–2 generations/year. Monitor October–December and February–March. |
| **Soft brown** | All areas | Tan-brown. Leaves, twigs and fruit. | Prefer warm dry conditions. 2–5 generations/year. Monitor October–December and February–March. |
| **White wax** (Figure 281) | All areas | Soft moist white waxy and globular. Twigs. | Prefer warm conditions with high humidity in summer. 1–2 generations/year. Monitor October–December and February–March. |

Source: Information extracted from '*Citrus pests and their natural enemies*', Smith et al. 1997.

Figure 274. Red scale on fruit.

Figure 275. Red scale on leaves.

Figure 276. Heavy red scale infestation on a citrus branch.

Figure 277. A heavy infestation of white louse scale.

Figure 278. Adult black scale showing young emerged crawlers.

Figure 279. Heavy sooty mould growth associated with black scale infestation. Note holes in some scales that have been parasitised.

Figure 280. Citricola scale.

Figure 281. White wax scale.

### Scale insects: best practice tips

- ☑ Monitor leaves, twigs and fruit fortnightly between October and May.
- ☑ Scale identification important for correct control timing.
- ☑ Ants and sooty mould are associated with soft scales – ants need to be controlled.
- ☑ Timing of control critical for soft scales – wait until eggs have hatched.
- ☑ Timing of control for hard scales not critical.
- ☑ Use HMO sprays as directed.

## Spined citrus bug

Spined citrus bug (SCB – *Biprorulus bibax*) is a native insect pest that attacks mainly lemons, but can also be a problem on some mandarin varieties. It can cause significant crop damage. Varieties reported to be attacked include Imperial mandarins, Ellendale and Murcott tangors.

### Damage

The bugs damage fruit by feeding with their piercing and sucking mouthparts, causing drying and brown staining of the fruit segments, gumming and premature fruit drop. Only a few bugs are needed to cause heavy fruit loss. Fruit are mostly attacked when half-grown, causing them to colour prematurely and fall. When more advanced fruit are attacked they tend not to fall, but are damaged internally.

### Description and life cycle

The adult is a lime-green bug approximately 20 mm long, with a sharp spine on each shoulder of the thorax (Figure 282). Adults fly strongly and can eject a caustic liquid when disturbed. The young bugs go through five nymphal stages before becoming adults. The nymphs are variously marked with black, green or orange in the early stages, becoming green in later stages. The bugs are active between spring and autumn. Overwintering females start laying eggs in September and all stages of the bug's life cycle can be present on trees during this time.

### Management

SCB control should be focused on the conservation of natural enemies, removal of overwintering adults and careful use of selective insecticides at low-rates.

Chemical intervention should be undertaken when SCB pressure exceeds the action threshold. The recommended action threshold is 10% of trees infested with SCB adults or nymphs. Chemical control, if warranted, should be aimed at the immature stages when the bugs cannot fly. For information on registered pesticides refer to the *APVMA PubCRIS* website.

SCB eggs are parasitised by at least 12 wasp species. Parasitism can be as high as 100%, with the highest parasitism occurring during spring to early summer. SCB populations and parasitism levels of SCB eggs should be monitored fortnightly between November and March.

Other predators of SCB nymphs and adults include spiders, predatory bugs, praying mantids and the assassin bug. Ants and lacewing larvae consume significant numbers of SCB eggs.

Figure 282. Adult spined citrus bug. Photo: Max Hill.

### SCB: best practice tips

- ☑ Predatory wasps are important in controlling SCB – monitor SCB eggs for parasitism fortnightly between November and March.
- ☑ If chemical control is warranted, target immature flightless stages.

## Snails

There are numerous species of snails that occur in citrus orchards. Some cause damage to fruit and leaves, whilst others tend to feed on decaying organic matter in the leaf litter and on weeds and grass in the inter-row sod. Some snail species are a quarantine pest for some overseas markets. Snails common in citrus orchards include the small brown snail, common white snail, white Italian snail, the pointed snail, common garden snail and the small pointed snail. Snails prefer cool, damp conditions.

### Damage

Snails chew the fruit, leaves and young twigs of trees leaving holes and scarring the plant tissue. The main access points for snails into the tree canopy is via the tree trunk and any low hanging branches.

### Life cycle

Snails feed mostly at night and in the early morning, prefering cool damp conditions and are most active in autumn, winter and spring. They become dormant in hot dry weather, seal the opening of their shell and shelter in leaf litter and the crotches of trees.

The common white, white Italian and pointed snails tend to climb up trees and other structures such as picking bins, fence posts and farm machinery. In this way they can easily be transported around farms, regions and into packing sheds.

The small pointed, small brown and common garden snails tend to congregate in tree guards, under bins and debris or on the lower trunks and crotches of trees for protection during hot weather (Figure 283).

Good harvesting and postharvest handling and packing procedures need to be implemented to avoid snails being present on fruit, cartons, pallets and containers.

### Management

Trees should be skirted to limit the movement of snails from the ground into the trees. The trunks and lower parts of trees can be sprayed with copper in autumn to repel snails.

To check for the presence of snails in the orchard place a large sheet of moist cardboard under trees during dry conditions. Check underneath the cardboard the next day as snails will tend to shelter underneath. The snails can be collected and destroyed.

Ducks can be also used to control snails. The best breeds are Khaki Campbell and Indian Runner.

There are few chemicals registered for snail control. Iron EDTA baits can be used but timing is critical. The best time for baiting is in autumn before the adult snails lay their eggs. Be careful that the baits are not contaminated with any copper products as copper is highly repellant to snails and they will not eat the bait.

Figure 283. Snails can hibernate in the crotch of trees during summer.

**Snails: best practice tips**

- ☑ Skirt trees.
- ☑ Baiting should be done in autumn before adults lay their eggs.
- ☑ Copper sprays applied to the trunk and lower canopy in autumn can repel snails.
- ☑ Store bins on bare ground and inspect regularly.
- ☒ Do not leave bins in the orchard overnight.
- ☒ Do not pick up fallen fruit.
- ☒ Do not let weeds get too tall in the orchard.

## Thrips

There are several species of thrips that cause fruit damage in citrus. The main thrips species affecting cirtus are listed in Table 74.

### Damage

Their feeding causes scarring on fruit which becomes more obvious as the fruit colour. Damage varies with thrips species; some cause a circular ring scar around the fruit calyx (Figure 284), while others cause irregular scarring on the fruit surface (Figure 285). The scars are typically rough to touch, silvery-grey in colour and darken with age.

### Description

Thrips are small, slender, cigar shaped insects between 1.5–3 mm in length. They normally prefer protected sites, around the calyx, where fruits touch or leaves touch fruit. They thrive in warm dry conditions and are often carried into orchards on the prevailing winds.

### Management

Thrips can be difficult to control because they prefer protected sites such as around the fruit calyx, between touching fruit or where leaves touch fruit. There are a range of natural predators that have been found in association with pest thrips. Soil borne predatory mites can play an important role in the control of thrips, so the addition of organic matter to the soil surface will help encourage these natural enemies.

Thrips populations should be monitored during the warmer months. Yellow sticky traps are commonly used to monitor the presence of thrips in the orchard. The traps are also useful for identifying species of thrips. Attach the sticky traps to star pickets at a height of 1–2 m above ground level facing the prevailing winds. Chemical control may be necessary if populations reach damaging levels. Be aware that the overuse of some broad-spectrum insecticides (e.g. most organophosphates and synthetic pyrethroids) can exacerbate a pest problem by killing natural enemies.

For information on chemicals registered for the control of thrips in citrus refer to the *APVMA PubCRIS* website.

Figure 284. Halo damage around the fruit button, most likely from Kelly citrus thrips.

Figure 285. Thrips damage to fruit.

