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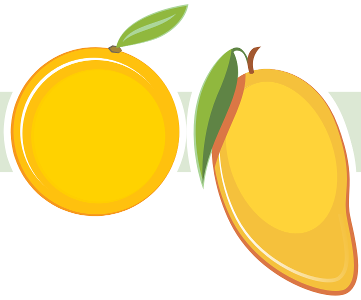
Nursery Manual for Citrus and Mango

Nerida Donovan, Ian Bally and Tony Cooke
Susan House (Editor)



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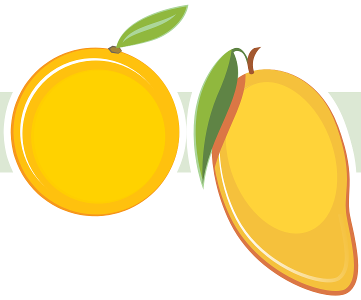

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Cover: Citrus and mango produce for local markets in Pakistan. (Photos: Department of Agriculture and Fisheries, Queensland).

Foreword

Pakistan has a long history of citrus and mango cultivation. Both crops add rich colour and diversity when in season, providing an abundance of fresh, nutritional food. Traditional methods of production have been passed down through the generations but change is now happening at a rapid pace to meet the challenges of the twenty-first century and its global market. Small-scale family farms are prevalent but larger orchards with modern packing and cool storage facilities are improving domestic and export market opportunities for producers.

Successive projects aiming to improve citrus and mango production in Pakistan have operated under the umbrella of the Australia-Pakistan Agriculture Sector Linkages Program (ASLP). The Australian Centre for International Agricultural Research (ACIAR) managed ASLP, supported by funding from the Australian Government through the Australian Aid program. The teams working on our ASLP projects identified that citrus and mango production in Pakistan is constrained by a lack of healthy nursery stock, and a skill shortage in Pakistan's nursery sector for developing these healthy production systems.

This technical manual will be a useful training tool for future generations as it guides citrus and mango nursery operators in managing their nurseries and enhances the availability of high quality, healthy planting material for orchard plantings. This establishes the knowledge base for better income streams and employment opportunities across all sectors of the mango and citrus industries throughout Pakistan.

Professor Andrew Campbell
Chief Executive Officer, ACIAR

Contents

Dedication

This manual is dedicated to Dr Iftikhar Ahmad (1952–2016).

Dr Iftikhar Ahmad's visionary approach to Pakistan Agriculture and support for Australia-Pakistan agricultural linkages was greatly valued.

Dr Iftikhar achieved considerable academic qualifications: PhD (University College of North Wales, Bangor, 1982); MSc (University of Agriculture, Faisalabad, 1976); BSc (University of Agriculture, Faisalabad, 1973); FSc Agriculture, West Pakistan Agricultural University, Lyallpur, 1970).

Dr Iftikhar Ahmad was one of Pakistan's most accomplished and celebrated agricultural scientists; he received the 2006 Norman Borlaug Award for his work in crop protection that included designing national integrated pest management (IPM) programs for various cropping systems. These were implemented through high-impact and innovative channels such as farm-level research, Farmer Field Schools, Women Open Schools, and Children Ecology Clubs.

He held high-level positions at the Pakistan Agricultural Research Council (PARC), the National Agricultural Research Centre (NARC) and represented Pakistan on ACIAR's Policy Advisory Council. This manual is a legacy of Dr Iftikhar's support for the citrus and mango nursery sectors of Pakistan.

About this manual

The Australian Centre for International Agricultural Research (ACIAR) has supported agricultural research and development in Pakistan under the Australia–Pakistan Agriculture Sector Linkage Program (ASLP), between 2007 and 2015.

Mango project: Integrated crop management practices to enhance value chain outcomes for the mango industry in Pakistan and Australia. (ACIAR project HORT/2012/006).

Citrus project: The enhancement of citrus value chain production in Pakistan and Australia through improved orchard management practices. (ACIAR project HORT/2010/002).

This manual reflects the key importance of the nursery sector in the successful establishment of true-to-type, disease-free orchards and their ongoing productivity.

This nursery manual was produced with the goal of improving management practices that will reduce the spread of infectious diseases, reduce field transplanting losses and provide true-to-type nursery trees for the citrus and mango industry in Pakistan. The manual has been written as a training aid for commercial nursery staff, and agriculture officers or consultants who promote improved nursery management practices.

Acknowledgments

The authors would like to thank the Australian Centre for International Agricultural Research (ACIAR) for funding the project; and the Queensland Department of Agriculture and Fisheries (DAF); New South Wales Department of Primary Industries (NSW DPI); Ministry of Agriculture; Fruit and Vegetable Development Project Punjab, Lahore; Sindh Agricultural University; University of Agriculture, Faisalabad; Agriculture Research Institute, Tarnab, Peshawar; Citrus Research Institute, Sargodha; and the National Agriculture Research Centre, Islamabad for their in-kind support.

The authors would also like to thank those colleagues in Australia and Pakistan who contributed technical information, photographs or editing time to the manual including:

Citrus

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Mango

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Glossary

air-pruning	Roots die when exposed to air in the absence of high humidity. The remaining unexposed roots continue to produce new, branching roots.
asymptomatic	Without visible (disease) symptoms.
bent root	Severely bent or s-shaped roots.
beneficials	Insects, mites, fungi or other organisms that perform a service by feeding on pest organisms; also pollinators.
budwood, bud stick	A small piece of scion wood with only a single bud that is inserted into the rootstock during budding. Used most often for citrus.
budding (bud grafting)	Grafting by inserting budwood into a rootstock. A bud is taken from one plant and inserted under the bark or onto the wood of another. Used mostly for citrus.
budwood mother tree or source tree	The tree from which the budwood or scion was cut.
callus	A thickened area that develops when soft tissue forms over a wounded or cut plant surface.
cambium layer	The cambium area is a layer of actively dividing cells in the vascular system of the stem. Graft healing only occurs in this region and if the cambium layers are not matched the union will fail.
chip budding	Grafting by inserting a bud (chip) into a rootstock.
dibbling tool	A tool for making planting holes in potting media.
disinfest, disinfestation	To rid of pests, for example insects and rodents.
electrical conductivity (EC)	A method for measuring salinity.
flush	A spurt of growth when shoots elongate. A mature 'flush' is hardened but still green.
fungicide	A chemical used to control fungi.
grafting	Inserting a part of one plant (scion) into part of another (rootstock) to make an organic union.
herbicide	A chemical used to control weeds.
Integrated Pest Management (IPM)	Managing pests and diseases with a planned program that integrates cultural and chemical control methods.
lath	A traditional construction material of plant house roofs and walls.
marcotting or layering	The process of rooting branches, twigs or small stems that are still attached to the parent plant.
monoembryonic seed	A seed with a single embryo containing genes from seed and pollen parents.
mother stock	The original, identifiable source of the rootstock seed or the tree from which the scion or budwood was cut. It should be free from pests and diseases.
mycorrhiza	A symbiotic association between hyphae of a specific fungus and the roots of a specific plant.
necrotic	Tissue that turns brown and dies.
nematodes	Microscopic worms that feed on microorganisms: some species invade and feed on plant roots, reducing plant growth.
off-type seedlings	Seedlings that do not have the expected characteristics for that plant variety.
pathogen	An agent that causes disease.

pathogenic	Describes a disease-causing microorganism or pathogen.
pesticide	A chemical used to control insect or mite pests.
pH	A measure of the acidity or alkalinity of the soil or a solution.
phytotoxicity	Symptoms of toxicity in a plant caused by excessive applications of a nutrient, for example.
polyembryonic seed	A seed with several embryos, genetically similar to the parent tree.
quonset	A shelter or storage shed constructed with a curved (semi-circular) frame.
rootstock	The stem (and roots) to which the scion is grafted. Rootstocks are usually container-grown plants that have been raised from seed from the mother stock plant.
Rootstock seed source tree or mother stock	The tree from which seed is taken to grow a rootstock plant.
saprophytic	Fungi and other microorganisms that feed on dead plant or animal tissue.
scion	A piece of stem that is grafted onto a rootstock. Scions are shoots selected from a tree variety with the (above-ground) characteristics wanted in the new tree.
scion wood	The piece of scion that is inserted into the rootstock during grafting. In mango, scion wood is a relatively long piece of scion. In citrus, it is usually called budwood containing several buds, a small piece of the bud stick holding a single bud is used.
solarisation	Using the heat of the sun to pasteurise potting media.
symbiont	An organism living in symbiosis (usually interdependently) with a dissimilar organism.
true-to-type seedlings	Seedlings that have the characteristics and genetics of the female, seed tree.
vector	An animal that can transmit a pathogen.
virus and viroid	Sub-microscopic, disease-causing agents.

1 Citrus and Mango in Pakistan

What to consider

1.1 The importance of the nursery sector

Citrus and mango production is important for the livelihood and employment of many of the farming communities in Pakistan. Citrus and mango farmers have followed traditional, tried-and-proven methods for countless generations. However, Pakistan faces increasing demands from both domestic and export markets, and there are greater demands on fruit farmers to increase yields and produce high quality fruits.

The nursery sector is critical for the ongoing health and productivity of citrus and mango orchards. Healthy, true-to-type propagation material is required to produce healthy and high-yielding citrus and mango trees. See Figures 1.1 and 1.2. Many diseases can be introduced to orchards by infected nursery trees. The key to a successful and productive orchard is to start with healthy nursery trees.

Many traditional mango and citrus nurseries in Pakistan operate at well-below world's best practice, and they are contributing to low productivity in these industries. These nurseries frequently use poor quality, diseased propagating materials and plant trees in local, disease-infected soils, reducing tree health and lowering tree productivity. Many traditional nurseries are also responsible for perpetuating debilitating tree diseases and for spreading them to previously clean orchards.

This manual outlines high quality nursery management practices for the mango and citrus sectors in Pakistan that will:

- improve the health of nursery trees that are available to farmers
- improve the identification of trees for sale
- shorten the time to grow, graft and prepare trees for sale
- improve the quality and uniformity of trees for sale
- reduce the risk of spreading pests and diseases via nursery trees
- reduce tree loss when transplanted on farms.

Figure 1.1 A modern citrus plant house in the Punjab.

Figure 1.2 Healthy, well-managed nursery trees of citrus (left) and mango (right). Disease-free trees are essential for producing healthy fruit for domestic and export markets.

1.2 Citrus production in Pakistan

Pakistan is an important global producer of mandarin fruit. Most of the fruit produced is consumed domestically but exports are becoming more important. It has been estimated that approximately 10% of the total production is exported, 2% is processed, 20–40% suffers from postharvest loss and the remainder is sold on the domestic market. Citrus production in Pakistan relies on the Kinnow variety of mandarin, contributing approximately 80% of production. Most Kinnow production is centred in the Punjab province where an estimated 2,000 growers produce around 95% of Pakistan's Kinnow crop. Oranges, including blood oranges, are also grown in Pakistan, mainly in the province of Khyber Pakhtunkhwa.

Most citrus nurseries in Pakistan use traditional practices. It is hoped that by introducing practical and, where possible, low cost changes to the production system, the quality of nursery plants will increase significantly. This will lead to improvements in orchard survival and production. See Figures 1.3 and 1.4.

A number of commercially significant citrus diseases are found in Pakistan. They include graft-transmissible diseases that are spread (often without symptoms) in infected propagation material. They also include diseases that affect the fruit, roots and foliage, which can be introduced to new orchards via infected nursery trees. To help nurseries produce better quality plants more efficiently, key changes can be introduced including:

- using healthy propagation material
- introducing rootstocks that tolerate some diseases
- chip-budding to increase bud-take
- growing nursery plants in good quality potting mix.

Figure 1.3 A citrus crop ready to harvest (left) and selling fresh citrus on the local market.

Figure 1.4 Examples of citrus nurseries: traditional, with trees in the ground (left) and modern, with trees in pots in a clean, well-managed plant house (right).

1.3 Mango production in Pakistan

Pakistan is one of the largest mango producers in the world. Most mango fruit is consumed within Pakistan, Figures 1.4 and 1.5, but exports are increasing. Traditionally, mangoes were exported to the Middle East but more recently new markets like China, South Korea, Europe and the USA are being explored.

Favourable climatic conditions mean that fresh fruit is available for four to five months of the year. Most production occurs in the Punjab and Sindh. The industry is based on five main varieties: Sindhri, SB Chaunsa, Chaunsa, Dasehari and Langra. These varieties are propagated by grafting on to several common, local monoembryonic rootstocks that are not genetically uniform and often of unknown origin.

Seed sources for traditional rootstock are often taken from trees that are already infected with mango malformation and other diseases.

Traditional mango nurseries grow nursery trees in the shade between the orchard trees. This means that the nursery trees become infected early in the life of the seedling, with fungal disease organisms such as *Fusarium mangiferae* (mango malformation disease) and *Ceratocystis fimbriata* (mango sudden death disease). The nursery sector has been a significant agent for the spread of these diseases throughout Pakistan in recent times.

Figure 1.5 A mango harvest (left) and mangoes for sale in a local market (right).

Figure 1.6 Examples of mango trees for sale in a traditional nursery (left, not recommended) and a modern nursery (right).

1.4 Challenges for nursery growers in Pakistan

The poor conditions often found in traditional nurseries result in slow growth, for example in some cases grafted seedlings take up to three years to be ready for sale, Figure 1.6. This also results in very uneven tree sizes. Digging out grafted trees in preparation for sale is extremely damaging to the root system, which is often fragile due to water logging and disease. Such weak and damaged root systems are responsible for 50% to 80% of transplanting deaths that are common in traditionally-produced nursery trees.

Typically, harsh growing conditions such as poor soil and water quality, high temperatures and low humidity have prevented good quality nursery plants from being grown in Pakistan, Figure 1.7.

It is hoped that by adopting the nursery management techniques introduced in this manual, nursery producers will be able to overcome many of the negative issues associated with traditional practices.

This manual attempts to address these problems while setting out a complete guide to growing healthy nursery citrus and mango plants.

Figure 1.7a Poor growing conditions results in unhealthy trees with poor root systems.

Figure 1.7b Nursery crop management must ameliorate extremes in temperature and humidity in Pakistan.

2 Setting up a nursery

It is important that the nursery is located away from orchards and is designed to maximise production efficiency and tree growth, and to minimise the development and spread of pests and diseases.

Many of the recommendations for setting up a nursery are specifically designed to manage nursery hygiene properly. This will reduce the risk of pests and diseases entering the nursery or harming production and it will maximise the health of high quality trees for sale.

What to consider

2.1 Selecting a site
2.2 Production areas and facilities
2.3 Plant houses
2.4 Structural components of plant houses
2.5 Nursery floors and benches
2.6 Controlling temperatures in plant houses
  2.6.1. Shade houses
  2.6.2. Greenhouses

2.1 Selecting a site

Climate. Climate affects the length of the growing season and the time taken to produce nursery trees that are ready for field planting. Temperature and rainfall affect irrigation schedules and the nutritional requirements of trees, see Figure 2.1. Windbreaks may need to be planted or installed in areas that experience frequent or strong winds to protect young foliage from damage.

Surrounding environment. Ideally the nursery site should be free of excessive dust and shade.

Isolation from orchards. Nursery sites should be isolated from orchards of the same crop. Neighbouring orchards are a source of pests and diseases that reduce the growth rate or quality of the nursery trees. Keeping the nursery away from orchards reduces the risk of diseases being introduced to the nursery by insects, wind or storms. See Figures 2.2 and 2.3. For example, to produce healthy trees in mango nurseries, it is essential to isolate seedlings from trees infected by mango malformation disease and mango sudden death disease. Find more information in *Chapter 9—Managing diseases, pests and weeds*.

Figure 2.1 Pakistan experiences weather extremes such as flooding and drought. Take these conditions into account when planning your nursery site.

Figure 2.2 Select a site as far as possible from mature orchards.

Figure 2.3 These seedlings are too close to mature trees that may harbour pests or diseases.

Area of land. Sufficient space must be available to construct plant houses, unprotected growing areas, work areas (for preparing potting mix, potting-up, grafting), storage sheds (including separate chemical storage), water storage and treatment, fencing and pathways, offices, amenities and parking for vehicles.

Topography and soil type. Encourage drainage and prevent rain or irrigation water accumulating on the nursery site by building a level, well-drained site on a slight slope (up to 2%). A well-drained site is achieved by building on free-draining soil or installing a drainage system. Land can be levelled to the correct slope by grading.

Water supply. The nursery site should have access to a reliable source of high quality water that is adequate for current and potential future needs. Chemical water treatment may be needed to manage water-borne soil diseases (For more information see *Chapter 11—Managing water*).

Power supply. The nursery should have a reliable supply of electricity. Load-shedding in the mains electricity supply can interfere with automated irrigation scheduling and other powered nursery operations.

Vehicle access. The nursery site needs good access for vehicles delivering raw materials and transporting nursery trees to customers.

2.2 Production areas and facilities

A typical production nursery is divided into separate areas with different functions.

Area	Used for	Good practice
Propagation	▷ Sowing rootstock seed ▷ Grafting scions to rootstocks	▷ Isolated from orchard trees and sources of diseases and pests. ▷ Clean work surfaces.
Potting	▷ Potting-up germinated rootstock seedlings ▷ Potting grafted trees into larger containers ▷ Cleaning pots	▷ Located near the stored potting mix and accessible by vehicles and trolleys. ▷ Includes a well-drained washing area that is free of soil.
Growing (unprotected area or plant house)	▷ Germinating rootstock seedlings ▷ Growing rootstocks and grafted trees ▷ Hardening-off trees before sale	▷ Hardening-off trees grown in a plant house by exposing them to semi-shade then full sun for a few days before sale.
Dispatch	▷ Sorting trees before transporting them away from the nursery	▷ Keep customers and their vehicles away from the clean production areas. ▷ Maintain conditions for hardening-off.
Wash down	▷ Cleaning pots and equipment	▷ Use a clean water supply. ▷ Used water should drain away from nursery trees to prevent contamination. ▷ Keep the area free from soil.
Chemical	▷ Storing and mixing chemicals	▷ Store chemicals in a cool and dry location. ▷ Always wear protective gloves and clothing when handling concentrated chemicals.
Systems	▷ Irrigation unit ▷ Water treatment system	▷ Keep corrosive fertilisers and chemicals away from equipment.
Storage	Maintain separate areas for storing: ▷ Water ▷ Potting mix components and assembled mix ▷ Chemicals ▷ Equipment and machinery ▷ Other supplies ▷ Waste, before disposal	▷ Prevent stored water from being contaminated by pests and diseases. ▷ Chemicals should be a stored in a contained area in case of spills.
Support services	▷ Customer reception and office administration ▷ Amenities	▷ Keep non-nursery staff away from the clean production areas to minimize contamination.

Setting up to avoid problems with pests and diseases

Several measures can be taken when setting up a nursery that will reduce the risk of pests and diseases:

- maintain a cleared buffer zone
- establish windbreaks to reduce dust
- seal the ground surface
- use clean water and install good drainage
- position nursery trees away from mature orchards and off the ground.

Find more information about nursery hygiene in *Chapter 8—Nursery hygiene*.

2.3 Plant houses

Plant houses provide a protected environment for tree growth. Different structures provide different levels of control over light, heat and wind. Some plant houses are also insect-proof (e.g. screen-houses), providing a barrier against insects that could damage trees or transmit diseases.

The size and sophistication of plant house structures varies depending on the budget, materials and what the house will be used for.

Plant house designs

There are three basic types of commercial plant house: lean-to, detached and ridge-and-furrow, shown in Figures 2.4 and 2.5. A lean-to plant house is a building that leans against the wall of an existing building.

Detached plant houses stand independently, although they may be connected to a work area or access another plant house through a corridor. The most common types of detached plant houses for commercial production are single gable and quonset (or igloo). Quonset houses are constructed with arched rafters and may have solid end walls for additional support. Quonset plant houses are suitable for producing most types of crop, but the growing area may be restricted towards the side walls, which may reduce efficiency and productivity.

Ridge and furrow plant houses have two or more houses attached at the eave by a common gutter. Ridge and furrow houses may have gabled or curved arches. As the area of span connected by gutters increases, light and heat becomes less uniform and harder to control.

2.4 Structural components of plant houses

Framing materials

Plant houses can be constructed from several framing materials, depending on availability and budget. Traditionally, bamboo frames are used whereas modern plant house frames in commercial nurseries are constructed using aluminium or steel. Aluminium is the most economical and light-weight frame. Pipes may be used to frame low-cost quonset houses.

Covering materials

The materials covering the plant house must transmit light and be durable and economical. Modern structures in commercial nurseries are typically covered with shade cloth, plastic film or polycarbonate, see Figure 2.6. Lath is a traditional covering used in plant houses in Pakistan. It provides effective shade, is readily available and economical but it is not insect-proof or vermin-proof and is not recommended.

The plant house should be designed to allow good ventilation (airflow) through the structure. Plant houses should be insect-proof to keep out pests that can cause damage to the trees or infect the trees with diseases. Insect-proof plant houses are costly to establish because they need to be covered or constructed with insect-proof screen (mesh), plastic film or polycarbonate. In addition, all ventilation points must be screened.

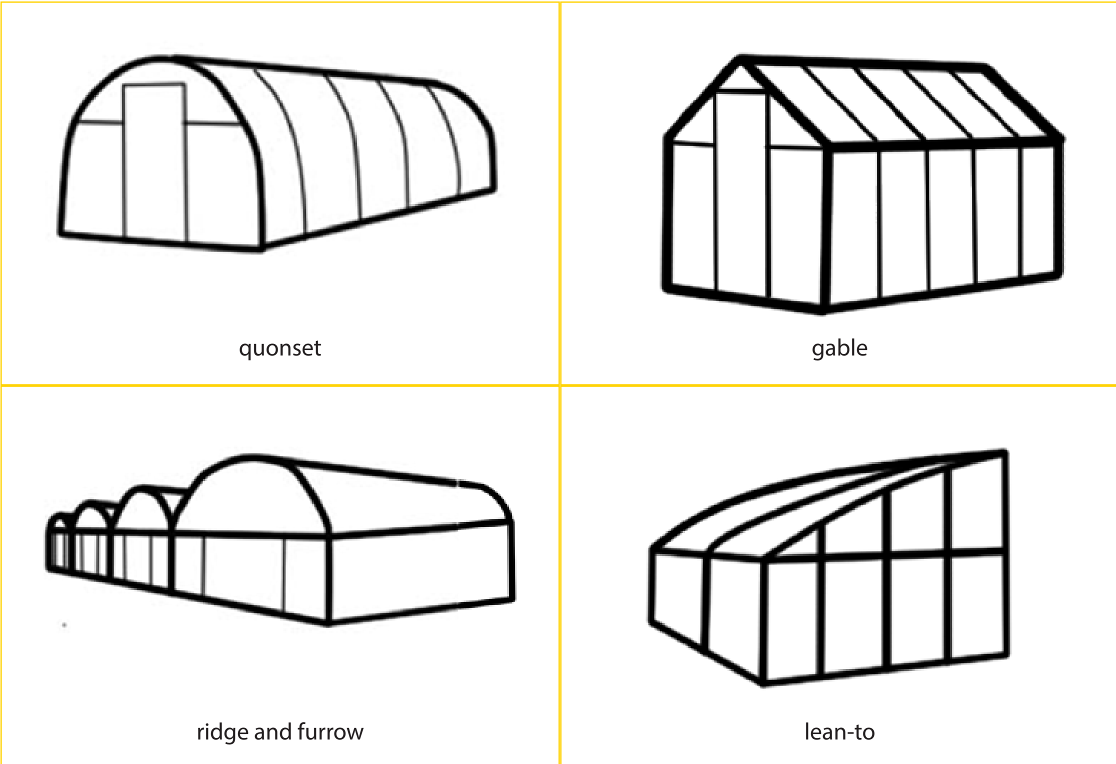


Figure 2.4 Types of plant house: some plant house designs are detached; lean-to plant houses are positioned against buildings.

Figure 2.5 Quonset plant houses. In Pakistan, quonset plant houses are often made with bamboo frames and covered with plastic (left & centre). Modern quonset plant house frames in commercial nurseries are often constructed with light-weight aluminium (right).

Figure 2.6 Materials for covering plant houses include lath (not recommended, left) shade cloth (centre) and polycarbonate (right).

2.5 Nursery floors and benches

The nursery floor should:

- allow water to drain from the site, so that rain and irrigation water does not pool around the pots
- cover the soil to avoid contaminating pots, trees, equipment and shoes with soil-borne diseases
- be a barrier that prevents tree roots from growing into the ground (in situations where pots are on the ground and not on benches)
- provide a stable support for pots and equipment, and for working comfortably
- bear the load of potted trees, equipment and traffic (for example, people and trolleys).

Modern nursery floors are typically concrete, cement or gravel, shown in Figure 2.7. Gravel floors are often covered with plastic weed mat.

The benefits of placing pots on benches instead of the ground include better drainage, fewer disease problems and the pots are easier to handle, as shown in Figure 2.8. Benches can be made from a variety of materials, depending on budget and availability. Avoid wood, which can harbour tree diseases.

If trees are grown in pots on the ground, make sure there is a barrier between the soil and the bottom of the container. A well-drained gravel substrate can be used but make sure that it can be kept free of weeds.

Figure 2.7 Concrete (left) weed mat (centre) and gravel surfaces (right).

Figure 2.8 Seedlings raised off the ground on benches are healthier and easier to handle.

2.6 Controlling temperatures in plant houses

2.6.1 Shade houses

In Pakistan, many plant houses are covered in green or black shade cloth to reduce the intensity of sunlight, providing shade for the trees. In these nurseries, the temperature can be controlled using shade, managing the colour and position of plant containers, and irrigation.

Increasing shade cover

Increasing shade at the hottest times of the year can also reduce heat building up in the plant house, see Figure 2.9.

Internal screens can reduce heat in summer and conserve heat in winter. A system of curtains on wires can be used during the hottest months of the year.

Figure 2.9 Internal shade cloth screens in a plant house with solid walls (left) and a screen house made with green shade cloth that protects plants from strong sunlight, while allowing for air movement and rainfall.

Maintaining optimum temperatures in plant containers

Prolonged exposure to hot and cold temperatures can affect tree growth. The temperature range for best growth is 15–30°C. In temperatures outside this range young trees will suffer more than mature trees. The position of trees in the nursery will also affect root growth in containers, see Figures 2.10 and 2.12. To maintain reasonable temperatures in containers:

- use additional shade cloth to protect trees from over-exposure to the sun
- use light-coloured, opaque containers or white poly-bags* (black poly-bags may be painted white on the outside), Figure 2.10a
- protect the outer row of containers from direct sunlight
- irrigate regularly with cool water, Figure 2.10b
- increase air movement in the plant house as much as possible, Figures 2.10b and 2.12.

* This may reduce the soil temperature in the container although white poly-bags may not last as long as black poly-bags.

Managing frost

In some plant nurseries frost can be a problem in the cooler parts of the year. On sloping land, cold air settles into low-lying areas and will stop at any barrier that impedes its movement. Ways to reduce damage to trees from frost in these areas include:

- covering trees in plastic, Figure 2.11
- using large fans to push cold air away from trees.

Figure 2.10a Soil temperatures are lower inside white poly-bags than in black poly-bags.

Figure 2.10b Make sure there is space between containers to provide adequate ventilation.

Figure 2.10c Temperatures may be reduced by irrigating with sprinklers or misters.

Figure 2.11a Seedlings and grafted trees can be covered with plastic to protect them from frost.

Figure 2.11b Plastic removed to show the frame construction.

2.6.2 Greenhouses

Greenhouses are plant houses with solid walls, typically made from transparent materials like plastic film or polycarbonate. Houses can provide a more controlled environment than shade or screen houses, with built-in watering systems, ventilation windows, fans and evaporative coolers.

Ventilation is the key to preventing greenhouses from overheating. Windows near the roof or along the sides can be used to control ventilation. Large greenhouses may be cooled using an evaporative cooling system, which blows humid air into the greenhouse. Space out the coolers as recommended in the manufacturer's manual. Ventilation points should be screened to prevent insects from entering the greenhouse.

Figure 2.12a Ventilation near the roof allows heat to rise and escape.

Figure 2.12b Side windows increase the ventilation.

Figure 2.12c Evaporative coolers duct cool air through to the plant house.

3 Potting mixes

Potted nursery trees need a potting mix to grow in. A good potting mix contains all the essential ingredients for tree growth in balanced proportions. The potting mix makes water, dissolved air and nutrients available to the tree roots.

The proportions of each component will vary over time as potting mix dries out between watering, and the nutrients are used by the tree or leached from the pot. The starting proportions of these ingredients depend on the tree species and age.

Potting mix is simply a mix of different ingredients that provide the most beneficial environment for trees to develop in. Although potting mixes may contain soil, there are many benefits of soil-less potting mixes.

What to consider

3.1 Healthy root systems and the growing mix

The growing medium for seeds and seedlings has a significant effect on root systems. The growing environment for healthy roots can be controlled easily by altering the proportions of potting mix ingredients.

Mango roots. Mature mango trees form a long, un-branched tap root with a dense mass of superficial feeder roots at the base of the trunk. The young tap roots must remain un-damaged when transplanted from the nursery. This means that mango seeds should be planted directly into the pots that they will develop in until planting out; this avoids damaging the roots in unnecessary transfers between pots.

Citrus roots. The root system of a mature citrus tree is made up of a network of woody, lateral roots from which masses of fibrous roots arise. A major tap root may be difficult to identify. Modern nurseries aim to reduce the number of times a nursery tree is moved to a larger container to avoid root damage and increase survival when transplanted in the orchard.

3.1.1 Benefits of a soil-less potting mix

Using a clean, soil-less potting mix free from disease microorganisms will reduce the risk of disease contamination. When essential ingredients are added to a soil-less base, a growing mix is created that has significantly fewer harmful microorganisms than soil.

Soil properties are very variable and a soil-less potting mix provides the most suitable mix of air, mineral and organic matter for growing healthy trees. Unlike soil, a soil-less potting mix produces a growing environment that helps resist disease organisms.

3.1.2 Essential qualities of good potting mix

Potting mix plays a vital role in producing healthy and vigorous trees in the nursery. An ideal potting mix has a balance of ingredients that creates good aeration, water-holding capacity and drainage for root development. Potting mixes should be easy to wet, but not prone to waterlogging. For the mix to function well it should also have a balance of organic matter and nutrients, a stable pH value, a uniform consistency and it should be clean and lightweight.

Figure 3.1 shows the structure of a good potting mix.

Air spaces: small and large pore spaces facilitate aeration and water drainage.

Coherence: enough coherence for particles to stay in the pot and hold the seedlings upright.

Organic matter: enough organic matter to absorb and release water and nutrients, and suppress the growth of disease organisms.

Cleanliness: pasteurised and free from weed seeds, nematodes (microscopic worms that feed on plant roots) and disease microorganisms.

Nutrients: supplying adequate nutrition for all stages of growth.

Lightweight: easy to move around and work with.

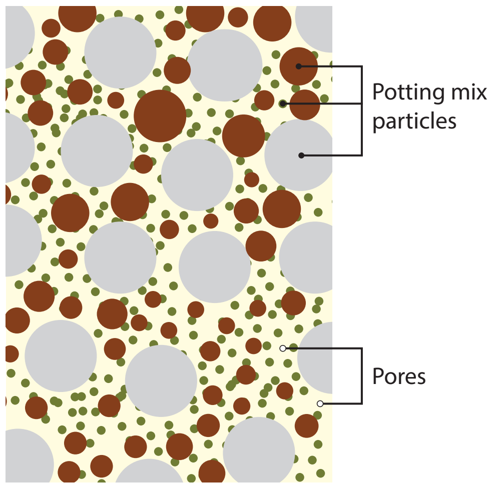


Figure 3.1 Structure of a growing medium. *Adapted from techalive.mtu.edu/meec/module06/Porosity.htm*

Benefits of a soil-less potting mix

- soil-less mixes reduce the risk of soil-borne diseases
- soil-less mixes are lighter
- air, water and drainage are more easily balanced in soil-less mixes
- soil-less mixes help resist some soil pests.

3.2 Making your own potting mix

Many different materials can be incorporated into a potting mix. Ideally, the ingredients will be readily available from local sources. The ingredients of potting mix are either organic (more porous) or inorganic (less porous).

Figure 3.2 Hand-mixing peat and sand to make a potting mix with an even consistency.

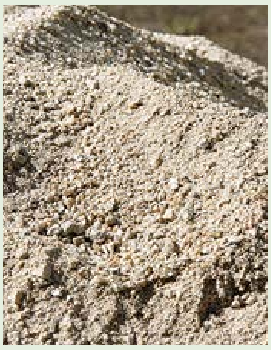
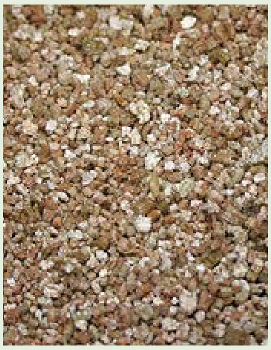
3.2.1 Choosing potting mix ingredients

Different ingredients of potting mixes vary in their capacity to aerate, hold water and nutrients, and release toxins. Avoid materials that reduce air-filled porosity, including press mud, fine silts and heavy clays.