**Thrips: best practice tips**

- ☑ Use yellow sticky traps to monitor for the presence of thrips in orchard.
- ☑ Use a ×10 hand lens for monitoring leaves and fruit (especially fruit calyx and touching fruitlets) between spring and autumn.

Table 74. Summary of the main thrips species affecting citrus.

| Pest | Region | Damage | Occurrence, conditions and monitoring |
|---|---|---|---|
| **Citrus rust thrips** | Coastal Qld and NSW | Feed on fruit and leaves causing brown rusty patches. | Prefers protected sites where leaves and fruit touch. 2 generations/year. Monitor summer–autumn. |
| **Greenhouse thrips** | WA and coastal NSW | Feed generally between touching leaves, fruit or leaves and fruit, causing scarring. Also present are black spots of excreta. | 6 generations/year. Monitor October–March. |
| **Kelly citrus thrips (KCT) (Pezothrips, previously Megalurothrips)** | Inland growing regions SA, VIC, NSW | Feed on young fruitlets causing ring scarring and scurfing (halo) damage. | Prefers sheltered sites. Congregate under the calyx of young fruit and protected sites between touching fruit. 6 generations/year. Monitor from petal fall through spring and summer. |
| **Scirtothrips** | SE QLD, northern NSW | Feed on leaves, shoots, blossoms and young fruit causing ring scarring and scurfing on fruit surface. | Prefers protected sites between touching fruit and under calyx. 6 generations/year. Monitor in spring. |

## Other pests

There are many other pests that can damage citrus. Some of these are listed in Table 75. For more information on these pests, refer to '*Citrus pests and their natural enemies*', (Smith et al. 1997).

Figure 286. Citrus aphids damage young, new growth and can transmit citrus tristeza virus (CTV).

Figure 287. Citrus branch borer damage.

Figure 288. Fresh katydid damage to young fruit.

Figure 289. Old katydid damage that has healed.

Pests

Table 75. Summary of other pests affecting citrus.

| Pest | Region | Damage and location | Occurrence, conditions and monitoring |
|---|---|---|---|
| **Aphids** (Figure 286) | All areas | Commonly found in dense groups on new shoots and leaves. Their feeding distorts growth. | Several species affect citrus. They produce honeydew, so ants and sooty mould are usually also present. Can transmit citrus tristeza virus. |
| **Citrus branch borer** (Figure 287) | SE QLD, coastal NSW | The larvae feed inside branches and trunk causing branch death. | Weak trees, those recently pruned and those close to native bush are particularly susceptible. 1 generation/year. Monitor spring–autumn. |
| **Citrus rind borer** | QLD, NT | Larvae feed on young foliage and fruit surfaces and bore into fruit. Fruit fall. | Prefers protected sites. 7 generations/year. Monitor October–April. |
| **Katydids** (Figure 288 and Figure 289) | QLD, NSW, VIC | Adults and nymphs chew the rind of young fruit leaving large chalk white scars on the fruit. The scars heal over as the fruit grow. | Infestations tend to be patchy. Adults can fly. Monitor September–January. |
| **Light brown apple moth** | NSW, VIC, SA | Caterpillars feed around stem end of fruit causing 'halo' scars and fruit drop. | Prefers mild, moist conditions. 3–4 generations/year. Monitor all year. |
| **Longicorns (several species)** | QLD, coastal NSW | Larvae tunnel into branches and trunks causing ringbarking and death. Evidence of frass (chewed wood or sawdust). | 1 generation/year. Monitor spring–autumn. |
| **Orange fruit borer** | QLD, NSW, NT | Larvae bore into fruit causing large holes. Fruit colour prematurely and drop. | Prefers protected sites under calyx and where fruit touch. 5–6 generations/year. Monitor summer–autumn. |

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# Harvesting

## General guidelines

Mandarins require more careful handling than other citrus fruit. Mandarins are more susceptible to rind damage and plugging of the stalk from the fruit. Satsuma and Imperial mandarins are particularly susceptible. Mandarins also tend to have a much shorter maturity period than other citrus and fruit left on trees can quickly pass the stage of optimum maturity.

If fruit are left on the tree past maturity they will continue to grow until they become puffy, where the fruit rind separates from the pulp. When this occurs the pulp quickly dries out and becomes woody.

Most mandarin varieties are selectively picked a number of times during the harvest period for size and quality. The number of picks depends on the variety. For example Imperial mandarin trees are picked over at least twice. The first harvest targets the largest, best coloured fruit, while the smaller fruit are left on the tree to size. These fruit are then either 'strip' picked (removing all the fruit from the tree) or size picked again.

Most varieties have a distinct window where fruit quality is at its peak. The length and timing of this window varies with variety and location. For example some mandarins, such as the Satsumas, have a very short period of optimum maturity (7–10 days). If fruit are not harvested during this time, quality parameters such as % juice and flavour deteriorate. Other varieties, such as Afourer mandarin, have a much longer harvesting window, between 4–6 weeks.

For some varieties it is common practice to reduce or stop irrigating the trees one to two weeks prior to harvest. This can improve flavour by increasing the sugar content of fruit, making them sweeter. For more information see the Irrigation chapter.

Mandarins are usually picked using soft cotton gloves to reduce rind damage. Most mandarin varieties are clipped from the tree using fruit snips. Fruit are clipped close to the calyx in one step or 'double clipped' – where a longer stem is left and then removed with a second cut (Figure 290).

A new citrus harvesting handbook has recently been released, covering fruit harvesting techniques and personal safety measures for pickers. The handbook is available on the *NSW DPI citrus* website.

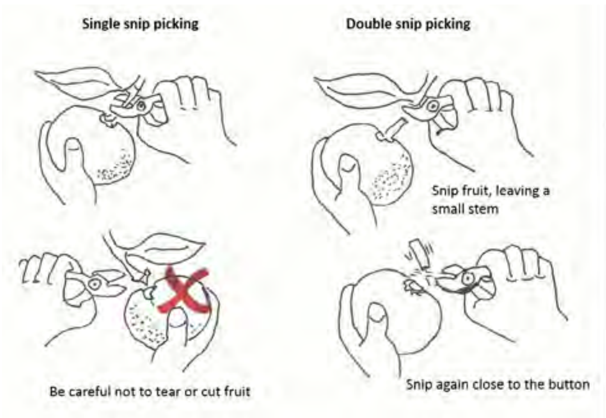


Figure 290. Single and double snip method of harvesting mandarin fruit. Source: Citrus Growers of South Australia Inc. 1999.

Figure 291. Mandarin fruit are harvested using cotton gloves and clipping the fruit close to the button using fruit snips.

Figure 292. Harvested fruit should be delivered to the packing shed as soon as possible.

**Harvesting: best practice tips**

- ☑ Snip stems off close to the button.
- ☑ Wear cotton gloves when picking (Figure 291).
- ☑ Pick fruit at optimum maturity.
- ☑ Handle fruit carefully and gently place into bins.
- ☑ Get fruit to the packing shed as soon as possible (Figure 292).
- ☑ If required, treat fruit with postharvest fungicides within 24 hours.
- ☑ When using harvesting ladders make sure they are stable.
- ☒ Do not pick up fallen fruit.
- ☒ Do not leave harvested fruit in the sun for long periods.
- ☒ Do not over-fill picking bags or field bins.
- ☒ Do not harvest wet fruit. When wet fruit are handled the oil glands can rupture, releasing oil which can burn the fruit rind causing oleocellosis.

## Maturity standards

The flavour of fruit is affected by a number of factors including the amount of juice, the sugar and acid content, sugar to acid ratio and the level of volatile compounds. These components will vary between fruit; even those taken from the same tree can have different levels, creating a different taste.