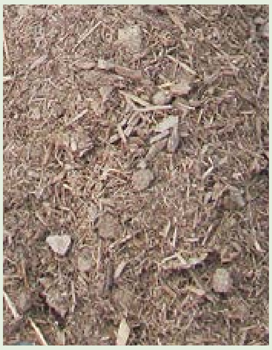
Potting mix ingredients must provide:

- **drainage** by opening the mix structure so that air and water moves through it and it doesn't become anaerobic
- **aeration** by being light and fluffy, allowing air pockets to form, allowing tree roots and organisms to have enough oxygen to thrive
- **water retention** by providing a suitable moisture-holding capacity, so that the roots have a consistent supply of water and nutrients and the mix doesn't become water-repellent
- **nutrient retention** by binding or holding onto minerals, so that fewer minerals are leached.

Potting mix ingredients

Inorganic products		
	**Washed river sand** Washed river sand is the most commonly used sand in potting mix. Sand improves aeration but it is heavy and holds very little water. Some sands also contain a high level of salt, which is toxic to tree growth. Sand doesn't provide nutrients or a buffering capacity. Coarse sand has the best consistency for potting mix. Fine sand is not recommended.	**Aeration:** Fair to good **Water-holding:** Poor **Nutrient-holding:** Poor **Toxins:** Low salinity
	**Canal silt** Canal silt is occasionally used in potting mix, depending on its availability. The nutrient status and physical properties of silt can vary. It is best used in large pots where its characteristics for buffering and nutrient retention are most useful, and it has less effect on lowering air-filled porosity (AFP).	**Aeration:** Poor **Water-holding:** Moderate **Nutrient-holding:** Variable **Toxins:** Variable
	**Vermiculite** Vermiculite is formed by heating mica (a silicate product) until it expands to form exfoliated vermiculite. It is mixed with other materials such as peat or compost to produce a soil-less growing mix.	**Aeration:** Good **Water-holding:** Good **Nutrient-holding:** Fair **Toxins:** Low salinity
	**Perlite** Perlite is an amorphous, natural volcanic glass that, when heated, expands to create a light-weight, pebble-like material.	**Aeration:** High **Water-holding:** High **Nutrient-holding:** Good **Toxins:** Low

Organic products



Bagasse

Bagasse is the fibrous residue left after the juice has been extracted from sugar cane. Ideally it should be composted for several months before using it in potting mix. Bagasse is a fibrous, low density material with a very wide range of particle sizes and high moisture content.

Aeration: Variable
Water-holding: Very good
Nutrient-holding: Good
Toxins: Low salinity

Rice hulls

Rice hulls are left after the grains have been removed from rice. They have little nutrient value for trees and hold a minimal amount of water. Rice grains remaining among the rice hulls are a potential weed problem in pot culture because the moist conditions are ideal for germination.

Aeration: Very good
Water-holding: Poor
Nutrient-holding: Poor
Toxins: Low salinity

Coconut fibre / coir peat

Coconut fibre is from coconut husks and is a product of the coco fibre industry. It holds up to nine times its weight in water, improving the water-holding capacity of the mix considerably, yet drains well. It is highly stable but has few nutrients. It may have a high salt content, so choose a supplier who washes it properly. Use coarse (not fine) fibres in potting mixes.

Aeration: Good
Water-holding: Very good
Nutrient-holding: Good
Toxins: Variable salinity

Animal manure

Composted farm yard manure is often used to build up organic matter in potting mix. However, over time, it increases the EC (salinity) of the mix, which eventually can be lethal for young seedlings. It also contains weed seeds, although these are usually killed during composting. Raw manure, and composted chicken manure, will burn the roots of seedlings.

Aeration: Good
Water-holding: Good
Nutrient-holding: Good
Toxins: Toxic if not composted

Peat moss

Peat moss is a natural fibre mined from peat bogs. It is a biodegradable, organic material that contributes cation-exchange and water-holding properties to the soil or in a potting mix.

Aeration: Good to very good
Water-holding: Very good
Nutrient-holding: Very good
Toxins: Low salinity

Organic products		
	**Sphagnum (peat moss)** Decayed sphagnum can be used as a soil conditioner. It is a biodegradable organic material that contributes cation-exchange and water-holding properties to the soil or in a potting mix.	**Aeration:** Very good **Water-holding:** Very good **Nutrient-holding:** Good **Toxins:** Low; good buffer
	**Pine bark** Some species of *Pinus* break down too quickly to be useful, so check which are available. *Pinus radiata* is robust and durable in potting mix (the size of the pieces should be 5–12 mm). It may contain toxins when fresh, so use it after composting for 4–8 weeks. Composted bark should have a pH around 7, while the pH of fresh bark is around 4.5.	**Aeration:** Good to very good **Water-holding:** Fair **Nutrient-holding:** Fair to good **Toxins:** Low if well-composted
	**Softwood sawdust** Sawdust becomes less aerated as is decomposes. Sometimes decomposition is so rapid that it compacts in the bottom of the pot, preventing drainage. It also ties-up nitrogen during decomposition. Softwood sawdust contains low levels of toxins. Do not use sawdust from wood treated with preservatives. It must be composted before using.	**Aeration:** Reduces rapidly **Water-holding:** Fair **Nutrient-holding:** Good, but breaks down rapidly **Toxins:** Low if well-composted
	**Hardwood sawdust** Sawdust becomes less aerated over time as it decomposes, which requires 6 to 8 weeks. It ties-up nitrogen during decomposition. It contains high levels of natural toxins that need to be leached out before using it. Do not use sawdust from wood treated with preservatives. It must be composted before using. It remains relatively sterile if kept in a clean environment.	**Aeration:** Generally fair **Water-holding:** Fair **Nutrient-holding:** Good **Toxins:** Low if well-composted
	**Press mud** Press mud is the soil and organic material collected from processing sugar cane. It contains a high proportion of very fine particles that can clog air spaces in the potting mix, causing waterlogging.	**Aeration:** Very poor **Water-holding:** Prone to waterlogging **Nutrient-holding:** May be high in potassium (K) **Toxins:** High K

3.2.2 Making up the mix

Each nursery should experiment with different mixes to develop one that is most suited to their water quality, climate and crops grown. It also depends on which ingredients are available locally. For instance, animal manure may be the most convenient organic matter for many areas.

Coir (coconut fibre) is becoming popular in many citrus nurseries around the world and some nurseries use 100% coir as potting mix. Some starting recipes are suggested below.

Citrus potting mix recipes

Mix the ingredients in these proportions by **volume:**

Rootstock seedlings

Recipe A:	100% medium to coarse sand
Recipe B:	50% medium to coarse sand 50% peat moss

Grafted trees

Recipe A:	70% medium to coarse sand 30% peat moss
Recipe B:	50% composted pine bark 50% coir

Mango potting mix recipes*

Mix the ingredients in these proportions by **volume:**

Recipe A:	65% bagasse 30% canal silt 5% coir
Recipe B:	70% bagasse 25% canal silt 5% coir

* Developed by the Mango Research Station, Shujabad in the Punjab.

Check for contaminants. Make sure all the ingredients are free from contaminants; check for weed seed. Natural organic products should be tested regularly for potential toxicity.

Mix the ingredients. Aim for a balance between organic and inorganic ingredients, for example 50:50 ratio of organic ingredients to sand. See the potting mix recipes for growing mango and citrus, above. See also Figures 3.2 and 3.3.

Figure 3.3a Potting mix ingredients.

Figure 3.3b Using a hoe to mix potting mix ingredients.

Add water. Mix in a commercial cement mixer. The final mix should be saturated, but with no excess water.

Clean. Either pasteurise (hours to weeks) or fumigate (days to weeks). See the details in Section 3.3 below—Keeping potting mix free from disease.

Store. Store the mix in a suitable, clean and dry container with a lid until needed. It shouldn't be stored for more than a couple of weeks. See details in Section 3.4 below—Storing and handling potting mix.

Figure 3.3c Filling a poly-bag with a potting mix containing white perlite.

Figure 3.3d Prepared potting mix with pots, labels and trowel.

3.3 Keeping potting mix free from disease

Soil organisms help decompose dead material and contribute to recycling plant residues and inorganic nutrients back into the soil. However, top-soils obtained from orchards may also be a source of disease organisms, so if it is used in the potting mix it will affect the type of organisms growing in the tree containers. Find more information in *Chapter 9—Managing diseases, pests and weeds*.

Reduce the potential for harmful microorganisms in pots by:

Using free-draining mix ingredients. This will help prevent root diseases such as *Phytophthora* in citrus and provide a suitable environment for optimum root growth.

Preparing and pasteurising a soil-less potting mix. To grow clean, disease-free seedlings it is necessary to use clean, pasteurised potting mix. Potting mix is pasteurised to eliminate weed seeds and disease microorganisms. The nursery must have a clean area for storing and mixing raw materials for potting mix, as well as facilities for pasteurising it.

Raising pots off the ground and removing them from orchards. This reduces the risk of contaminating container-grown trees with soil-borne diseases and harmful soil microorganisms.

Cover the nursery floor with gravel or plastic. This will create a barrier between the soil and the nursery trees and prevent contaminated soil from splashing into pots when watering.

3.3.1 Pasteurising potting mix

Potting mixes can be cleaned by pasteurising (with steam or solar heat) or fumigating (with chemicals).

Pasteurisation is best achieved using steam, but it can also be done with solar heat (solarisation).

Steam pasteurisation. Steam pasteurisation involves heating the moist potting mix to 60°C. This will kill disease organisms while leaving many beneficial microorganisms alive. Before pasteurising with steam, thoroughly mix and moisten all ingredients for 4 hours. Introduce the steam from the bottom of the potting mix and treat for 30 minutes after the surface temperature has reached 60°C.

Solar pasteurisation (solarisation). Potting mixes can also be pasteurised using solar radiation over longer periods of time (5–15 days). This technique uses the sun's rays to heat mounds (25 cm high) of potting mix that have been wrapped in clear, thin (25–50 μm), UV-resistant plastic sheeting, shown in Figure 3.4. The potting mix must remain moist throughout the pasteurising period.

Solarisation also kills many annual and perennial weed seeds. Winter weeds are generally more sensitive than summer weeds. Weed susceptibility is influenced by the ingredients of the mix and the moisture content. There are some important things to remember when solarising potting mix:

- Transparent (not black) polythene sheet should be used because this transmits most of the solar radiation that heats up the soil.
- Solarisation should be carried out during periods of high temperature and intense solar radiation, particularly during the summer months.
- Potting mixes should be kept moist during the solarisation process; this increases the sensitivity of disease organisms and improves heat conduction within the mix.
- Thin plastic sheets should be used because they heat more effectively. Both 25 μm and 50 μm polythene plastic is suitable.

Solarisation is most effective when two layers of plastic sheet are used: one over the top and one beneath the mounds (25 cm high) of potting mix or mix ingredients. Two layers of transparent polythene sheet raise temperatures more effectively than a single sheet. In smaller nurseries, an option is to place quantities of soil in clear plastic bags.

Figure 3.4 Solarisation of potting mix using transparent plastic sheeting.

Chemical fumigation. Potting mixes can be fumigated using chemical fumigants such as chloropicrin or dazomet. These chemical fumigants are effective for a wide range of soil fungi, nematodes, insects and germinating weed seeds. Treatment times vary depending on the chemical from days to weeks.

3.4 Storing and handling potting mix

The potting mix (and all the individual ingredients) should be handled carefully and stored in a protected environment to minimise the risk of contamination.

Non-pasteurised sand may be stored either in non-sterilised bins or in a concrete bunker.

Commercial mixes may be stored in the bulk bags in which they are delivered.

The mix can be stored for a couple of weeks, although ideally a fresh batch of mix would be made up as required.

3.5 Keeping records

Records of day-to-day operations should be kept. This includes activities such as:

- propagation activities
- seed sources
- recipes and dates for preparing mixes
- measurements of pH and EC for monitoring
- the source(s) of ingredients, in case any issues arise
- the dates and the person(s) responsible for each activity.

3.6 Testing potting mix properties

Potting mix plays a vital role in producing healthy and vigorous trees in the nursery and an ideal potting mix has the right balance between air spaces, coherence, organic matter and nutrients, and is clean and lightweight. Some methods for managing the pH of potting mix are discussed in *Chapter 10—Nutritional disorders*.

The combined physical, chemical and biological properties of the potting mix control the supply of water and nutrients to the trees, forming a complex influence on tree health. The properties of a good quality potting mix include:

- physical characteristics—the combination of materials in the potting mixture and the way they influence structure and the availability of air and moisture
- chemical ingredients—nutrient concentration, pH and electrical conductivity (EC)
- biological qualities—the living component and the way in which its by-products affect seedling health.

3.6.1 Physical properties

Important physical properties include: water-holding capacity (WHC), air-filled porosity (AFP), wettability and shrinkage.

Physical property	Preferred range
Water-holding capacity (WHC)	40–50%
Air-filled porosity (AFP)	10–20%
Wettability	5–10 minutes
Shrinkage	less than 15% by volume per year

Water-holding capacity (WHC)

A good potting mix should hold enough water to prevent the tree from becoming stressed. The mix must not hold too much water because this could reduce the air-filled porosity. Water-holding capacity is the amount of water (by weight) that a potting mix can hold after it has been watered and drained.

What you need to calculate WHC (See Figure 3.5):

- 1 plastic container (a milk carton is suitable)
- 2 buckets
- 4 wooden blocks
- graduated measuring cylinder
- marking pen
- flat tray
- balance, accurate to 0.5 g.

Figure 3.5 Equipment for the WHC and AFP tests.

Method

1. Select a container that is the same height as the pot used for the mix. Cut 4 holes (about 10 mm diameter) in the base of the container so that fingers can easily plug these holes. See Figure 3.6a.
2. Moisten the potting mix and leave for 24 hours to make sure it is saturated.
3. Fill the container with the moist potting mix and tap the sides firmly to settle the mix.
4. Fill a bucket with water to a level that is slightly less than the container height, See Figure 3.5, and place 2 blocks inside the bottom of the bucket.
5. Slowly lower the container (with mix) into the water and rest it on the blocks to allow water to be in contact with the container holes. Lowering the container too quickly might cause the potting mix particles to float.
6. Slowly fill the bucket with water until the water is level with the top of the potting mix in the container. See Figure 3.6b.
7. Allow the mix to settle for 1 hour. Then lift the container straight out of the bucket and allow it to drain for 5 minutes.

8. Repeat the wetting and drying cycle twice more, allowing 10 minutes soaking in the bucket each time.
9. At the end of the third cycle, lower the container into the bucket once more until the top of the mix is level with the water level. This time, plug the 4 holes in the bottom of the container with your fingers, before lifting the container quickly out of the bucket. Keep the holes plugged while moving the container to the dry bucket and place it on 2 blocks inside the bottom of the bucket. Allow it to drain freely for 1 hour.
10. Remove the container from the bucket, keeping it upright. Transfer the wet potting mix to a flat tray and weigh it to the nearest gram (g). This represents the weight of the tray and drained potting mix.
11. Dry the mix overnight on the tray in an oven at 100°C. Weigh the dry mix to the nearest gram (g). This represents the weight of the tray and dry potting mix.
12. Determine the volume of mix that was in the container by measuring the volume of water required to fill the empty container.
13. Calculate the total WHC of the mix as:

$$\text{WHC \%} = \frac{\text{Weight of tray \& drained mix} - \text{weight of tray \& dried mix}}{\text{Total volume of the moist mix}} \times 100$$

Example: if 800mL of moist mix has a wet weight of 600 g and a dry weight of 200 g,

$$\text{WHC \%} = \frac{600 - 200}{800} \times 100 = 50\%$$

Preferred range = 40–50%.

Figure 3.6a Make 4 holes, each about 10 mm in diameter, in the base of the container.

Figure 3.6b Saturating potting mix for the WHC and AFP tests.

Air-filled porosity (AFP)

Air-filled porosity is the percentage of air (by volume) in a potting mix after it has been saturated with water and allowed to drain. It is the % by volume of air space in the mix.

What you need to calculate AFP (See Figure 3.5):

- 2 buckets
- 4 wooden blocks (2 for each bucket)
- graduated measuring cylinder
- marking pen
- ruler
- 1 plastic container (a milk carton is suitable). See Figure 3.6a.