Maturity standards for citrus fruit quality have been developed to ensure minimum product standards are achieved for fruit sent to market. In most states of Australia these maturity standards are not mandatory, but are recommended to maintain product consistency and consumer confidence. Western Australia is currently the only state where minimum standards are mandated. These standards were gazetted in 2009 and all fruit produced and sold on the fresh fruit market in WA must meet these standards (Table 76).

Table 76. Western Australia internal maturity standards.

| Variety | % juice content | TSS:TA | TSS at 20 °C |
|---|---|---|---|
| Mandarin | 28 | 8:1 | 8 °Brix |

Source: Department of Agriculture and Food Western Australia 2016.

Citrus Australia Limited (CAL) released maturity standards for most citrus types in 2011. These standards outline the minimum acceptable total soluble solids (TSS), total acidity (TA), TSS:TA (°Brix or sugar to acid ratio) and percentage juice content.

Since 2014 CAL has used BrimA to help define the maturity standards for mandarins. Prior to this, fruit maturity standards were based on the °Brix:acid ratio.

The Australian Citrus Standard (ACS) is based on the California Standard which is derived from BrimA. BrimA is a formula that shows the relationship between °Brix and acid and is a better predictor of consumer acceptability compared with the older index based on the °Brix:acid ratio (Obenland et al. 2009). BrimA more closely reflects flavour, by taking into account the sensory impacts of different combinations of sugars and acids in fruit (Jordan, Seelye & McGlone 2001). In 2013 consumer taste panel testing was conducted in the Perth and Melbourne markets on Afourer mandarin. The results from that testing helped validate the use of a minimum BrimA standard for Australian mandarins (Storer et al. 2014).

The same methods are used to measure the Brix and % acid but the calculation is different. To calculate BrimA, the % acid of the sample is multiplied by 4 and then subtracted from the °Brix. A further multiplier of 16.5 is used to simply make the number bigger.

The ACS is calculated using the following formula: [°Brix – (acid × 4)] × 16.5. The current maturity standards recommended by CAL for mandarins are outlined in Table 77.

Table 77. Recommended minimum quality standards for mandarins.

| Mandarin variety | % juice content | Australian Citrus Standard* |
|---|---|---|
| Imperial | 33 | 110 |
| Other varieties | 35 | 110 |

Harvesting

*Australian Citrus Standard = [°Brix − (acid × 4)] × 16.5 Source: Citrus Australia Limited 2015.

For more information on how to test the maturity of mandarins refer to the CAL website (www.citrusaustralia.com.au), 'Citrus quality and marketing section' or NSW DPI Primefact 980 *'Citrus maturity testing'*. Maturity standards can change so it is recommended these be checked each season.

### Granulation standard for Imperial mandarins

In some seasons granulation or internal dryness can be a serious problem in Imperial mandarins. Fruit show no obvious external symptoms, but when cut the fruit segments appear to be dry, white or colourless and are relatively tasteless. Fruit have a lower extractable juice percentage, decreased soluble solids and decreased sugar and acid levels. For more information on granulation see the Disorders chapter.

Currently there is no non-destructive method for detecting the presence of granulation in fruit. Harvested fruit need to be cut to detect the disorder. In spring 2016 Citrus Australia Limited (CAL) released a new sampling methodology for assessing granulation, as well as a maximum standard for granulation in Imperial mandarins (Hancock, 2016). The standard allows for no more than 3 fruit/30 piece sample to have granulation levels >55%. Examples of different levels of granulation are depicted in Figure 293.

The new sampling protocol involves sampling a minimum of 30 pieces of fruit per consignment. Fruit should be cut in half and visually assessed for the presence of granulation. No more than 3 pieces of fruit should have granulation levels exceeding 55%. In samples where there are more than 3 pieces of fruit with granulation levels above 55%, the affected fruit should also be subjected to a juice test. If the percentage of juice in the piece of fruit is <25%, then the fruit is confirmed to have granulation levels exceeding 55%. For more information on the sampling protocol see the CAL website (www.citrusaustralia.com.au).

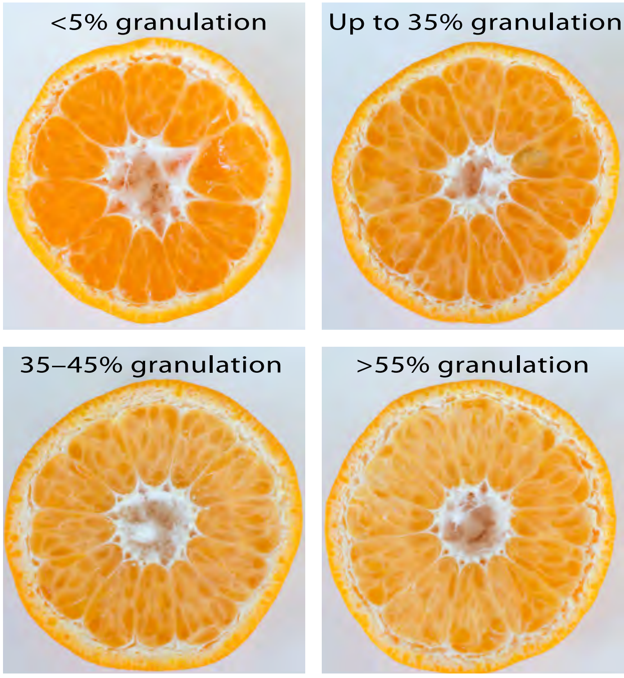


Figure 293. Examples of fruit with different levels of granulation. Source: Citrus Australia Limited.

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# Postharvest handling

## Introduction

After harvest, fruit are delivered to the packing shed where they go through a range of treatments. The sequence of postharvest operations can vary, depending on fruit condition and market destination.

Generally fruit are washed and cleaned, treated with a postharvest fungicide, sorted, graded, waxed and packed for market. Early season fruit are sometimes degreened to improve rind colour. Figure 294 is a general outline of the most common sequences of postharvest operations.

Packing sheds should always be kept free of mouldy and diseased fruit to prevent contamination of clean fruit. Diseased or decayed fruit should be discarded in the field during harvest operations and not sent to the packing shed.

Dedicated mandarin packing lines tend to be shorter and with fewer brushes to reduce mechanical damage (Figure 295). Postharvest packing lines should be well maintained and regularly cleaned to prevent a buildup of dirt and wax which can damage fruit.

Where possible reduce the number of hard surfaces that fruit hit by using foam or rubber on contact surfaces. The potential to damage fruit on the packing line can be assessed using an instrumented sphere about the same size as fruit. The sphere travels along the length of the line recording the force of each impact fruit experience.

Postharvest handling procedures for all citrus varieties are similar, especially hygiene, sanitation and disease control practices. Some postharvest handling steps can have a major effect on mandarin quality. This chapter is concerned with the postharvest handling of mandarins that require special attention.

For the latest Australian best practice news on postharvest handling of citrus, refer to the Packer Newsletters available on the *Citrus Australia Limited* (CAL) website.


Figure 294. Outline of the most common postharvest handling sequences.

Figure 295. Mandarin fruit moving along a packing line.

## Postharvest handling

Mandarins have a much shorter shelf life compared to other citrus varieties, especially oranges. Mandarins are more prone to a loss of flavour and the development of 'off' flavours during storage. Postharvest handling and storage conditions can influence the taste and aroma of mandarins and the effects vary with variety.

Fruit taste is largely governed by the level of total soluble solids (TSS) and total acid (TA) in the fruit and their ratios. As fruit mature on the tree, TSS (a measure of the sugar content) increases and the level of TA decreases. This trend continues throughout the fruit maturation period.

Good tasting fruit typically require high levels of sugar and moderate levels of acid for consumer acceptance. Maturity standards have been developed to help identify when fruit reach the minimum level of consumer acceptability based on taste. For more information on maturity standards refer to the Harvesting chapter.