Method

1. Select a container that is the same height as the pot used for the mix. Cut 4 holes (about 10 mm diameter) in the base of the container so that fingers can easily plug these holes. See Figure 3.6a.
2. Moisten the potting mix and leave for 24 hours to make sure it is saturated.
3. Fill the container with the moist potting mix and tap the sides firmly to settle the mix.
4. Fill one bucket with water to a level that is slightly less than the container height and place 2 blocks inside the bottom of the bucket.
5. Slowly lower the container (with mix) into the water and rest it on the blocks to allow water to be in contact with the holes in the container. Lowering the container too quickly might cause the potting mix particles to float. See Figures 3.6a and 3.6b.
6. Slowly top-up the bucket with water until the water is level with the top of the potting mix in the container.
7. Allow the mix to settle for 1 hour. Then lift the container straight out of the bucket and allow it to drain for 5 minutes.
8. Repeat the wetting and drying cycle twice more, allowing 10 minutes soaking in the bucket each time.
9. At the end of the third cycle, lower the container into the bucket once more until the top of the mix is level with the water level. Before lifting the container out of the bucket again, this time plug the 4 holes with your fingers, and then lift quickly. Keep the holes plugged while moving the container to the dry bucket and place it on 2 blocks in the bottom of the bucket. Allow the container to drain freely for 1 hour.
10. After 1 hour, remove the container from the bucket, keeping it upright.
11. Using the measuring cylinder, measure the volume of drained water to the nearest millilitre (mL). This represents the volume of air in the mix.
12. Mark the height of the potting mix on the side of the used container, then empty the container and rinse it.
13. Fill the container with water to the mark then measure the volume of water (mL) required to fill the container. This represents the volume of the potting mix.

14. Calculate the AFP of the mix as:

$$\text{AFP \%} = \frac{\text{Volume of air in mix}}{\text{Total volume of mix}} \times 100$$

Example: If 90 mL water drains from 500 mL mix,

$$\text{AFP \%} = \frac{90}{500} \times 100 = 18\%$$

Preferred range = 10–20%.

Wettability

Wettability is the ease with which a potting mix may be re-wet once it has dried out, and this varies between different potting mixtures. Many types of organic material used in potting mix are hard to wet initially, and particularly hard to re-wet once they have dried out in the pot. Adding a wetting agent may help to re-wet.

What you need to calculate wettability (See Figure 3.7):

- baking tray
- flat tray (30 mm deep)
- pipette or syringe that can measure 10 mL
- stop watch
- measuring cylinder.

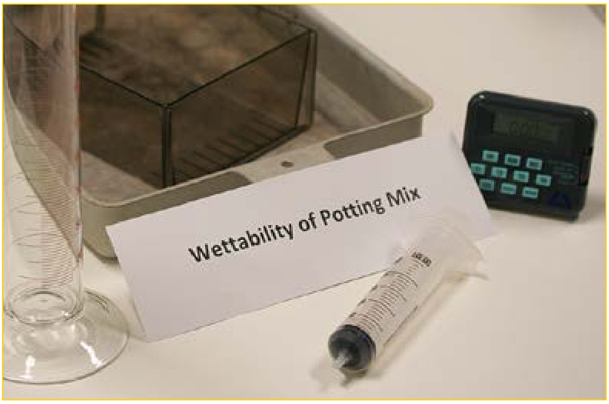


Figure 3.7 Equipment for the wettability test.

Method

1. Dry 300 mL of potting mix at 50°C in a flat tray overnight.
2. Pack the dry mix firmly into a smaller tray to a depth of 20 mm.
3. Make a small depression in the centre of the mix with an index finger.
4. Add 10 mL water to the centre of the depression, using a measuring cylinder, syringe or pipette.
5. Record the time taken for the water to soak into the potting mix.

Preferred time: 5–10 minutes

Shrinkage

Shrinkage in the potting mix causes inconsistent changes in porosity, water-holding capacity and nutrient availability, so it is important to use a potting mix with good wettability, maintain watering and not allow the mix to dry out. It is preferable that potting mix shrinks by less than 15% by volume per year.

Method

1. At the time of potting or sowing seeds, calculate the average volume of potting mix used to fill a standard pot and record this volume in your diary.
2. At one year of age, calculate the volume of potting mix left in several pots by removing the trees and measuring the volume of potting mix left.
3. Calculate the shrinkage as:

$$\% \text{ shrinkage} = \frac{\text{Volume at beginning} - \text{volume at 1 year}}{\text{Volume at beginning}} \times 100$$

$$\frac{5{,}000 - 4{,}300}{5{,}000} \times 100 = 14\% \text{ shrinkage}$$

3.6.2 Chemical properties

The chemical properties of the potting mix determine the supply of essential nutrients for tree growth. It is important that none of the nutrient elements are in short supply or in excess, and that toxins are absent. Important chemical characteristics of potting mix are electrical conductivity (EC) and pH.

Chemical property	Preferred range
EC	<1500 µS/cm
pH	5.5–7

Electrical conductivity (EC)

EC measures the salt content of a potting mix. The total amount of dissolved salts in irrigation water or potting mix can be measured with an EC meter that measures the electrical conductivity. The EC meter does not show which types of salts are present, but it indicates whether the salt level is too high or too low.

What you need to determine EC (see Figure 3.8):

- Portable, electronic EC meter
- buffer solution with EC 1,413 µS/cm
- plastic container
- distilled water

Method

1. Saturate about 500 g of potting mix with distilled water in a plastic container to make a watery paste.
2. Allow the paste / solution to stand for about 15 minutes.
3. Calibrate the EC meter by placing the probe (glass electrode) into the buffer solution (supplied with the meter) that has an EC of 1,413 µS/cm at 25°C. Make sure the digital reading matches the conductivity value of the buffer solution.
4. Rinse the probe in clean water.

5. Place the probe into the watery paste and record the digital EC reading for the potting mix.
6. Rinse the probe in clean water and store carefully.

Potting mix should have an EC of less than 1500 µS/cm.

pH

pH measures the acidity or alkalinity of a potting mix or soil, which is simply a measure of the concentration of hydrogen ions in the mix. pH is recorded on a scale from 0 to 14, where 7 is 'neutral'. If there are a lot of hydrogen ions in the mix, then the pH will be less than 7 and 'acidic'. If there are few hydrogen ions, then the pH will be greater than 7 and 'alkaline'. pH can be measured using a portable pH meter or a soil pH kit.

What you need to determine pH with an electronic pH meter:

- a portable pH meter
- a buffer solution with pH 7
- distilled water
- a plastic container

Figure 3.8 A portable conductivity meter.

Method

1. Saturate about 500 g of potting mix with distilled water in a plastic container to make a watery paste.
2. Allow the paste / solution to stand for about 15 minutes.
3. Calibrate the pH meter by placing the probe (glass electrode) into the buffer solution (supplied with the meter) that has a known pH 7 ± 0.02 at 25°C. Make sure the digital reading matches the pH value of the buffer solution.
4. Rinse the probe in clean water.
5. Place the probe into the watery paste and record the digital pH reading for the potting mix.
6. Rinse the probe in clean water and store carefully.

Potting mix should have a pH between 5.5 and 7.

What you need to determine pH with a soil pH kit:

- A soil pH test kit
- A small piece of white card

Method.

The method is illustrated in Figure 3.9. Potting mix should have a pH between 5.5 and 7 for growing citrus and mango plants.

1

1. Take soil sample

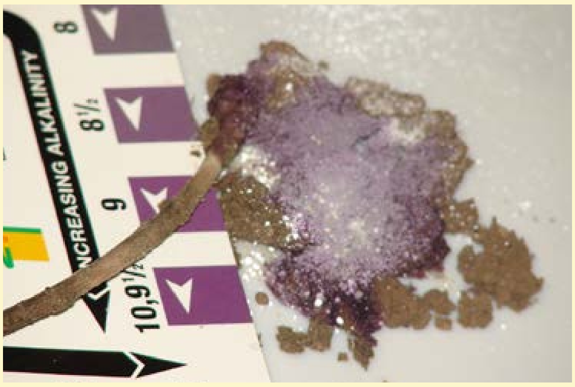
2

2. Open pH testing kit. It contains a chemical (a) and a pH colour card (b).

3

3. Take some pH testing chemical from the kit.

4



4. Add the dye to a soil sample and compare with the colour card. The closest match gives you an accurate pH reading.

Figure 3.9 Testing the pH of potting mix or soil with a soil pH kit.

4 Plant containers

Nursery trees may be grown in containers or in the ground, although there are many advantages to growing trees in containers. Tree roots benefit from being grown in free-draining potting mix and the costs of establishing a container nursery will be recouped through the good quality and survival of nursery stock.

What to consider

There are many advantages of growing trees in containers:

- Container trees need less water than trees in the ground.
- Quality of growing mix is more easily managed in containers.
- It is easier to contain and manage the spread of diseases.
- Container trees are more tolerant of transplanting and handling.
- Containers enable root air-pruning.
- Container trees are less likely to suffer during transport.

See the example in Figure 4.1 of root growth in soil compared to growth in a container.

4.1 Features of a good container

Several features of containers need to be considered when choosing pots because they affect the quality of root growth, drainage, temperature and the availability of air.

Drainage holes

Plant containers should have holes that allow excess water to drain away. If excess water cannot drain from the container, water replaces air in the soil pores and the roots die from lack of oxygen. The drainage holes should be on the bottom of the container but may also be on the side of the container. See Figure 4.2.

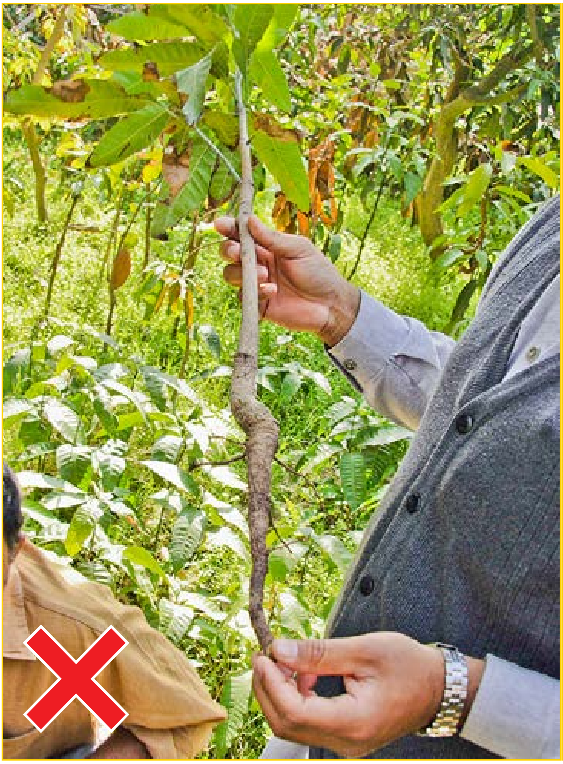


Figure 4.1a Poor root development in field-grown mango that has been dug up from the soil.

Figure 4.1b Healthy seedling roots grown in a well-drained potting mix.

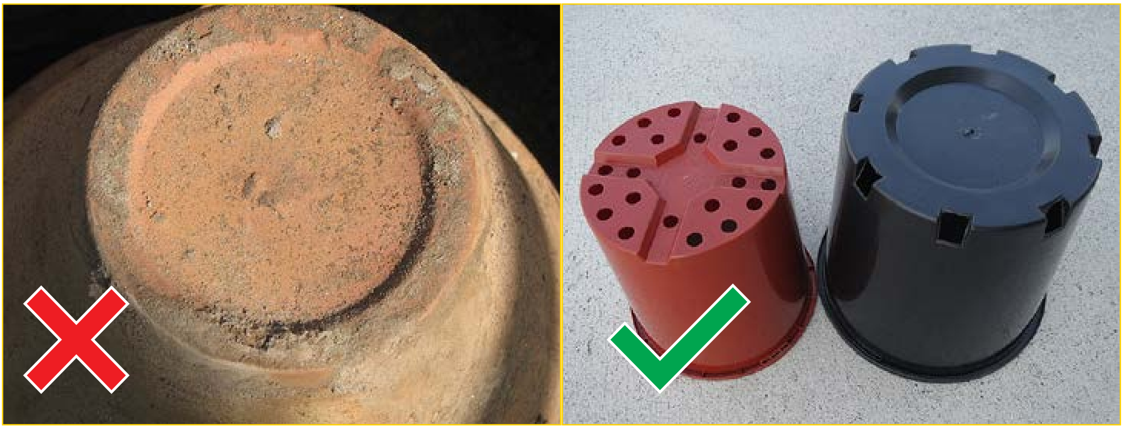


Figure 4.2 Compare the poor drainage capacity of the clay pot (left) with the excellent drainage provided by plastic pots (right).

Size

The size and shape of the container can affect the shape and growth rate of the root system. Containers should be deeper than they are wide. Trees grown in a pot that is too deep may have poor lateral growth when transplanted. Tapered pots (tubes) may reduce root curling in young trees that sometimes occurs in flat-bottomed containers. Tapered tubes usually need to be held in trays.

Citrus. Generally, citrus trees are transplanted at least once during the production cycle. It is possible to use the same container for germinating the seed and growing the grafted tree, although this is not ideal due to variable germination percentages and the importance of selecting rootstocks for trueness to type. Citrus seeds may be sown into shallow trays and transplanted when young into larger pots. Seedlings may be transplanted at a more advanced stage when seed is germinated in tall, narrow tubes or pots that allow for good root growth.

Mango. The larger mango seed can be sown directly into a 5 litre pot, so that the roots remain undisturbed until field-planting.

See Figure 4.3, and *Chapter 5—Germinating seeds and growing seedlings* for more information about germinating seeds in pots.

Air, moisture and temperature in the growing mix

The quantity of air in the growing mix decreases with depth in the pot. Lack of air in the mix creates an ideal environment for soil-borne disease and leads to root death.

One disadvantage of black pots or poly-bags is that black plastic can trap very high temperatures. Other colours may maintain a cooler temperature in the pot. Different coloured containers can also be a practical way to identify different growth stages or varieties in the nursery.

Figure 4.3 Plastic pots are available in many sizes.

Durability

Plastic pots are ideal for use in commercial nurseries because they are durable, easily cleaned and disinfected for recycling, and economical to use. Poly-bags are not as durable as plastic pots and cannot be recycled.

Root trainers

Some pots have internal, vertical ribs that encourage the external roots to grow downwards to reduce root curling. Trees grown in root trainer pots have a greater survival rate and are often ready for planting out earlier than those planted in poly-bags. These ribbed containers often require a tray and may be set up above the ground level so that the roots can be air-pruned. See Figure 4.4.

Figure 4.4 Root trainer pots encourage straight growth in roots.

4.2 Types of containers

Many types of containers may be used for growing nursery trees. The choice of pots in regional areas may be restricted by cost and availability, although the internet may increase access to a wider range of pots and growing containers.

Consider whether the complete growth period from seed germination to the final, grafted tree (ready for sale) can be achieved in a single container to avoid damage at transplanting (particularly for mango trees). Alternatively, more than one type of container can be used to suit the different stages of tree growth (particularly for citrus trees).

Containers can be made from a number of different materials.

Clay and cement pots

Clay pots are not ideal for commercial nurseries and are generally used as decorative planting pots. Clay pots dry out quickly and are fragile and heavy compared with plastic pots. Clay pots can be re-used but are difficult to clean between uses. They are often made from brick clay containing salt residues that are harmful to trees. Many traditional clay pots used in Pakistan have too few or no drainage holes, which may cause waterlogging and root death. See Figure 4.5.

Jiffy® pots

Jiffy® pots are made from compressed peat. Roots can penetrate the container walls, which helps to reduce root curling. They are biodegradable and the Jiffy® pot with its seedling can be planted directly into a larger pot.

Plastic pots

Plastic pots are suited to growing fruit trees. They are economical, durable, free from disease organisms when new, and are easy to clean, sterilise and re-use. Plastic pots that stack together require less storage space. Ridges around the outside make them easy to handle. See Figures 4.5 and 4.6.

Figure 4.5 Traditionally, clay pots (a, left) were common but plastic pots are now used in modern nurseries (b, right).

Figure 4.5c Plastic pots are easier to clean than clay and can be recycled.

Figure 4.6 Modern nurseries use poly-bags (a, left) and plastic pots (b, right) to raise healthy citrus and mango trees ready for planting into the field.

Poly-bags

Poly-bags are made from polyethylene (usually black) and have drainage holes in the bottom. They range in size from 0.3 to 45 litres. They can be cut without harming the roots when planting in the field. They are relatively cheap and take up little room when stored, although they can only be used once. See Figures 4.6, 4.7 and 4.8.

One problem with poly-bags is that roots may become spiralled at the base; this may restrict tree growth and reduce the ability of trees to withstand strong winds.

Figure 4.7 Citrus trees in poly-bags ready for planting in the field.

Figure 4.8 Cutting the poly-bag when transplanting a mango tree to minimise damage to the root system.

4.3 Cleaning and re-using containers

Use a high-pressure water spray to clean used pots. To sterilise them, either steam in a steaming trailer at 110°C for at least 30 minutes OR soak them in a strong sodium hypochlorite (bleach) solution of at least 1.25% or 12,500 ppm.

4.3.1 Storing containers

Store the new and recycled pots or containers on clean, metal shelves above floor level in an area reserved for storing pots.

4.3.2 Handling large pots

To avoid injury, it is important that containers are not too heavy for workers to handle. Equipment that helps workers handle larger containers safely should be available. Large pots can be lifted with a drum lifter, for example.

Comparing plastic pots with poly-bags

Advantages of both:

- light-weight and easily handled and stored when not in use
- contain adequate drainage holes
- when new, they are not contaminated with diseases or toxins such as salt.

Pots:

- durable and sturdy
- good for maintaining trees over a longer term
- more expensive to buy, but can be recycled.

Poly-bags:

- easily cut to remove trees at transplanting, minimising root damage
- easy to carry and use less storage space
- are cheaper to buy, but only used once
- may encourage root-spiral.

5 Germinating seeds and growing seedlings

The rootstock plants used for grafting citrus and mango are grown from seed. Best practice for raising citrus and mango seedlings is in containers, raised off the ground. There are many benefits of growing nursery plants in containers. In particular, it allows a greater ability to manage the properties of the growing medium to maximise plant health and growth and to prepare the trees for field planting. Find more information in *Chapter 4—Plant containers*.

In some countries, nursery trees are still grown in the field, in areas isolated from orchards to reduce their exposure to diseases found in mature orchards (such as mango malformation). In situations where plants are raised in the ground in field nurseries, it is better to germinate the seeds in a separate container before transplanting the robust seedlings into the soil. In Pakistan, growing nursery trees in the field is not recommended because of the risk of soil-borne diseases such as mango sudden death.

What to consider

- 5.1 Polyembryonic or monoembryonic seed varieties
- 5.2 Citrus
  - 5.2.1 Sourcing and selecting seed
  - 5.2.2 Extracting and preparing seed
  - 5.2.3 Germinating seed
  - 5.2.4 Transplanting from germination trays
  - 5.2.5 Potting up from tubes, cones or other containers
  - 5.2.6 Looking after the rootstocks
  - 5.2.7 What to avoid
- 5.3 Mango
  - 5.3.1 Sourcing and selecting seed
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  - 5.3.5 Thinning polyembryonic seedlings growing in the same pot
  - 5.3.6 What to avoid

Raising seedlings in containers—best practice

- Grow seedlings in containers, raised off the ground.
- Use potting mix with a good ratio of ingredients that optimise chemical and physical properties.
- Use high quality seeds from known, clean source trees.
- Use fungicide-treated seed.
- Follow planting and watering guidelines.
- Follow thinning and potting-up guidelines.
- Monitor germination regularly.

Field nurseries—more risk

- Germinate seeds in containers before planting out only the strongest seedlings.
- The planting site must be well away from orchards.
- The planting site must be free from soil-borne disease.
- The planting site must be well-drained and graded.
- Fence the area to protect it from animals and vehicles that may carry diseases or weed seeds.

5.1 Polyembryonic and monoembryonic seed varieties

Different varieties of both mango and citrus produce either polyembryonic or monoembryonic seed, see Figure 5.1.

Polyembryonic varieties are preferred due to their genetic uniformity.

Polyembryonic varieties

Seeds consist of many embryos that are usually genetically similar to the parent trees. This genetic uniformity means that polyembryonic varieties are often preferred as rootstocks. Polyembryonic seeds produce several, uniform seedlings when germinated.

Monoembryonic varieties

Seeds consist of only one embryo each, which is a true, zygotic embryo; it has a combination of genes from the seed and pollen parents. Trees grown from monoembryonic seed will vary genetically from the parent trees.

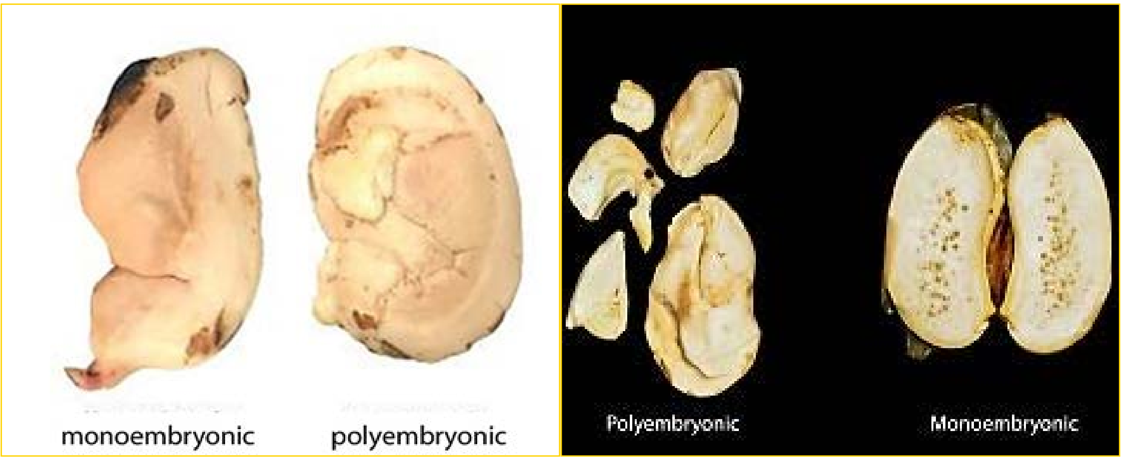


Figure 5.1 Examples of monoembryonic and polyembryonic mango seeds. In each case, the endocarp and outer casing have been removed to expose the embryos. Left, embryos in the polyembryionic seed are still intact. Right, the embryos in the polyembrionic seed have been separated.

5.2 Citrus

Citrus varieties may be grown on their own roots or grafted onto seedlings of rootstock varieties. Grafted nursery plants are preferred because the rootstock provides the tree with a strong root system that can tolerate a range of soil conditions. Citrus rootstocks are produced from seed that are collected from rootstock fruit.

5.2.1 Sourcing and selecting seed

Obtain seeds from a reliable supplier who checks that the seed source trees are true-to-type, and free from disease (Figure 5.2a). Either use seed already treated with a fungicide or treat seeds with a broad-spectrum fungicide that is suitable for seed treatment (Figure 5.2b).

If a reliable supplier is not available, extract seed from source trees that have been checked for trueness-to-type and cleared of seed transmissible diseases, such as citrus leaf-blotch virus. For seed collection, harvest fruit that is higher than one metre above the ground.

Figure 5.2a Healthy citrus seed.

Figure 5.2b Citrus seed treated with fungicide.

5.2.2 Extracting and preparing seed

Extract seed from mature fruit either by hand or mechanically.

Hand extraction. Open the fruit cross-wise with a knife. Do not cut too deep as this will damage the seed. Separate the two halves by twisting. Collect the seeds in a container. Float seeds in water and baking soda to remove the pulp.

Mechanical extraction. Seed extraction machines are designed to cut or macerate the fruit without damaging the seed, the seed is then separated from the pulp and rind. Ensure all the equipment is cleaned with disinfectant after each use.

Seed treatment. Rinse seed in fresh water. Prepare a chlorine dip using 0.8L of 12.5% sodium hypochlorite in 19.2L of water to make a final volume of 20L (0.5% NaOCl). Place the seed in a mesh basket. Immerse the seed in the chlorine dip for 2 minutes then allow the seed to drain. Pre-heat a water bath to 51.6°C. Immerse the seed in the water bath for 10 minutes then wash the seed with clean water to cool it down. Dry the seed in a shaded area until it is surface-dry. Treat the seed with a broad spectrum fungicide like 8-hydroxyquinoline or thiram. Surface-dry the seed before putting it into bags. Record the variety, extraction and treatment information on each bag.

Seed storage. Store seed in polyethylene bags at 2–4°C (in the nursery cool room or fridge). Seed may be stored in bulk for up to 12 months if treated and stored correctly. If cool storage is not available, seed storage is not advised; extract and clean the seed, dip in chlorine and sow immediately.

5.2.3 Germinating seed

Handling seed. If the seed has been treated with fungicide before sowing, everyone handling the seed should wear gloves and a face mask.

Trays and containers. Seeds may be sown into germination trays or singly into tubes, cones or other containers (Figure 5.3).

Use clean containers. Clean the trays, tubes or pots before using them; treat them with a disinfectant, then rinse with clean water.

Potting mix. Germinate seeds in a light, free-draining potting mix such as sand, coir, vermiculite or a commercial seedling mix. There is more information in *Chapter 3—Potting mixes*.

Figure 5.3a Citrus seed germination in trays.

Figure 5.3b Citrus seed sown directly into containers.

Sowing seed.

Sowing in trays: Spread the seed evenly in germination trays and cover with 10 mm of potting mix.

Sowing in tubes or other containers: Press one seed into the growing medium, to a depth of 10 mm. If poor seed germination is predicted, sow two seeds in each container.

Labelling containers. Label the sowing containers with the rootstock variety and the sowing date.

Watering. Water the sowing containers thoroughly but gently, with a fine mist.

Position. Place the sowing containers on a bench in a seedling propagation house or in a controlled-environment cabinet.

Monitoring. Monitor the geminating seed daily. Keep the potting mix moist but not overwatered. If too much water is applied, the seeds are likely to rot before they have a chance to germinate. If germination is poor, check the moisture content and monitor the temperature of the growing medium. The optimum temperature range for citrus seed germination is 29–34°C.

5.2.4 Transplanting from germination trays

Seedlings germinated in trays are potted-up into their final rootstock container when 5–7 cm high (Figure 5.4).

Handling and sterilising the potting mix for the new container. Take care not to breathe in the dust when handling potting mix. Wash hands after handling potting mix. Sterilise all the equipment used to pot-up seedlings before using it and again between using each batch of potting mix.

Selecting seedlings to pot-up. Seedlings should be at least 5–7 cm tall before they are removed from the sowing container. Choose 'true-to-type' seedlings, which will be uniform in size and leaf shape, as expected for that variety:

- *Citrus trifoliata* and its hybrids (e.g. Troyer citrange) have 3-lobed leaves.
- Rough lemon, Sour orange, Volkameriana and Sweet orange have leaves with 1 lobe.

Figure 5.4a Citrus seedlings ready for potting up.

Figure 5.4b Citrus seedlings potted up and labelled.

Discard any seedlings that are off-type (i.e. with leaves that are not typical for the type). Discard any seedlings that have severely bent roots (bench roots). Leave seedlings that are smaller than average in the germination container until they can be assessed for trueness-to-type.

Removing seedlings. Prick out seedlings by gently pulling them from the potting mix. A small, pointed stick may be useful in loosening the soil around the seedling before pulling. Keep the seedlings moist by placing them into a container of clean water immediately after pulling.

Potting-up. Fill the new container for the rootstock seedlings with potting mix, tap gently and then top up with additional mix. Make a deep hole in the potting mix using a dibbling tool, Figure 5.5. The hole should be deep enough to take the entire root system of the seedling. Place the seedling to the same depth in the hole as it was in the seedling mix.

5.2.5 Potting-up from tubes, cones or other containers

Grow seedlings on in their tubes until about 6 months old when the roots are well-formed and then transfer each true-to-type seedling to a larger container (Figure 5.6). Transfer the root and all the potting mix to the new container. Top up the container with new potting mix and firm down. If two seeds germinate, remove the weakest seedling, leaving a vigorous one to grow on as the rootstock.

Figure 5.5a One example of a dibbling tool.

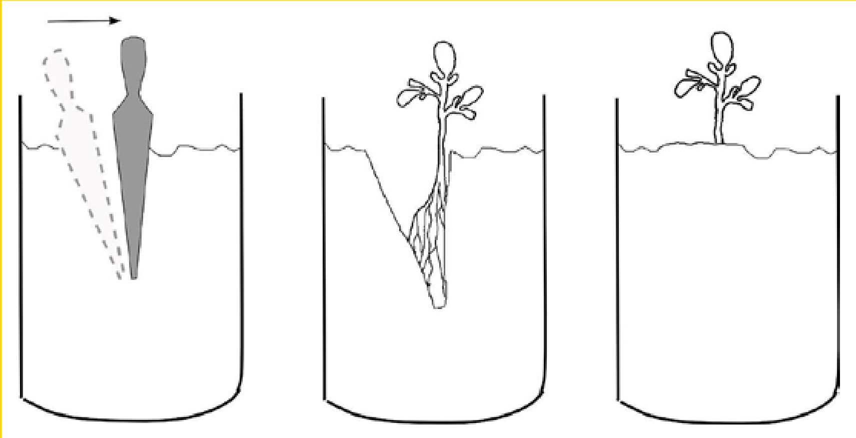


Figure 5.5b Use the dibbling tool to make the planting hole, insert the seedling and firm the soil.

Figure 5.6a Rootstock seedlings growing in tubes.

Figure 5.6b Seedlings grown on to 6 months ready to pot up.

Figure 5.6c Seedling ready for potting-up.

5.2.6 Looking after the rootstocks

Watering. Water the seedlings thoroughly and allow them to drain.

Labelling. Label the pots to show the variety, sowing date and propagation date. See Figure 5.7.

Positioning pots. Place the potted rootstocks on a bench or on weed mat or gravel in the production area. Space the pots to avoid over-crowding and to stimulate healthy, vigorous growth. See Figure 5.7.

Figure 5.7a Label the seedlings clearly.

Figure 5.7b Careful pot spacing stimulates vigorous growth.

Figure 5.7c Plants on well-drained gravel in the production area.

5.2.7 What to avoid

Health and vigour in citrus plants is determined by conditions during germination and the seedling growth stages. Planting seeds or seedlings in poorly-drained potting medium or poor soils in the field will affect the development of the root system, Figure 5.8.

Figure 5.8 Overcrowded citrus seedlings in water-logged, weedy conditions.

5.3 Mango

5.3.1 Sourcing and selecting seed

Know the source of seed. Always use seed from a known, clean source of a proven rootstock variety.

Use polyembryonic seeds. Seeds from polyembryonic mango varieties produce more uniform plants than monoembryonic seeds (see Section 5.1 above). Whenever possible, use polyembryonic mango varieties for rootstocks as they produce genetically uniform rootstocks that have uniform orchard growth patterns.

Use healthy mother trees. Rootstock seeds should only be taken from healthy mother trees that are free from pests and diseases. Look out for mango malformation disease; do not use any seeds from mother trees that have symptoms of mango malformation disease.

Use seed from healthy fruit. Select seed from healthy fruit.

5.3.2 Extracting and preparing seed

Remove fruit flesh. Let the fruit ripen, then remove as much flesh as possible. It is easier to remove the flesh from ripe fruit but it is also acceptable to cut the flesh off unripe fruit. Once the mango flesh is removed you are left with a husk (stone) enclosing the seed, which contains one or more embryos.

Dry the husks. Dry the husks containing the seeds in the shade for 24 hours to make them less slippery to handle when opening.

Extract the seed. Open the husks with a sharp knife or secateurs, by carefully cutting along the edge of the husk, to extract the embryos (seed) inside (Figure 5.9a). Avoid damaging the embryos because damaged seeds might not germinate. Discard any embryos that have been damaged or show signs of insect attack or are dark in colour (Figure 5.9b).

Figure 5.9a The seed may contain one or more embryos. Source: *www.instructables.com/id/How-To-Grow-A-Mango-Tree/*

Figure 5.9b A healthy seed (left) and a diseased one (right).

Treat with fungicide. To avoid fungal infection of the seedlings, soak the seeds in a 1% chlorine solution for one minute before sowing.

Storing husks or seeds. If you need to store the husks or seeds, keep them dry and plant within a couple of weeks. Do not store them in the fridge. Mango seeds will not store well. It is best to germinate them as soon as the fruit containing the seed are ripe.

5.3.3 Germinating seed

Pots or trays. Single seeds can be planted in pots that are big enough for the life of the tree, up to field planting. Alternatively, they can be planted in germination trays. See Figure 5.10.

- Sowing in pots or other containers: A suitable pot size for single seeds is approximately 30 cm deep and 10 cm in diameter (containing approximately 5 litres of potting mix).
- Sowing in trays: Germination trays for mango should be at least 20 cm deep to allow the taproot to develop.

Potting mix. The potting mix used for germinating seed and growing seedlings should be open and well-drained. There is more information in *Chapter 3—Potting mix*.

Planting seeds. Plant each embryo on the flat side, cover with 4 to 6 cm of potting mix, then water thoroughly and drain. Fertiliser is not needed at this stage, because the seedling takes its nutrients from the seed.

Germination time. Seeds should germinate within three weeks.

Figure 5.10a Mango seeds sown in a germination tray.