TA typically declines during storage, making the fruit less acid, whilst TSS remains more or less constant – resulting in an increase in the TSS/TA ratio. The level of TA is closely related to flavour and a decline in acidity generally equals poor flavour. The longer fruit are stored, the greater the impact on flavour.

For early and mid season varieties that tend to have higher TA levels at harvest, this decrease in TA during storage may not be as serious as that for late season varieties where juice TA levels are relatively low at harvest.

Fruit aroma is determined by a mixture of different naturally occurring aroma volatiles. Mandarin fruit have a large number of aroma volatiles including alcohols, aldehydes, ketones, terpenes and esters. There are changes in these aroma volatiles during storage. The largest changes are increases in the alcohol and aldehyde contents, which results in an increase in 'off' flavours and volatiles.

The longer fruit are stored, the greater the negative impact on fruit flavour. Optimum storage time varies with variety, but generally fruit should only be stored for a maximum of 4–6 weeks.

Storage temperature also has a strong effect on fruit flavour by influencing the development of 'off' flavours. However, these changes are also dependent on variety and storage time. Fruit are best stored at temperatures between 5–8 °C prior to consumption. Large scale accumulation of bad or 'off' aroma volatiles can largely be prevented by storing fruit at these temperatures.

Generally storing fruit at higher temperatures (e.g. 20 °C) can be detrimental to flavour. At high storage temperatures, fruit have a higher respiration rate which lowers internal oxygen levels. Low internal oxygen levels cause ethanol and other 'off' volatiles to be produced as well as 'off' flavours.

Storing fruit at lower than recommended temperatures can also result in a loss of fruit flavour, particularly in cold sensitive varieties (see the Storage section).

In addition, some less permeable waxes and excessive wax can cause the development of 'off' flavours in mandarins by restricting gas exchange between the fruit and the atmosphere. This causes anaerobic conditions (without oxygen) to develop, resulting in the increased production of 'off' flavours and volatiles (e.g. ethanol) – see the Waxing section. Quite a bit of variation exists between mandarin varieties in the amount of ethanol produced in response to exposure to anaerobic conditions. More work is needed to fully evaluate the effects of waxing and storage on each variety. The best waxes to use are the more permeable ones, for example carnauba wax. Exposure of mature mid and late season fruit to ethylene during degreening may also enhance the accumulation of 'off' flavours and volatiles.

### Summary

- ☑ Mandarins have a relatively short shelf life.
- ☑ The effects of postharvest handling procedures on mandarin quality and flavour vary with variety.
- ☑ Fruit should be kept at 5–8 °C along the whole supply chain. Storing fruit at higher temperatures increases the accumulation of 'off' flavours and volatiles.
- ☑ TA declines during storage.
- ☑ Varieties with low levels of TA at harvest, such as late season fruit, should not be stored for long periods.
- ☑ Use the most permeable wax on mandarins to reduce the development of 'off' flavours.
- ! The longer fruit are stored the greater the negative impact on fruit flavour.
- ! During storage there are changes in the concentration of 'off' flavours and aroma volatiles.
- ! Waxing and storage greatly enhance ethanol levels in mandarin fruit, resulting in the development of 'off' flavours.
- ! Degreening mature, mid or late season varieties may enhance the development of 'off' flavours.

## Washing and cleaning

Washing fruit removes dirt, fungal spores and spray residues from the fruit surface. However, it also disrupts the natural wax layer on the fruit surface. The water used for washing should be of good quality and treated with a sanitiser. The wash water in recirculating systems should be replaced regularly.

Do not let decayed or mouldy fruit get into washing and fungicide treatment tanks. Remove mouldy fruit before it enters the packing line to reduce spore contamination. Unless a sanitiser is used, spores will be released and infection of other fruit is likely.

High pressure washers are sometimes used to remove insects pests (e.g. red scale) and fungal growth (e.g. sooty mould) from the fruit surface (Figure 296). High pressure washers are used with roller-brushers at pressures of 100–150 psi. Low pressures are better for sensitive mandarin rinds, but longer dwell times are needed to clean fruit. For more information on using high pressure washers refer to the 'Best practice user manual for citrus high pressure washers' on the *Citrus Australia Limited* website.

Figure 296. High pressure washers are sometimes used to remove insect pests or fungal growth.

### Sanitisers

There are a range of sanitisers that can be used in citrus packing sheds to improve hygiene and reduce the spread of disease. Sanitisers are normally used in the wash water to kill any free floating fungal spores and bacteria in the water. Sanitisers will not control disease development on infected fruit, nor kill fungal spores already present in the fruit. Sanitisers are complementary to postharvest fungicides. They do not have a residual affect or protect fruit from re-infection during storage and marketing.

Sanitisers are particularly important in recirculating systems where the wash water can quickly become contaminated by fungal spores which can then infect clean fruit through any wounds.

Most of the sanitisers used in packing sheds are chlorine releasing compounds. They include the hypochlorites; bromo-chloro-dimethylhydantoin (Nylate®) and chlorine dioxide (Vibrex®). Another sanitiser used is peroxyacetic acid (Tsunami™). For more information on sanitisers, including the advantages and disadvantages of each, refer to the *Packer Newsletter No. 107* or the product manufacturer.

It is critical to test the water pH before mixing hypochlorites (i.e. pool chlorine) because its stability and activity are affected by pH. Products vary in their sensitivity to pH. Nylate® and chlorine dioxide are fairly stable over a range of pH values.

It is important to change solutions frequently, as chlorine compounds react with all organic matter, such as dirt, leaves and twigs to produce inactive by-products.

Chlorine can be inactivated when it is mixed with some other chemicals. Check compatibility with other products such as surfactants and postharvest fungicides. It is preferable not to mix postharvest fungicides with chlorine. Sanitisers are important for packing line hygiene. For more information on compatibility refer to *Packer Newsletter Nos. 105 and 106* or the sanitiser/fungicide compatibility chart in Taverner et al. 2008.

**Summary**

- ☑ Sanitisers kill free floating fungal spores.
- ☑ Solutions should be changed frequently.
- ☑ Measure the water pH before mixing.
- ☑ Follow all the manufacturers' guidelines.
- ☑ Do not mix with other products or postharvest fungicides unless compatibility is assured.

## Postharvest fungicides

The effectiveness of all postharvest fungicides depends on the prompt treatment of fruit after harvest. The maximum time between harvest and treatment varies with temperature but should not exceed 24 hours. Table 78 lists the registered postharvest chemicals for mandarins and the diseases controlled. It is important to use these chemicals carefully, following all label directions.

To check on registered products go to the Australian Pesticides and Veterinary Medicines Authority (APVMA) *PubCRIS database*.

For export fruit it is also important to check the requirements of the destination country as some postharvest chemicals may not be permitted. For chemical residue limits of destination countries refer to the *Citrus Australia Limited website.*

Table 78. List of registered postharvest chemicals for mandarins.

| Active ingredient | Example trade name | For control of |
|---|---|---|
| 2, 4-D | Stop Drop® | Colour retention of buttons |
| Fludioxonil | Scholar® | Blue and green mould; *Diplodia* fruit rot |
| Guazatine | Panoctine® | Blue and green mould; sour rot |
| Imazalil | Fungaflor® | Blue and green mould |
| Imazalil pyrimethanil | Philabuster® | Blue and green mould |
| Thiabendazole (TBZ) | Tecto® | Blue and green mould; stem end rot |
| SOPP (Sodium ortho-phenylphenate) | Preventol ON® | Blue mould |

## Application methods

### *Bulk dip or drench*

Bulk dipping is the complete immersion of bulk bins of fruit in the fungicide (Figure 297). Bulk dipping provides a convenient method of fruit treatment within 24 hours of harvest when fruit are not packed or processed immediately. Bins should be immersed in the fungicide solution for at least 30 seconds as per label directions.

### *In-line fungicide application*

Effective disease control can also be obtained using an in-line fungicide application. These treatments are normally effective by themselves if applied within 24 hours of harvest. Fruit should be thoroughly coated with the fungicide for at least 30 seconds.

- High volume recirculating system

This high volume system ensures good fruit coverage, but there can be issues with dirt and fungicide stripping. Generally high volumes of the fungicide mix are sprayed on fruit over metal rollers, followed by a few brushes to spread and remove the excess liquid.

- Low volume/run to waste system

This system applies only enough solution to cover fruit. The solution provides a constant fungicide concentration because it is single use.

There can be problems with fruit coverage if the fruit are wet or not rotated properly. Generally low volume application is undertaken over brushes which hold and spread the fungicide solution.


Figure 297. Bulk bin dip tank.

### *Fungicide stripping*

As postharvest fungicides are applied to fruit, either as a bulk dip, drench or shower (recirculating systems only) in the packing line, the fungicide is gradually removed from the solution by the fruit. Accumulated dirt and organic matter also bind some fungicides and reduce their effectiveness. Because the fungicides are removed they must be replaced if an effective concentration is to be maintained.

The type of fungicide application equipment and the quality of water used can also influence the fungicide loss rate. Maintaining the correct concentration of fungicide in the water can be achieved either by changing fungicide tanks regularly or by topping up with more fungicide as per label directions. The concentration of fungicide in the dip tank and in line equipment should be monitored at regular intervals.

## Waxing

Normal postharvest handling procedures such as washing and brushing can damage and remove some of the natural wax layer on fruit, making them more prone to postharvest diseases, water loss and other disorders. The application of wax to fruit imparts shine, protects fruit and reduces water loss and shrinkage. Fruit should be dry before waxing. Aim to apply a thin, even layer across the entire fruit surface (Figure 298).

Some waxes and excessive wax application can also cause the development of 'off' flavours in mandarins. Thick layers of wax restrict gas exchange between the fruit and the atmosphere. This alters the internal atmosphere of the fruit causing elevated carbon dioxide levels and reduced oxygen levels. Atmospheres devoid of oxygen are termed 'anaerobic' and mandarins are more sensitive to anaerobic conditions compared with other citrus varieties.

Anaerobic respiration leads to increased production of the 'off' flavour volatiles, such as ethanol and aldehydes.

Research in California found that mandarin varieties had substantial differences in the amount of 'off' flavours (e.g. ethanol) present in freshly harvested fruit and in the amount produced in response to waxing and storage. Waxing and storage greatly enhanced ethanol levels in every mandarin variety tested, including W. Murcott (Afourer), Gold Nugget, Minneola and Pixie mandarins. However, other factors such as fruit maturity, management practices and locality may also influence varietal response to waxing and storage. More research is needed to fully evaluate the effects on each variety.

The best waxes to use on mandarins are the most permeable ones. Carnauba wax is more permeable than Shellac based waxes.

Figure 298. Wax being applied to fruit using a spinning disk.

## Drying

After waxing, fruit are dried by running high velocities of air across the fruit. It takes between 2·5–3 minutes to dry the wax. Cool or warm air is used to dry fruit, depending on the conditions. Fruit should not be rolled during drying, but should be turned once. There are several types of dryers, including open line and closed recirculating tunnel dryers.

## Sorting

Fruit are sorted on the packing line to remove blemished or unmarketable fruit and to grade fruit according to market specifications. Ideally any fruit that are diseased or badly damaged should be discarded in the field and not brought into the packing shed.

Sorting can be done by hand (Figure 299) or by using automated sorting equipment in the packing line. Good lighting is essential when hand sorting. Sorting staff need to be provided with detailed information on the tolerance levels of different defects for which fruit will need to be discarded. Photographic charts and posters showing the type and degree of blemish allowed on fruit are the most common methods used.

Figure 299. Manual sorting to remove unmarketable fruit.

## Sizing

Fruit can be sized mechanically (using belts or rollers), electronically or by weight. Weight sizers are not recommended when pattern packing fruit as there is too much variation, leading to poor packout presentation.

## Packing

Mandarins are packed into fibreboard 9–10 kg cartons (half citrus pack). Top grade fruit are pattern packed, but some grades and varieties are volume filled. Bulk fibreboard bins (200–300 kg) are sometimes used for delivery to supermarket chains requiring large fruit volumes. Each package of fruit should be graded to have a similar size, shape, colour and condition (blemish level). A range of pattern pack configurations for common counts of some mandarin types is listed in Table 79.

Table 79. Some common pattern packing configurations.

| Variety | Count | Front on | Sideways | Fruit/ layer |
|---|---|---|---|---|
| Imperial | 125 | 5 × 5 | 3 × 2 | 25 |
| | 100 | 4 × 4 | 3 × 2 | 20 |
| | 88 | 6 × 5 | 2 × 2 | 22 |
| | 64 | 4 × 4 | 2 × 2 | 16 |
| | 48 | 3 × 3 | 2 × 2 | 12 |
| Murcott/ Ellendale | 125 | 5 × 5 | 3 × 2 | 25 |
| | 104 | 6 × 7 | 2 × 2 | 26 |
| | 88 | 6 × 5 | 2 × 2 | 22 |
| | 64 | 4 × 4 | 2 × 2 | 16 |
| | 36 | 4 × 4 | 2 × 1 | 12 |

Source: Owen-Turner, Fullelove and Vock 1998.

## Degreening

Most early season varieties are internally mature before the fruit rind loses all of its green pigment (chlorophyll).

Colour development of the rind in citrus in the orchard is promoted by cool overnight temperatures (<15 °C). At cooler temperatures the natural growth regulator (ethylene) breaks down the chlorophyll and promotes the development of the yellow, red and orange pigments in the rind.

In the majority of citrus growing regions with a Mediterranean type climate, cooler temperatures in late autumn promote good colour development. However, in the warmer subtropical and tropical growing regions these cooler temperatures may not occur until much later, well after the early varieties are internally mature. In these regions it is common practice to use ethylene gas to degreen early season fruit, such as Imperial mandarins.

The application of ethylene gas in a controlled environment mimics the natural degreening process. Ethylene accelerates chlorophyll break down, but also hastens rind aging, making fruit more susceptible to breakdown. Immature fruit rinds, excessive rates of ethylene, high temperatures and long treatment times increase the susceptibility of fruit to the postharvest disease anthracnose (see the chapter on Postharvest diseases and disorders).

The success of degreening can vary with variety, the initial colour of the fruit, concentration of ethylene used and the duration of exposure to ethylene. When degreening it is critical to selectively pick fruit based on colour during harvesting.

Depending on rind colour, fruit are normally exposed to ethylene for periods of 12–24 hours. The longer fruit are exposed to ethylene the shorter the shelf life. It is important to remember that fruit will continue to colour after degreening. When fruit have reached an acceptable colour, they are removed from the degreening room and left to stand for a period of time (e.g. 6–12 hours). Allowing the fruit to stand prior to being put through the packing line will also enable the fruit to lose some of its excess turgor, reducing the risk of possible rind damage.

### Degreening guidelines

Degreening rooms require careful monitoring and management of:

- fruit colour and condition
- air circulation and room ventilation
- temperature
- relative humidity
- ethylene levels.

#### *Fruit colour and condition*

Fruit to be degreened should be blemish free, internally mature and have some colour development in the rind. Colour pick fruit and handle carefully. Do not over-fill field bins or leave fruit in the sun for long periods. The greener the fruit the longer the degreening process. Long degreening periods increase the risk of fruit developing rind disorders, such as anthracnose, and reduce postharvest shelf life.

#### *Air circulation and room ventilation*

Degreening rooms need good air circulation through the fruit load to ensure the ethylene is distributed evenly throughout the room. Too much or too little air flow will result in uneven colouring of fruit.