Figure 5.10b Mango seeds sown directly into poly-bags.

5.3.4 Transplanting from germination trays

Pot into single tree pots. When seeds are germinated in germination trays, pot them up into single tree pots when about one month old.

Water before removing seedlings. Before potting-up the seedlings, water the germination trays thoroughly. This will make it easier to remove the seedlings and avoid damaging the roots. Seedlings with undamaged root systems are stronger and will grow better than those with damaged roots.

Separate and sort the individual seedlings. Remove the seedlings carefully and separate the individual seedlings that are growing from the same seed. Discard any seedlings that are less than 8 cm high and those with poor or damaged root systems.

Keep the roots moist. Keep the roots moist by covering them with a damp cloth or by placing them into a bucket half full of water. They should be potted up as soon as possible after removing from the trays.

Potting-up seedlings. Fill the bottom of a clean pot or plastic bag with potting mix. Place a seedling into the pot and fill around it with more potting mix, taking care that the roots are not damaged. The seedling should be planted at the same depth it was growing in the germination tray. Moist potting mix will cause less stress to the roots and reduce the amount of dust.

Watering. Water the seedlings as soon as they have been potted up. Water the pots or bags until water drips out of the bottom, and then leave them to drain. See Figure 5.11.

Figure 5.11 Healthy, well-formed, uniform seedlings set above the ground on benches (a, left) and on bricks over gravel (b, right).

5.3.5 Thinning polyembryonic seedlings growing in the same pot

Thin to a single stem. Polyembryonic mango seed planted into single pots will need to be thinned to a single stem in the first month after germination. Thinning polyembryonic seedlings is best done by selecting the strongest seedling and cutting all the others off at soil level. This method avoids disrupting the root system and maintains healthy growth, Figure 5.12.

5.3.6 What to avoid

Health and vigour in mango plants are determined by conditions during germination and seedling growth stages. Planting seeds or seedlings in a poorly drained medium will affect the development of the root system, Figure 5.13.

Figure 5.12a Multiple seedlings grown from a single polyembryonic seed need to be thinned to a single stem.

Figure 5.12b After thinning, the remaining stem becomes the rootstock.

Figure 5.13a Poor mango germination caused by planting in heavy, poorly-drained potting medium.

Figure 5.13b Roots of mango seedling grown in the ground are damaged when dug up to transplant (left) compared with pot-grown (right).

A note about growing seedlings in the ground.

Although best practice is to raise seedlings in pots, sometimes seedlings are planted in the ground. If the seedlings are planted too close to mature orchard trees they are vulnerable to any pests or diseases that may already be established in the orchard. Infected seedlings grown in the ground cannot be managed or isolated as easily as pot-grown seedlings. In Pakistan, ground raised nursery seedlings have been responsible for the rapid spread of diseases such as mango malformation (Figure 5.14).

Figure 5.14a Seedlings planted too close to orchard trees are vulnerable to diseases.

Figure 5.14b These field-grown rootstocks show symptoms of mango malformation at the tips. The source may be a mature tree nearby.

6 Grafting—rootstocks, scions and grafting

Commercial varieties of citrus and mango are grafted as scions onto compatible rootstock varieties in the nursery for several reasons:

- to produce a hardy root system suited to different soil conditions or tolerant of different soil-borne pests and diseases
- to reduce the juvenility of trees so that they begin to flower and crop at a younger age
- to produce uniform orchard trees
- to improve yield and fruit quality.

Field trees may also be re-grafted by 'top working', where the tree is cut down and a new scion variety is grafted onto the established rootstock. The new scion's rapid regrowth on the established root system results in a faster return to full production. This allows growers to change to a new variety or a better selection to meet changing market demands.

What to consider

6.1 Key terms used in grafting

Grafting. The process of joining a variety onto the root system of another variety; the top part is the scion and the bottom part is the rootstock.

> ***Mango.*** Scion wood (containing one or more buds) is inserted into a slit or groove in the rootstock plant, where it continues to grow after healing.
>
> ***Citrus***. Includes chip-budding, a form of grafting where an individual scion bud (bud chip) is grafted onto a root stock.

Mother stock or mother trees. Names given to either or both the seed source trees for rootstocks and the source trees for scion wood. Mother trees are selected from trees that are true-to-type and free from pests and diseases.

Rootstock. The bottom part of a grafted plant. Rootstocks are generally grown from seed but may also be propagated by cuttings. The rootstock variety is chosen for the benefits it will give to the scion (for example, its ability to grow well in different soils or its tolerance to a pest or disease). Not all scion varieties are compatible with all rootstock varieties. Not all seedlings grow true-to-type therefore seedlings must be selected carefully before they are used as a rootstock.

Scion. The top part of a grafted plant that forms the tree canopy. The scion source tree has desirable, above-ground characteristics. The scion is grafted onto a rootstock plant with a healthy root system. After budding or grafting, the rootstock is removed just above the graft site and the scion bud is encouraged to grow, to form the tree canopy.

Scion wood and budwood. The piece of scion that is inserted into the rootstock during grafting.

> ***Mango.*** Budwood is a piece of scion twig used in grafting that contains several swelling buds at its tip.
>
> ***Citrus.*** A *budstick* is a stick of scion wood (budwood) containing several individual buds. A *bud chip* is a small piece of scion budwood containing a single bud that is cut from the budstick and inserted into the prepared rootstock to create a tree.

Graft union. The place on a grafted plant where the scion and rootstock meet. The scion is the part of the tree above the graft union and the rootstock is below the graft union.

Budding. A form of grafting used mostly for citrus that uses single buds as bud chips.

6.2 Equipment

Grafting is most successful when clean equipment is used.

Grafting knife. The most important piece of equipment needed for budding and grafting is a good quality grafting knife. Budding and grafting knives differ from ordinary knives: they are sharpened with a bevel on only one side; the other side is flat, like the bottom of a chisel. The knife must always be kept razor-sharp and clean. A fine sharpening stone is needed to keep the knife very sharp. See Figure 6.1a.

Grafting tape. Special plastic tape (1.25 to 3 cm wide) is used to wrap up the graft union, hold the scion material in place and reduce moisture-loss during graft-healing (Figure 6.1a).

Secateurs. Clean, sharp secateurs are useful for cutting scions or budwood.

Bags. When grafting **mango**, the success rate improves significantly if small plastic bags and brown paper bags are placed over the graft to conserve moisture and to prevent the temperature from increasing too much (Figure 6.1b).

Disinfectant. Disinfecting liquids are used to sterilise grafting equipment by removing any potentially-transmissible infections. Maintain a high level of hygiene at all times and keep all equipment clean. Periodically, dip grafting knives into the recommended disinfecting solution to sterilise them.

Figure 6.1a Grafting knife and tape.

Figure 6.1b Using plastic bags to protect grafts in mango.

Grafting—general rules

- Keep everything clean
- Keep tools sharp
- Take care using tools
- Use healthy rootstocks
- Use healthy and fresh scion wood
- Use grafting tape over the graft union
- Cover to protect the graft union (mango)
- Keep trees moist, not wet
- Avoid spraying for 2–4 weeks before grafting.

6.3 Grafting citrus

Although some citrus varieties may be grown on their own roots, grafted nursery trees are preferred because the rootstock provides the tree with a strong root system that is able to tolerate a range of soil conditions. It is important to match the rootstock to the scion variety, climate and soil type.

6.3.1 General rules for grafting citrus

Keep everything clean. Work hygienically throughout the grafting process: sterilise and clean the knife regularly with chlorine bleach; sterilise secateurs and budding knives in chlorine bleach (1.25% or 12,500 ppm sodium hypochlorite) before use, between varieties and every hour. Budding should be done on a clean bench in the nursery. The bench should be made of non-porous material and cleaned with a disinfectant before use. For more information see *Chapter 8—Nursery Hygiene*.

Keep tools sharp. Always keep the grafting knife sharp.

Take care using tools. Take care when using sharp tools like knives and secateurs. Staff should be trained before undertaking these tasks.

Use healthy rootstocks. The rootstocks must be healthy and growing vigorously.

Use healthy and fresh scion wood (budwood). Buds on the scion wood should be healthy and swelling. Preferably use fresh scion wood. Keep unused scion wood wrapped in plastic and store in a cool place or a refrigerator to slow down the rate of water loss.

Use grafting tape to cover the graft. Always match the scion and rootstock cambium layers on one side when wrapping; don't worry if both sides do not match. Always cover the freshly-budded or grafted area with grafting tape.

Keep moist, not wet. Do not over-water the rootstocks after grafting.

Avoid spraying nursery trees and budwood source trees for 2–4 weeks before budding. Some sprays, such as oils used for scale control, can reduce budding success rates significantly.

Figure 6.2 Demonstrating grafting.

6.3.2 Selecting citrus rootstocks

Use healthy, vigorous seedlings. It is important that rootstock seed is obtained from trees that have been tested for seed-transmissible diseases. Seedlings should be healthy, actively growing and free from pests and disease (Figure 6.3a). Budding (grafting) is more successful when actively-growing rootstocks are used. This is achieved by using a well-drained potting mix, and maintaining optimum levels of nutrition and pest and disease control. Do not apply fertiliser or pesticide for at least two weeks before budding.

Use true-to-type seedlings. Seedlings used for budding should be true-to-type; do not graft onto off-type seedlings or seedlings that are unusually large or small.

Use clean seedlings. Make sure rootstock seedlings are clean; remove dust by hosing and allow to dry.

Rootstock size and age. Most commercial nurseries propagate onto citrus rootstocks that are 6–12 months old and have a stem thickness of 5–10 mm.

Keep moist. Make sure the seedlings are not water-stressed before or after budding.

Figure 6.3a Rootstocks are selected from healthy, actively-growing, true-to-type seedlings.

Figure 6.3b Scions are selected from healthy, actively-growing shoots from the mother tree.

6.3.3 Selecting citrus scions (budwood)

- Scion wood may be collected at any time of the year when a mature flush is present on the source tree and suitable rootstocks are available. The best times for budding citrus are late summer and early autumn or spring.
- The most suitable material for budding is found on the centre third of a shoot with rounded wood. Triangular wood may be used where material is limited.

Cut good quality, healthy scions. The scions should be healthy, vigorously growing shoots from the mother tree (Figures 6.3b and 6.4). It is important that propagation material used for grafting citrus is disease-free and true-to-type in order to produce healthy nursery trees of the desired variety. Do not use budwood that shows signs of infection (e.g. lesions of citrus canker or scab). Infection can spread through the nursery and into the orchard from infected nursery trees. Budwood must be obtained from trees that have been tested for graft-transmissible diseases (e.g. huanglongbing, citrus viruses or viroids) to ensure that healthy nursery trees are produced.

Prepare the scion wood. After the scion wood has been cut from the tree, remove the unwanted wood and leaves, leaving a petiole stub to protect the bud (Figure 6.5).

Use the scion wood quickly. Scion wood should be used immediately or stored in the refrigerator (at 5°C) in a sealed and labelled plastic bag for 1–2 weeks. Label the bag with variety, date and a way of identifying the tree from which the scion wood was cut (i.e. the source tree) (Figure 6.5).

6.3.4 Citrus grafting technique—chip-budding

Chip-budding is recommended for grafting citrus trees. Follow all the general rules as well as these guidelines for chip-budding. *Although T-budding may also be used, chip-budding is recommended because it has a higher success rate.*

Bud one variety at a time; discard any leftover wood before starting to bud the next variety.

Figure 6.4 Selecting citrus scions from healthy mother trees.

Figure 6.5 Citrus scions should be used quickly or labelled and stored in the refrigerator.

Prepare the rootstock. The preferred budding height is approximately 15–20 cm above the potting mix. Select a clean, smooth area to be budded and trim leaves and thorns from around the area. Make a long, shallow cut, slightly angled through the bark of the rootstock (Figure 6.6a) approximately 2 mm deep and 12 mm long. Make a second cut (Figure 6.6b) to remove the top section of the bark flap above it (approximately 5 mm of bark). This will leave a small area of rootstock wood exposed and a small flap of bark at the base.

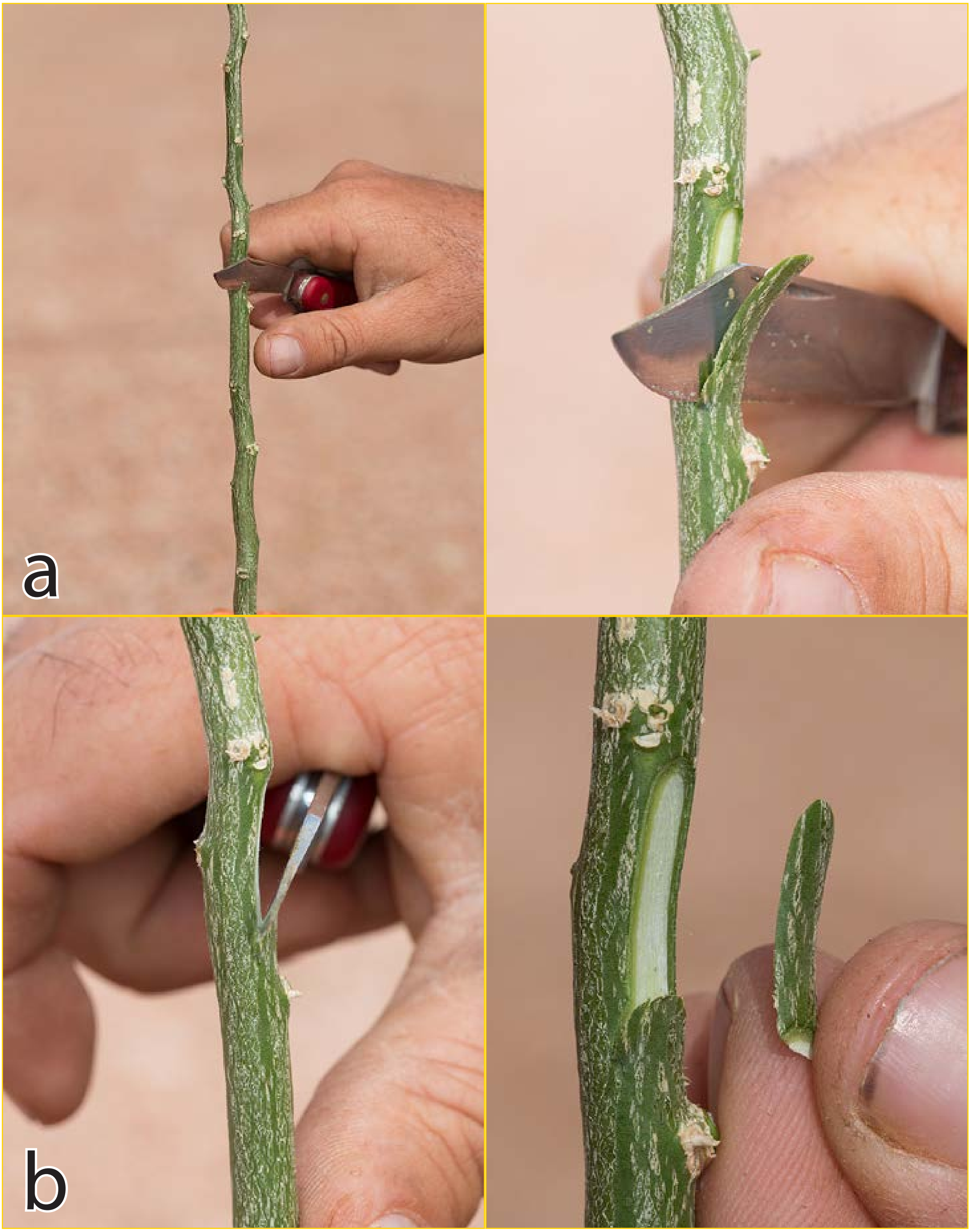


Figure 6.6 Preparing the rootstock: making a shallow, downward cut (a); removing the top of the bark flap (b).

Cut the bud chip from the scion wood. On the scion wood (or budstick), remove the petiole stub from below a bud (Figure 6.6 c–e). Cut downward through the bark from the top behind the bud. Then make a cut about 5 mm below the bud, meeting the original cut, to remove the bud; this piece of budwood is now called the bud chip (Figure 6.6 f–h). It is best if the bud chip is the same length and width as the cut made in the rootstock.

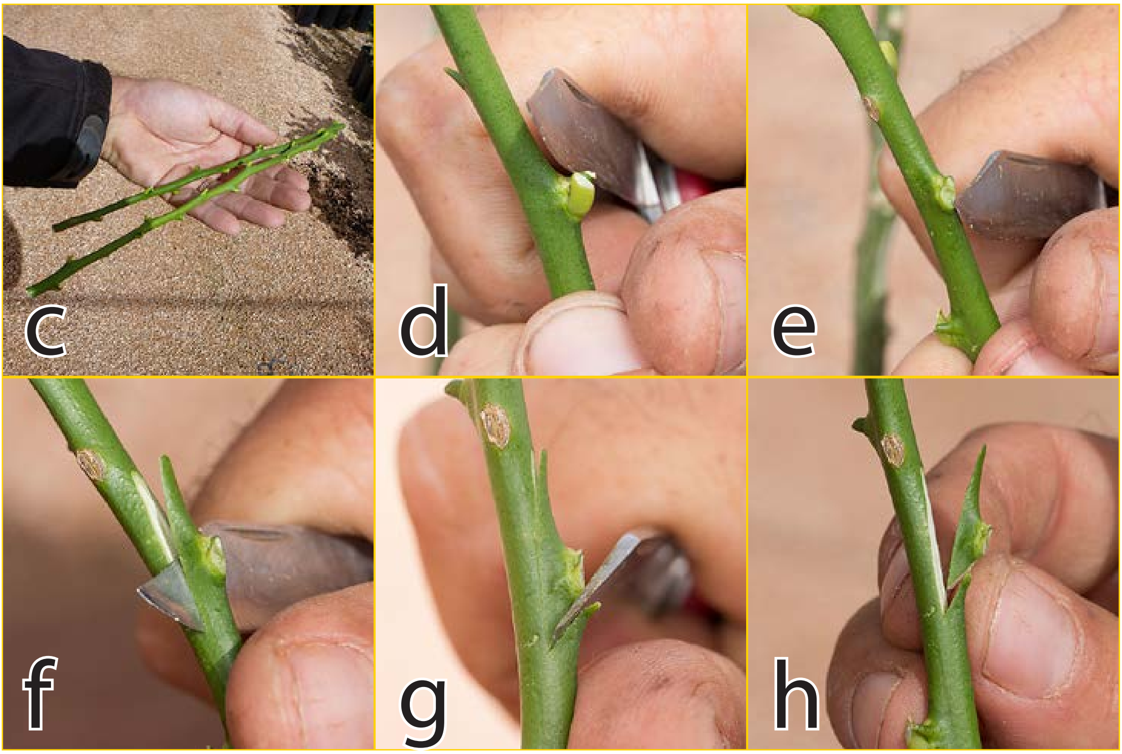


Figure 6.6 Cutting the bud chip: c–citrus bud wood; d–cutting the petiole stub; e–bud with stub removed; f–first cut; g–second cut; h-removing the bud chip.

Make the graft union by inserting the bud into the rootstock. Slide the bud in behind the flap of bark on the rootstock so that the edges of the bud line up with the cut in the rootstock. If the scion bud is smaller than the rootstock, set the bud to one side so that it lines up on that side (Figure 6.6 i–k).

Figure 6.6 Making the graft union: i–k.

To achieve a successful graft union, the cambium layers in both the rootstock and bud must be matched on at least one side.

The cambium area is where the cells are actively dividing, shown in Figure 6.7.

Graft healing only occurs in this region, and if the cambium layers are not matched, the graft union will fail.

Wrap the bud. Wrap the bud using budding tape, starting at the bottom and completely covering the bud and all cut edges. Wrap firmly, but not too tightly, and secure by tying. Different types of budding tape are available, including dissolvable tape. See Figure 6.8.

Label the grafted tree. Label the tree with the scion and rootstock varieties and the date it was budded.

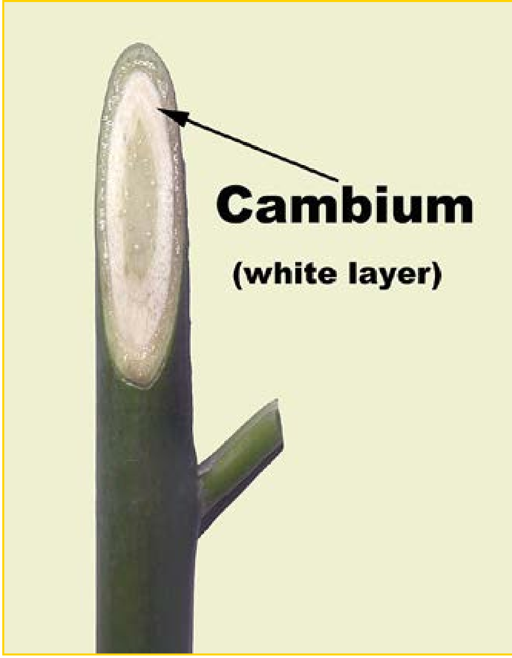


Figure 6.7

Figure 6.8 Wrapping the graft union with non-dissolvable budding tape.

Another type of budding tape.

Remove the budding tape. Dissolvable budding tape does not need to be removed. If non-dissolvable tape is used, remove the tape after 3 to 4 weeks. Check a few grafts to see if they have taken before removing the tape from the entire batch of trees, see Figure 6.9. Remove the tape by slicing it with a sterile blade along the back of the rootstock (away from the bud).

Remove the rootstock above the union. If trees are budded in spring, remove the top of the rootstock three weeks after budding, Figure 6.10. If the trees are budded in autumn, wait until spring to remove the top of the rootstock. Remove rootstock suckers below the graft union. See Figure 6.11.

Figure 6.9 Successful graft union with the tape removed.

Figure 6.10 Removing the rootstock above the union.

Figure 6.11a A grafted plant showing growth above the graft union and some rootstock suckers.

Figure 6.11b Removing rootstock suckers below the graft union.

6.3.5 Care after grafting citrus

Watering. Recently-grafted trees have fewer leaves and use less water. Over-watering recently-grafted trees is a common problem that contributes to graft failure.

Health checks. Monitor regularly for pests and diseases. Find more information in *Chapter 9—Managing diseases, pests and weeds*.

See Figure 6.12.

Figure 6.12 Healthy, grafted citrus trees in the nursery and ready for sale.

Graft-transmissible diseases

These can be spread by using infected scion wood, but the budwood usually does not show symptoms of these diseases. The disease particles flow through the food or water tubes of the plant.

There is no cure for these diseases. Once infected trees are in the orchard, disease may also be spread from an infected tree to a healthy tree via infected cutting tools, root grafting under the soil or insects that feed between trees.

Examples include viruses like **citrus tristeza virus**, viroids like **citrus exocortis viroid** and the bacterial disease **huanglongbing**.

6.3.6 Grafting citrus—a checklist

Propagating seeds for rootstocks

- Source the seed from healthy trees.
- If possible, treat seed with a fungicide.
- Propagate seed in the spring, unless you have a greenhouse to maintain warm temperatures.
- Germinate seed in a free-draining medium like sand in either trays or tubes.
- Germination containers may be individual tubes or community pots.

Selecting rootstocks

- Select actively growing, healthy rootstock seedlings that are true-to-type.
- Select mature plants (6–12 months old).
- Remove bent roots before transplanting into larger containers.

Selecting scion wood / budwood

- Select only true-to-type budwood from healthy mother trees.
- The most suitable budwood is the centre 1/3 of shoots with rounded wood.
- Remove all leaves immediately after cutting.
- Store in labelled plastic bags in a cool room or dedicated refrigerator.
- Use budwood within 1–2 weeks of cutting.

Preparing the rootstock

- Select rootstocks with a uniform height and stem diameter.
- Use sharp, sterilized implements to make a shallow cut in the rootstock at the graft union height: about 15–20 cm above the pot.
- Remove the top section of this flap of bark, leaving a small, projecting flap.

Cutting the bud chip

- Use a sharp, sterilised knife to cut the bud chip.
- On the scion wood (or bud stick), make a cut down from the top behind the bud.
- Cut through the bark about 5 mm below the bud, meeting the original cut, to remove the bud.

Making and protecting the graft

- Match bud chip size to rootstock diameter.
- Slide the bud chip behind the flap of bark on the rootstock.
- Match the cambium layers in the bud chip to that of the rootstock on at least one side.
- Firmly wrap grafting tape around the new graft to ensure good contact and seal.

Care after grafting

- Maintain newly grafted trees under shade.
- Give the trees optimum water and nutrition.
- Remove non-dissolvable grafting tape after 3–4 weeks. Check that a few buds have taken on a few trees before removing the tape from the whole batch.

Removing the rootstock above the graft union

- If trees are budded in spring, remove the top of the rootstock three weeks after budding.
- If the trees are budded in autumn, wait until spring to remove the top of the rootstock.

Removing rootstock suckers

- Remove rootstock suckers below the graft union.

Hygiene practices

Keep grafting material and equipment clean

- Keep rootstocks away from the ground and sources of contamination.
- Keep budwood away from soil and plant material.
- Work on clean, elevated benches.
- Clean all cutting tools thoroughly.
- Disinfect tools in chlorine bleach before use, and between trees or tree batches.

Personal safety and cleanliness

- Clean hands and fingernails frequently.
- If possible, use disposable gloves.
- Take care with sharp knives.

Healthy mother trees and scions

- Source rootstock seed and budwood from trees that have been tested for graft-transmissible diseases, and where pests and diseases are managed effectively.

6.4 Grafting mango

Mango varieties may be grown on their own roots, but grafted nursery trees are preferred because they produce a uniform fruit of a known commercial variety. It is important to match the rootstock to the scion variety, climate and soil type.

6.4.1 General rules for grafting mango

Keep everything clean. Work hygienically throughout the grafting process. Sterilise and clean the knife regularly with chlorine bleach (1.25% or 12,500 ppm sodium hypochlorite) or methylated spirit when grafting mangoes. Clean the work bench regularly. Find more information in *Chapter 8—Nursery hygiene*.

Keep tools sharp. Always keep the grafting knife sharp.

Take care using tools. Take care when using sharp tools like knives and secateurs. Staff should be trained in health and safety procedures before undertaking these tasks.

Use healthy rootstocks. The rootstocks must be healthy and growing vigorously.

Use healthy and fresh scion wood. Buds on the scion wood should be healthy and swelling. Preferably use fresh scion wood. Keep unused scion wood wrapped in plastic and store in a cool place or a refrigerator to slow down the rate of water loss.

Use grafting tape over the graft. Align the cut surfaces of the scion with the rootstock. Always match the cambium layers on one side when wrapping; don't worry if both sides do not match. Cover the freshly-grafted area with a plastic tape.

Cover to protect the graft union. If possible, cover the union with a plastic bag, which will create a humid and warm environment and prevent the scion from drying out. When grafting in full sunlight, cover the plastic bag with a brown paper bag, to prevent excessive heat from building up.

Keep moist, not wet. Do not over-water the rootstocks after grafting.

Avoid spraying nursery trees and budwood source trees for 2–4 weeks before budding. Some sprays, such as oils used for scale control, can reduce budding success rates significantly.

6.4.2 Selecting mango rootstocks

Use polyembryonic varieties for rootstocks. Polyembryonic varieties are preferred because their seed embryos are genetically true-to-type to the mother tree and provide uniformity across the orchard.

Use healthy, vigorous rootstocks. Rootstocks for grafting should be healthy, actively growing and free from pests and disease. Grafting is more successful when vigorously-growing rootstocks are used. This is achieved by using a well-drained potting mix, and maintaining adequate levels of nutrition and pest and disease control. See Figure 6.13a.

Rootstock size and age. Mango rootstocks most commonly used for grafting are between 6 and 12 months old. Rootstock seedlings are considered ready to graft when the stem diameter is pencil-thickness, between 5 and 10 mm (Figure 6.13b).

Use clean rootstock seedlings. Make sure rootstock seedlings are clean; hose to remove dust and allow to dry.

Keep moist. Make sure the seedlings are not water-stressed before or after grafting.

Figure 6.13a Mango rootstock seedlings ready for grafting in the nursery.

Figure 6.13b A 12 month-old seedling ready to be grafted.

6.4.3 Selecting mango scions

Characteristics of suitable scion wood

- The most suitable scion wood has swollen buds just before bursting.
- Tip wood is considered the best material to use for grafting, as it is softer and of a similar diameter to most rootstocks.
- The age of the scion wood is not critical, however un-hardened flushes should be avoided.
- The scions should have at least 3 buds and be about 10 cm long and the same diameter (size) as the rootstock.

Use good quality scions. Scions should be taken from vigorously growing, true-to-type mother trees that are of a known variety (Figure 6.14a).

Use healthy scion wood. Scion wood (or budwood) must be free from graft-transmissible diseases to ensure that healthy trees are produced. Mango malformation disease and mango sudden death can be spread by using infected scion wood.

Prepare the scion wood. After the scion wood has been cut from the tree, remove the unwanted wood and leaves, leaving a petiole stub to protect the bud (Figure 6.14b). Dip in a recommended fungicide.

Use the scion wood quickly. Scion wood should be used immediately or stored in the refrigerator (at 5°C) in a sealed and labelled plastic bag for up to 1 month (Figure 6.15). Label the bag with variety, date and a way of identifying the mother tree from which the scion wood was cut (i.e. the source tree).

Grafting time

Grafting should only be attempted when the rootstocks are vigorous and the buds on the scion wood are swollen.

Figure 6.14a Selecting scion wood from a healthy source tree.

Figure 6.14b Leaves removed from scion wood to reduce drying.

Figure 6.15 Scions wrapped in damp paper and sealed in a labelled plastic bag and stored in the refrigerator.

Best results are obtained during warm, humid weather. Grafting is most successful when day temperatures are between 25°C and 36°C, and night temperatures are between 18°C and 21°C.

In Pakistan, the two 'grafting seasons' are early spring (February to March) and the rainy season (July to August). The rainy season is ideal because it occurs after harvest, when there is plenty of scion wood available on trees. In spring, the trees are flowering, which means that less scion wood is available.

Grafting can be done at cooler times of the year if the temperature and humidity are increased by heating the nursery artificially.

Figure 6.16 Demonstrating grafting techniques.

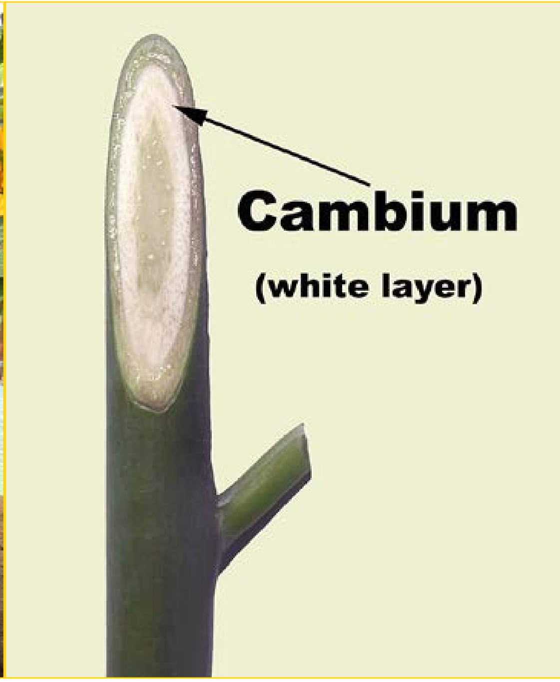


Figure 6.17 Graft healing occurs where rootstock and scion cambium are matched.

6.4.4 Mango grafting technique

In mango, the most suitable height for making a graft on the rootstock is about 20–45 cm above the potting mix or soil (Figure 6.13b).

The grafting point on the rootstock should be straight, at least as thick as a pencil, and have green bark. If the bark is old, brown or corky, the area should be avoided.

Retain at least five healthy leaves on the stem below the graft point to help the tree survive the grafting process.

To achieve a successful graft union, the cambium layers in both the rootstock and scion must be matched when the graft is wrapped.

The cambium area is where the cells are actively dividing, shown in Figure 6.17.

Graft healing only occurs in this region, and if the cambium layers are not matched on at least one side, the graft union will fail.

Several types of grafts can be used on mangoes, but the two most common are the cleft or wedge graft, and the whip-and-tongue graft.

Wedge or cleft graft

- Prepare the scion wood by making two sloping cuts at its base to form a wedge 2.5–3 cm long (depending on the width of the rootstock) (Figure 6.18a).
- Cut off the top of the rootstock at 20–40 cm above the potting mix or soil, and make a clean cut down the centre of the stem to about 3 cm deep (Figures 6.18a, 6.20a).
- Insert the scion wood wedge into the cut in the rootstock, matching the cambium layers on the rootstock and scion on at least one side, preferably both sides (Figures 6.18b, 6.19, 6.20b).
- Tie the graft firmly with grafting tape to seal the union, to stop scion movement and to prevent moisture loss (Figure 6.20c).