An efficient ventilation system is critical to extract the carbon dioxide ($CO_2$) generated by the fruit during degreening (Figure 300). Carbon dioxide levels should be monitored and kept below 0·3% because high levels are detrimental to fruit quality and are also unsafe for workers. If $CO_2$ levels cannot be monitored, the typical air ventilation recommendation is one room per hour.

#### *Temperature*

The optimum temperature for degreening depends on initial fruit colour and local climatic conditions (especially temperature) at the time of harvest. Current temperature recommendations for Australia are 20–25 °C for fruit grown in the Mediterranean type climates of southern Australia and up to 29 °C for fruit grown in the humid sub-tropical regions of Queensland.

In other parts of the world, temperatures used vary between 18–24 °C. In Spain temperatures of 18–22 °C for Satsuma and early season mandarins are recommended. A study in South Africa compared degreening of Satsumas at 18 °C and 24 °C and found that the higher temperature resulted in a darker orange colour, but more fruit changed colour at the lower temperature.

### *Relative humidity*

Relative humidity in the degreening room should be high, above 90% and ideally 95%. However, the high humidity combined with warm temperatures of degreening rooms make conditions ideal for the development of postharvest diseases. Therefore fruit should be treated with a postharvest fungicide prior to degreening.

### *Ethylene*

The 'trickle system' is the most common method used for the delivery of ethylene gas. This is where ethylene is continuously trickled into the degreening room using an airflow system to evenly distribute the gas. This is combined with an efficient ventilation system which extracts the $CO_2$ generated by the fruit.

Some growers are now using ethylene generators. Ethylene generators (e.g. Citrus generator™ and Easy-ripe™) can be leased. They produce small controlled amounts of ethylene and when used as directed cannot produce explosive levels of ethylene. They are a safer option than using cylinders of pure ethylene. They can be used in various sized rooms and have the capacity to be used in conjunction with a computerised ripening control system.

A concentration of ethylene of between 1–5 ppm is required. Never exceed 5 ppm. Rates of 1–3 ppm are commonly used for mandarins. Normally the lower the rate, the longer the duration of treatment.

Exposure of mature mid and late season fruit to ethylene may enhance the accumulation of 'off' flavours.

Figure 300. Bulk bins of fruit in a degreening room. The curtain allows the room to be easily ventilated to remove excess carbon dioxide.

Degreening: best practice tips

- ☑ Fruit should have some colour development and not be totally green.
- ☑ Fruit should be colour sorted when picking.
- ☑ Fruit should be internally mature.
- ☑ Fruit should be unblemished.
- ☑ Harvest fruit carefully as any rind damage will be exacerbated by the degreening process.
- ☑ Treat fruit with a postharvest fungicide prior to degreening.
- ☑ The success of degreening can vary with different varieties and the initial fruit colour. Consider trialling small quantities of fruit to determine ethylene sensitivity rates and duration.
- ☑ Good air circulation in the degreening room is critical – ensure air moves through the fruit load, not around it.
- ☒ Do not wax fruit prior to degreening as this will inhibit full colour development.
- ! The greener the fruit the longer the degreening process. The longer fruit are exposed to ethylene the shorter the shelf life.
- ! Fruit treated with a late gibberellic acid (GA) spray will take longer to degreen or may not fully colour.
- ! Fruit treated with an oil spray shortly before harvest (within 2–4 weeks) may not achieve full colour.
- ! High ethylene concentrations cause the fruit calyx (button) to dry out and turn brown. Fruit can be dipped in the synthetic auxin 2,4-D to help keep buttons green, but 2,4-D can also delay the degreening process.
- ! High rates of ethylene can induce the development of the postharvest disease, anthracnose.

## Quality assurance

Good quality management guidelines are critical in marketing fruit that is safe to eat and of consistent quality. All fresh food producers are required to have a quality assurance program in place.

There are several quality assurance programs designed for the horticulture industry. The most popular of these is the Freshcare program which provides on-farm safety and quality certification services. For more information on the Freshcare program refer to *www.freshcare.com.au.*

Additionally, suppliers need to develop detailed product specifications based on prospective customers' or markets' requirements. Product specifications are then used in the packing shed to sort and grade fruit. Throughout the packing process a percentage of fruit and boxes are then checked by quality assurance personnel to ensure quality standards are being met (Figure 301).

Various resources have been developed on product specifications for mandarin fruit. The most recent of these is the '*Citrus Quality Improvement Guide* (Version 2009.1)', which provides information and photographic guides for the assessment of fruit quality. Copies of the guide are available from Queensland Citrus Growers Incorporated.

Another useful resource is the *'Product description language oranges: Reference guide'* available for download at the *Citrus Australia Limited website.*

Figure 301. Quality assurance is important to maintain fruit quality standards.

## Storage

The storage life of mandarins is significantly less than other citrus varieties such as oranges. Generally mandarins can only be stored for 4–6 weeks before the fruit begins to deteriorate. If mandarins are stored at temperatures lower than 5 °C they may become susceptible to 'chilling injury' (see the Postharvest diseases and disorders chapter).

Storage time and temperature also have a strong influence on fruit flavour by altering the concentration of the aroma volatiles. However, these changes are dependent on variety, maturity stage at harvest and storage time. Research has shown that some mandarin varieties such as W. Murcott (Afourer) accumulate greater amounts of 'off' flavours during storage.

Fruit are best stored at temperatures between 5–8 °C prior to consumption, which prevents the large scale accumulation of the 'off' aroma volatiles. This temperature range applies to all parts of the supply chain from the farm to the packing shed, in storage, transport and on supermarket shelves.

During storage there are changes in the aroma volatiles of the fruit. The biggest change is an increase in the alcohol and ester groups which result in the development of 'off' flavours. The longer the fruit are stored the greater the impact on fruit flavour.

Generally storing fruit at high temperatures such as 20 °C can be detrimental to flavour. At high storage temperatures, fruit have a high respiration rate that lowers internal oxygen levels, which then induces fermentation and the development of 'off' flavours.

Lower storage temperatures can also result in a loss of the orange colour intensity of the peel. It can also affect fruit flavour, particularly in temperature sensitive varieties. Storage at 4 °C or lower can result in flavour loss due to the accumulation of the 'off' aroma volatiles, especially terpenes and their derivatives. However, there is a wide diversity in response to low storage temperatures for each variety. Some varieties are relatively resistant to low temperatures (e.g. Owari and Or), while others are extremely sensitive (e.g. Odem). It is critical to determine the optimum minimum safe storage temperature for each variety.

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# Postharvest diseases and disorders

## Anthracnose

The term anthracnose is applied to any lesion on fruit that contains fruiting bodies of the *Colletotrichum* fungus.

Anthracnose is usually only a problem in seasons when fruit are over-mature, held too long in storage or subjected to some kind of injury or stress (such as cold or heat) in the field. The likelihood of anthracnose symptoms appearing on fruit is higher during wet seasons.

Symptoms do not appear until after harvest and can be exacerbated if fruit are degreened. Anthracnose is sometimes referred to as 'gas burn' because symptoms can develop after degreening with ethylene, especially early season green fruit with no signs of colour break. Ethylene triggers the growth of the dormant fungus and also increases susceptibility of the rind to damage. For more information on degreening procedures refer to the chapter on Postharvest handling.

### Cause

Anthracnose is caused by the common fungus *Colletotrichum gloeosporioides*. Fungal spores are produced on dead twigs and foliage and invade the fruit rind symptomlessly during the growing season, especially when conditions are wet. The spores are spread by water.

Spores appear as pink or salmon coloured masses under humid conditions, or under drier conditions they appear brown to black.

After the spores germinate and invade the rind they remain dormant. Further invasion of the tissue and subsequent decay only occurs when the tissue is weakened or damaged.

### Symptoms

Anthracnose symptoms usually do not appear until after fruit are harvested. Symptoms associated with bruised or damaged rind from field injury show as brown to black spots (Figure 302).

Symptoms associated with ethylene degreening are silver grey and flat initially. Either sunken black lesions or a superficial reddish brown discolouration then develops on the fruit rind (Figure 303). Initially only the rind is affected, but in the advanced stages the fungus can penetrate deep into the flesh, causing fruit to rot.

Figure 302. Anthracnose symptoms on mandarins.

Figure 303. Anthracnose symptoms on mandarins. Photo: Andrew Miles.

### Control

There is much that can be done to prevent fruit infection in the field, especially during wet seasons. Field sprays of copper-based fungicides or mancozeb may inhibit spore germination. Keep trees free of dead wood to reduce the source and production of the spores. Controlled ripening using the trickle system or ethylene generators should reduce the likelihood of symptoms developing. The concentration of ethylene for degreening should not exceed 5 ppm.

**To reduce the risk of anthracnose**

- ☑ If degreening 'select pick' fruit based on colour.
- ☑ Handle fruit carefully to avoid injury.
- ☑ Harvest fruit at optimum maturity – do not let fruit become over-ripe.
- ☑ Wash fruit on revolving brushes to remove fungal spores, or dip in a thiabendazole (TBZ) fungicide (e.g. Tecto®) before degreening.
- ☑ If disease pressure is high use a combination of two different fungicides with activity against anthracnose, such as TBZ and fludioxonil (e.g. Scholar®), to provide superior protection and reduce anthracnose expression.
- ☑ Cool fruit immediately after packing.
- ☑ Carefully monitor temperature, humidity, ethylene concentration and condition and colour of fruit when degreening.
- ☑ Keep trees free of dead wood.
- ☒ Do not pick or pack wet fruit.
- ☒ Do not pick immature fruit that will require lengthy degreening periods.
- ☒ Do not leave harvested fruit in the sun for long periods; get fruit to the packing shed quickly.
- ☒ Do not store fruit for long periods.

## Black centre rot or core rot

Black centre rot can be a problem in Ellendale tangor, or any mandarin with a navel, in all regions. It is usually only a problem in fruit weakened by over-maturity or subject to adverse climatic conditions or stored for long periods. Imperfections in fruit with a navel also facilitate infection, especially if mealybugs colonise the navel.

### Cause

A pathotype of *Alternaria alternata* causes black centre rot. Different pathotypes of the fungus also cause brown spot of mandarins (see Diseases chapter) and a leaf spot on rough lemon rootstocks. The fungus grows saprophytically (on dead wood) and is spread onto fruit by wind and water. The spores commonly lodge in the 'buttons' (calyx) of young fruit and lay dormant until they enter the fruit when the button dies. The spores can also enter fruit through splits.

### Symptoms

Damage appears as a dark brown or black rot which starts at either the stem or stylar end of fruit (Figure 304) and penetrates into the central core of the fruit (Figure 305). Symptoms are not always obvious until the fruit are cut (Figure 306).

Figure 304. Black centre rot symptoms on Imperial mandarin.

Figure 305. Black centre rot symptoms on Imperial mandarin.

Figure 306. Black centre rot symptoms on Daisy mandarin.

### Control for black centre rot

- ☑ Keep trees free of dead wood.
- ☑ Clip fruit rather than snap pick.
- ☑ Copper fungicides for disease control may reduce infection.
- ☑ An application of gibberellic acid (GA) to delay rind ageing can help maintain button health.
- ☑ The application of a postharvest treatment of 2,4-D will help keep buttons green and healthy.
- ☑ Apply a postharvest fungicide such as Imazalil.
- ☒ Do not store fruit for long periods.
- ☒ Do not store over-mature fruit.

## Blue and green moulds

Blue and green moulds are the most serious postharvest diseases of citrus. These moulds develop in damaged areas in the fruit rind.

### Cause

Fungal pathogens of *Penicillium digitatum* (green mould) and *Penicillium italicum* (blue mould). Blue mould is more commonly seen in cool storage.

### Symptoms

Both infections develop in damaged areas in the rind. Initial symptoms include a softening of the tissue, followed by development of a water-soaked area. The infection site then develops into a white fungal growth that turns blue or green as spores are produced, but retains a white margin (Figure 307). The white margin is wider (10–20 mm) with green mould. The optimum temperature for mould growth is around 25 °C. No growth occurs above 30 °C and growth is slowed below 10 °C. However, blue mould develops better than green mould below 10 °C.

Figure 307. Blue (left) and Green (right) mould on a mandarin. Photo: Peter Taverner

## Brush burn

Soft skinned mandarin varieties are particularly susceptible to rind damage on the packing line.

### Cause

Contact with abrasive surfaces on the packing line such as brushes and wax knobs on rollers.

### Symptoms

Symptoms on fruit can vary and include superficial red or brown staining, scuffing or raised marks (Figure 308).

Figure 308. Brush burn staining on mandarin fruit. Photo: Peter Taverner.

### Control for brush burn

- ☑ Apply GA to delay rind ageing, help strengthen the rind and reduce sensitivity to mechanical damage.
- ☑ Keep packing lines clean.
- ☑ Reduce the number of brushes and/or brush speed to <100 rpm.
- ☑ Use purpose built mandarin packing and grading equipment.

## Chilling injury

Superficial damage to the fruit rind can occur as a result of low storage temperatures. The occurrence and severity of chilling injury varies with variety, growing region, seasonal conditions and in-field management practices which can affect fruit conditioning to low temperatures.

### Cause

Low storage temperatures, typically <5 °C.

### Symptoms

Symptoms of chilling injury can be quite variable. They include brown pitting of the rind with sunken lesions (Figure 309), darkening of the oil glands or brown staining or scald that is more a superficial discoloration of the rind and commonly seen in mandarins (Figure 310).

Figure 309. Chilling injury symptoms showing pitting on Ellendale tangors.

Figure 310. Chilling injury symptoms on Fremont mandarin. Photo: Peter Taverner.

### Control for chilling injury

- ☑ Keep fruit at recommended storage temperatures.
- ☑ Some waxes can help reduce chilling injury.
- ☒ Do not store fruit for long periods of time.

## Flavedo collapse

During the 2014 season Queensland growers reported a rind disorder of Imperial mandarin fruit that developed a few days after packing, following a period of cold storage and/or transport. Growers also reported that fruit generally appeared to be more susceptible to rind damage from both in-field handling operations and postharvest handling procedures, particularly brush damage. Other mandarin varieties were not affected.

### Cause

Many people suspected that the damage was caused by anthracnose, another postharvest disease – but no pathogens were isolated from any samples.

During the 2014 growing season there were some unusual weather conditions including two periods of >40 °C temperatures in January, a warm autumn with above average temperatures and wet weather in March following an unusually dry summer.

The disorder is thought to be physiological, a result of the unusual climatic conditions that may have affected rind development and condition, making fruit more susceptible to damage from normal postharvest handling procedures.

### Symptoms

Fruit developed small, dark, sunken pits that had well defined margins between damaged and healthy tissue (Figure 311). The damage was confined to the flavedo (which had collapsed) and did not extend into the fruit albedo.

Figure 311. Symptoms of postharvest rind damage to Imperial mandarin fruit during the 2014 season. Photo: Andrew Miles.

## Oleocellosis

Oleocellosis or oil spotting, occurs when oil glands in the fruit rind are ruptured, releasing oil which burns the surrounding tissue.

Fruit are most susceptible to oleocellosis when they are wet and turgid in conditions of high relative humidity. Tight skinned mandarin varieties are more susceptible.

Oleocellosis most commonly occurs during harvesting and packing, but can also occur while fruit are still on the tree, especially during cold, wet, windy conditions.

### Cause

Oil is released from the oil glands on to the fruit surface by rough handling. The oil seeps into the flavedo cells, causing them to collapse and the tissue to discolour.

### Symptoms

Damaged tissue shows up 1–3 days after the oil is released. Damage appears as a small discoloured spot or patch on the fruit rind (Figure 312).

On green, partially coloured or degreened fruit the damaged area will not colour, leaving a green or pale area.

On coloured fruit the damage initially is pale, followed by collapse and brown discolouration of the cells between the oil glands. On close inspection the oil glands remain intact and prominent, while the surrounding tissue collapses leaving a dark sunken area on the rind. The extent of the damage depends on how many oil glands are ruptured.

Figure 312. Oleocellosis symptoms on mandarin.

### Control

Oleocellosis occurs when the turgid fruit are subject to pressure, rupturing the oil glands. Careful fruit handling during harvest, transport and packing is the most important factor in reducing oleocellosis damage (Figure 313).

Fruit should not be harvested when they are wet or turgid. If conditions have been damp, harvest fruit from the warmest parts of the orchard and on the northern side of trees first.

Figure 313. Oleocellosis symptoms showing up as finger prints from picking. Photo: Peter Taverner.

**Control for oleocellosis**

- ☑ Application of GA to delay rind ageing can help strengthen the fruit rind and reduce susceptibility to oleocellosis.
- ☑ Handle fruit carefully.
- ☒ Do not harvest wet fruit.
- ☒ Do not harvest fruit in wet, humid conditions.
- ☒ Do not harvest fruit in the early morning when they are turgid.

## Postharvest pitting

This condition occurs intermittently on waxed fruit during storage. Varieties reported to be affected include Fallglo and Sunburst mandarins. Large fruit sizes appear to be more susceptible.

### Cause

The collapse of oil glands in the fruit rind causes pitting. The pitting appears to be a consequence of low oxygen exchange levels between waxed fruit and the atmosphere of the storage conditions in which they are being held. Waxes have different levels of permeability. Shellac and polyethylene based waxes cause more pitting than more permeable carnauba based waxes.

### Symptoms

Symptoms usually appear within the first 2 weeks after harvest on waxed fruit. Small, circular, sunken pits develop on the fruit rind, gradually darkening and forming brown or black blemishes. The pits can coalesce forming irregular patches.

### Control for postharvest pitting

- ☑ Handle fruit carefully.
- ☑ Application of GA to delay rind ageing reduces fruit sensitivity to pitting.
- ☑ Rapid cooling after waxing reduces pitting.
- ☑ On sensitive varieties use waxes that allow higher rates of gas permeability, such as carnauba based waxes.

## Septoria spot

Septoria spot can be an important disease in inland areas if protectant copper sprays are not applied before autumn rains. Although infection commonly occurs during late summer and autumn after wet weather, symptoms usually do not appear until winter with the onset of cold conditions (particularly frost), or after harvest when fruit are put in cold storage.

### Cause

Septoria spot is caused by the fungus *Septoria citri*. It occurs saprophytically on infected twigs, dead wood, leaves and leaf litter. The water-borne spores are splashed onto fruit by rain or irrigation water.

### Symptoms

Fruit symptoms can occur on the tree or after harvest. Initially small (1–2 mm), round, shallow depressions or pits appear on the fruit surface. The pits are initially light brown with a narrow greenish margin, turning reddish brown (Figure 314). As the fruit matures the pits may become dark brown or black, enlarge and coalesce (4–10 mm) and become deeply sunken, extending into the fruit albedo (Figure 315).

The lesions often exhibit a purplish tint and in the later stages small black dots (pycnidia or fruiting bodies) may be produced in the lesions.

Figure 314. Septoria spot symptoms on citrus fruit.

Figure 315. Septoria spot lesions may enlarge and coalesce and become deeply sunken.

### Control for septoria spot

- ☑ Apply a copper spray in mid-February to early March prior to autumn rainfall. A second spray may be required if conditions are wet.
- ☑ Use frost protection measures.
- ☑ Harvest fruit early before the onset of frost.
- ☑ Keep trees free of dead wood.
- ☑ Skirt trees to reduce rain splash onto fruit.

## Sour rot

Sour rot symptoms normally develop on fruit after harvest, but in some seasons symptoms can appear on mature fruit in the tree canopy. Sour rot is more prevalent in wet seasons.

### Cause

Sour rot is caused by the fungus *Geotrichum candidum*, which is commonly found in the soil. The fungus is carried on to the fruit surface in soil particles by wind or water splash. The fungus only enters the fruit rind through injury sites, such as those caused by insects (i.e. fruit fly) or mechanical damage. Fruit in the lower part of the canopy are more at risk of infection.

### Symptoms

Symptoms usually appear as a pale, soft, watery decay on the rind of mature fruit. In the early stages there is usually a clear margin between decayed and healthy tissue. The rot has a sour, putrid smell. A white fungal growth is often produced on the infected tissue (Figure 316).

Figure 316. Sour rot symptoms on navel oranges.

### Control for sour rot

- ☑ Handle fruit carefully to prevent injury.
- ☑ Treat fruit with a postharvest fungicide, such as guazatine. Note: Check overseas market restrictions before using guazatine.
- ☑ Use appropriate sanitisers in wash water to control free floating spores.
- ☑ Maintain good hygiene in the packing shed to reduce the spread of the fungus.
- ☑ Prevent damaged fruit from entering the packing line by pre-sorting.
- ☑ Routinely check stored fruit for signs of infection.
- ☑ Skirt trees to reduce water splash onto trees.
- ☒ Do not pick or place damaged, split or fallen fruit into packing bins.

## Stem end rot

Stem end rot starts at the stem end and invades the fruit from there. Infected fruit usually show no signs of the disease until after harvest. High ethylene concentrations during degreening exacerbate the disease. The likelihood of stem end rot occurring is higher under humid or wet conditions that are prevalent in coastal or more tropical regions.

### Cause

Stem end rot is caused by the fungi *Diaporthe citri* and *Diplodia* spp. The fungal spores live on dead twigs and branches and are carried onto fruit in water, usually during wet weather. After infection the fungus remains dormant in the fruit button until the fruit mature and the button dies.

### Symptoms

Stem end rot starts as a firm, brown rot in the stem end (Figure 317) and then spreads slowly through the fruit, which later becomes wet and mushy. The decay will not spread from infected to healthy fruit.

Figure 317. Stem end rot symptoms.

### Control for stem end rot

- ☑ Keep trees free of dead wood.
- ☑ Application of GA to delay rind ageing can help maintain button health.
- ☑ The application of a postharvest treatment of 2,4-D will help keep buttons green and healthy.
- ☑ Carefully monitor the duration, temperature and ethylene concentrations during degreening.
- ☑ Storage temperatures below 10 °C will slow development.
- ☒ Do not use more than 5 ppm of ethylene gas during degreening.

## Zebra skin

Zebra skin is most commonly seen in fruit harvested from water stressed trees that were suddenly exposed to wet conditions close to harvest. The rapid uptake of water into the fruit cells causes the fruit to become highly turgid. If fruit are then harvested in this condition the movement of fruit through the packing line can damage the rind in a pattern overlying the fruit segments. Murcott tangor are more susceptible to this condition.

### Cause

Damage to turgid fruit rinds by mechanical abrasion on the packing line.

### Symptoms

Damage appears a few days after grading and packing. Reddish brown stripes appear on the fruit surface, overlying the fruit segments (Figure 318). Brushing exacerbates the damage.

Figure 318. Mandarin fruit with zebra skin. Photo: Peter Taverner.

### Control for zebra skin

- ☑ Delay harvest for 5–7 days following rain on susceptible varieties.
- ☑ Handle fruit carefully.
- ☑ Use soft brushes on packing lines.

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Australian mandarin production manual

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