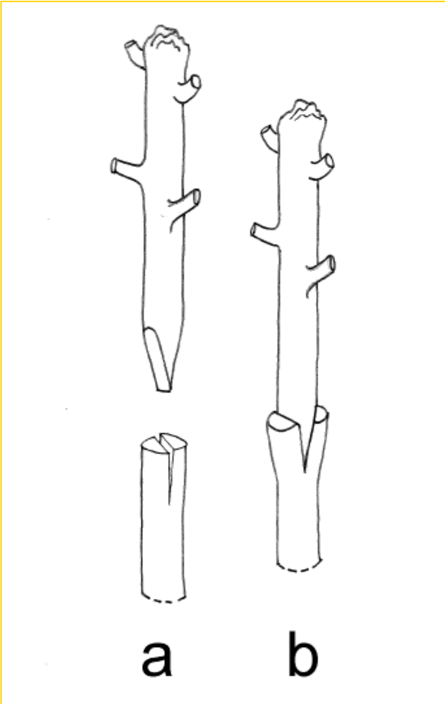


Figure 6.18 Cuts made in the scion and rootstock (a) for a wedge graft and assembled (b).

Figure 6.19 A rootstock cut to the correct height (left) and a scion 'wedge' inserted into a rootstock.

Figure 6.20a Making a cut in the rootstock.

Figure 6.20b Joining the scion and rootstock by aligning the cambium layers.

Figure 6.20c Taping the graft union.

Whip-and-tongue graft

The whip-and-tongue is slightly harder to master than the wedge graft, but it gives greater support to the graft union and a greater surface area for the union to heal (Figure 6.22).

- Make a diagonal cut (3–5 cm long) on both the rootstock and scion (Figure 6.21a).
- Make a second vertical cut, 1/3 inwards from the tip of both rootstock and scion to a depth equal to 1/3 of the original diagonal cut to make the tongue (Figure 6.21b).
- Fit the rootstock and the scion together, aligning the cambium layers (Figure 6.21c).
- Wrap the join with grafting tape to hold the union firm while it heals.

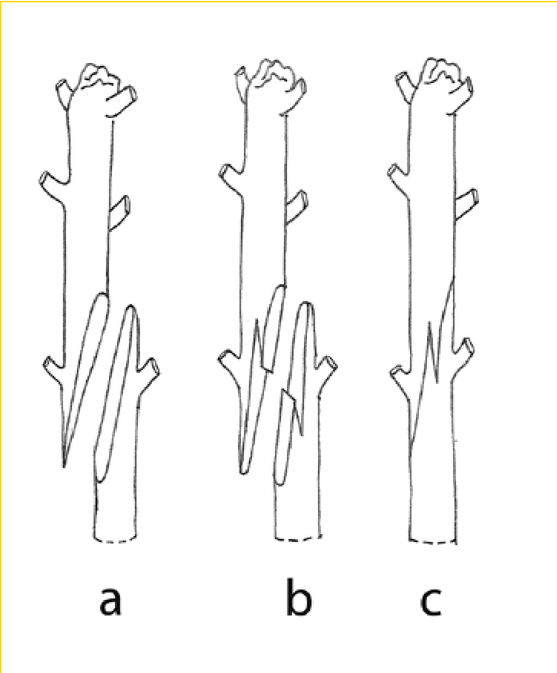


Figure 6.21 Cuts made in the scion and rootstock for a whip-and-tongue graft.

Figure 6.22 A healed whip-and-tongue graft union showing how the scion and rootstock were matched.

6.4.5 Care after grafting mango

Grafting success can be improved significantly using the following procedures.

Protect the graft. Immediately after grafting, cover the graft and scion with a plastic bag, tied just below the graft union. This helps to prevent the scion from drying out (Figure 6.23).

Protect from sun. If the grafted trees are in full sun, cover the plastic bag with a white paper bag to reduce heat stress.

Remove the protecting bags. The plastic and paper bags should be removed when 1–2 cm of new growth appears. This takes between 2 and 4 weeks.

Scion growth. After the bags have been removed, the grafted seedlings should remain in the nursery until at least two growth flushes have hardened.

Remove the tape. Remove the tape securing the graft union after the scion wood has produced two growth flushes (Figures 6.22 and 6.24). If the plastic graft tape is not removed it will strangle the developing tree. Trees should never leave the nursery with graft tape attached.

Watering. Recently grafted trees have fewer leaves and use less water. Over-watering recently grafted trees is a common problem that contributes to graft failure.

Health checks. Monitor regularly for pests and diseases. Find more information in *Chapter 9—Managing diseases, pests and weeds*.

Figure 6.23 Protecting new grafts with plastic bags prevents them from drying out.

Figure 6.24 First flush after grafting.

6.4.6 Grafting mangoes—a checklist

Propagating seeds for rootstocks

- Select healthy, clean 'stones' from well-managed trees.
- Propagate seed in the warmer months (July – August). Dry then use within 2 weeks.
- Extract the seed from the husk.
- Discard dark or damaged seed (embryos).
- Germinate seeds in trays or pots.

Selecting rootstocks

- Select actively growing, healthy trees.
- Ideal age: 6–12 months.
- Ideal diameter: pencil thickness (10–15 mm).
- Height of graft union will be 20–40 cm above the potting mix.

Selecting scion wood

- Select only true-to-type cultivars.
- Select dry, disease-free scion wood.
- Length: about 10 cm (with 3–5 viable buds).
- Shoot diameter 0.7–1.0 cm.
- Remove all leaves immediately after cutting.
- Store scions in moist paper in a labelled plastic bag in the refrigerator.

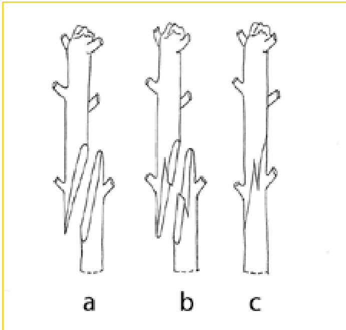
Making a wedge (cleft) graft

- Rootstock: cut the top off at 20–40 cm above the potting mix, using a sharp, clean knife; retain 5–10 leaves on the stem below the graft. Cut down the centre of the stem to about 3 cm.
- Scion: make 2 cuts to make a wedge 2.5–3 cm long.
- Insert the wedge into the rootstock, matching the cambium on at least one side.



Making a whip-and-tongue graft

- Rootstock: cut the top off at 20–40 cm above the potting mix, using a sharp, clean knife; retain 5–10 leaves on the stem below the graft. Make a diagonal cut (3–5 cm); make a second cut 1/3 inwards to make the tongue.
- Scion: make 2 cuts as for the rootstock.
- Fit the scion and rootstock together, aligning the cambium.
- Wrap the graft union with plastic grafting tape.




Protecting the graft and after-care

- Attach a clear, plastic grafting bag to make sure the graft doesn't dry out.
- Cover with 50% shade cloth; give the trees optimum water and nutrition.
- Remove any suckers that grow.
- Remove the bag and grafting tape when the graft has taken.
- Spray to deter insect pests.



Hygiene practices

Keep grafting material and equipment clean

- Keep rootstocks away from soil.
- Keep the scion wood away from the soil and other plant material.
- Work on clean, elevated benches.
- Clean all the cutting tools thoroughly.
- Disinfect the cutting tools with chlorine bleach or methylated spirits.


Personal safety and cleanliness

- Clean hands and fingernails frequently.
- If possible, use disposable gloves.
- Take care with sharp knives.


Healthy mother trees and scions

- Always select scions from healthy, labelled mother trees managed regularly for pests and diseases.
- Dip the cut scion in an appropriate fungicide for 1–2 minutes.



7 Managing advanced trees in the nursery, during transport and field planting

Looking after the advanced stock in the nursery will produce healthy trees for sale. Understanding how to transport, plant out and manage trees in the field will enable you to advise farmers how to reduce losses during transplanting in the field.

Maintaining optimum environmental conditions in the nursery (see *Chapter 2—Setting up a nursery*) will enable advanced trees to develop the healthy and strong growth required for field planting.

What to consider

- 7.1 Potting up advanced trees
- 7.2 Training the tree canopy
    - 7.2.1 Mango—training mango trees in the nursery
    - 7.2.2 Mango—training mango trees in the orchard
    - 7.2.3 Citrus—training citrus trees in the nursery
    - 7.2.4 Citrus—training citrus trees in the orchard
- 7.3 Preparing for sale and transport
    - 7.3.1 Hardening
    - 7.3.2 Transporting plants
- 7.4 Planting grafted trees in the field
    - 7.4.1 Planting
    - 7.4.2 Watering
    - 7.4.3 What to avoid

7.1 Potting up advanced trees

When trees are to be held in the nursery beyond the minimal field planting size they are considered to be advanced trees (Figure 7.1). Generally, tree growth rate is better when the roots are not disturbed and they are germinated and grown in the pots they will be sold in. Advanced nursery trees (which are larger than the usual, field-planting size) will need to be replanted into a larger pot or poly-bags to avoid restricting root growth. Advanced trees will require potting up from their 3–5 litre pots to 10–15 litre pots if they are to continue to grow without root-restriction or stunting.

When a tree outgrows the pot, its root growth and development becomes restricted (pot bound) and it is less able to take up and transport water and nutrients around the tree. In a larger pot, the larger volume of potting mix allows the roots of advanced trees to grow and develop.

Undisturbed, unrestricted growth means that the trees can also tolerate temperature extremes better, helping survival in hot weather, and they show less transplant shock when planted out in the field.

Figure 7.1a Advanced mango trees in the nursery.

Figure 7.1b Advanced citrus trees in the nursery.

7.2 Training the tree canopy

Training encourages the tree to develop a strong framework of branches, increasing the potential fruit yield. Training is done in two main stages:

- the first stage is done with advanced nursery trees that are still in the pot in the nursery
- the remaining steps are carried out over the following two years, beginning 6–8 weeks after field planting, when the first flush has hardened.

Also,

- take care with sharp pruning implements
- maintain a high level of hygiene; remove residual plant material from pruning equipment and disinfect with bleach (1.25% or 12,500 ppm sodium hypochlorite) or methylated spirits (mango only) before use, and regularly during use. Refer to *Chapter 8—Nursery hygiene*.

7.2.1 Mango—training mango trees in the nursery

Step 1. First cut

Train the trunk straight for 80–120 cm above the pot without branches. At this height, prune to encourage two to three primary branches to develop, shown in Figure 7.2 Step 1.

7.2.2 Mango—training mango trees in the orchard

After the trees have been transplanted in the field, continue the canopy training that was started in the pot with the following steps:

Step 1. First cut

If the first cut was not done in the pot, it should be done in the field after transplanting by cutting 80–120 cm above the ground, shown in Figure 7.2 Step 1. Make the cut just below a node to encourage the development of numerous shoots.

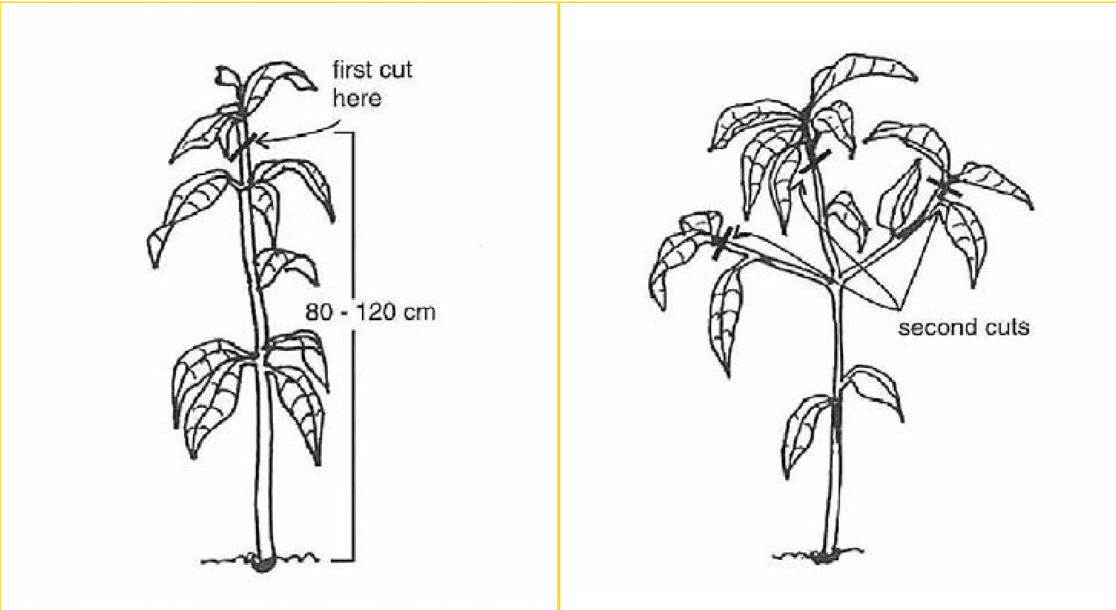


Figure 7.2 Training mango trees
Step 1—First cut Step 2—Second cut

Step 2. Second cut

After the first cut has stimulated multiple shoots (at about 90 cm), select three of these shoots to become the main branches, and remove all the other shoots.

When the selected branches have grown to about 60–80 cm (1 to 1 ½ growth flushes), cut once again, below the node area to encourage further branching, shown in Figure 7.2 Step 2.

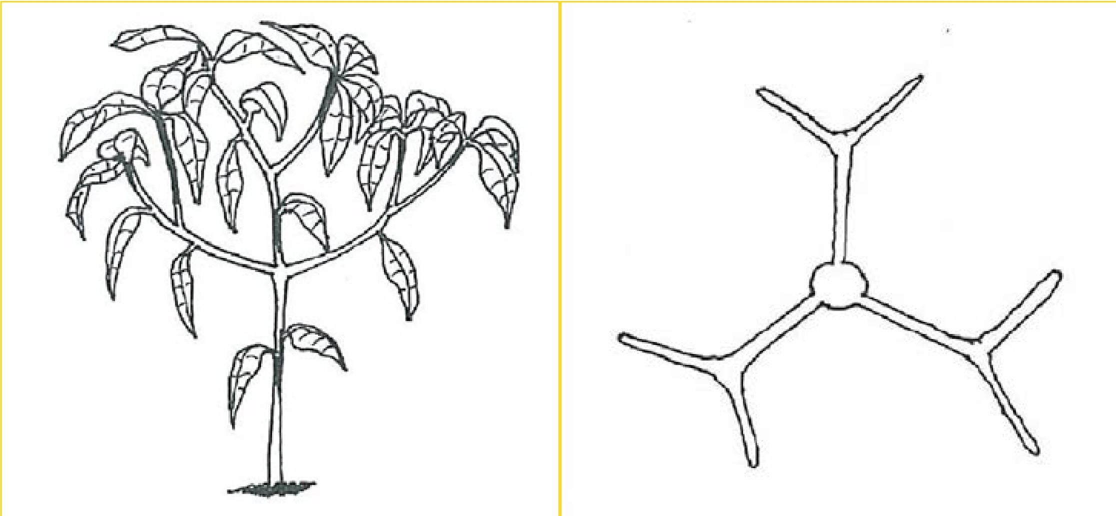


Figure 7.3 Training mango trees
Steps 3 and 4

Plan view of the pruning framework

Step 3. Third cut

New shoots will grow from the pruned side-shoots.

Select two or three of these shoots and repeat the pruning procedure from Step 2. See Figure 7.3, Step 3.

Remove all other shoots.

Step 4. Further cuts

Continue pruning in this way until you obtain the desired pruning framework or until flowering occurs, shown in Figure 7.3, Step 4 and 'Plan view of pruning framework'.

7.2.3 Citrus—training citrus trees in the nursery

Citrus trees may leave the nursery as 'whips' or 'headed trees'.

Whip trees. These are nursery trees that have had rootstock suckers removed but the scion has not been pruned and forms a single upright stem.

Headed trees. Nursery trees that have been pruned to encourage branches to develop are known as 'headed' trees. Headed nursery trees are usually older than 'whips' when they leave the nursery.

7.2.4 Citrus—training citrus trees in the orchard

Canopy management techniques can differ depending on the citrus variety grown. It is important to manage the canopy to ensure adequate light penetration and ventilation; this will maximise fruit size, quality and yield, and reduce the impact of disease.

Tree guards or trunk wraps can be used in the first two years after planting; this will limit the growth of unwanted shoots below the main canopy, and protect the trunk of young trees from sunburn, frost, grazing predators, and contact herbicides used for weed control.

Train to encourage the development of open-angled scaffold branches (30° to 45° from the horizontal plane) at different heights along the trunk.

Remove the upright branches and 'water-shoots' (shoots that form rapidly from the rootstock and compete with the parent tree for nutrients).

Ensure the lower limbs are at least 50–100 cm above the soil to manage the trees more easily, and to reduce the risk of infection from diseases like *Phytophthora* brown rot.

Remove dead wood from the canopy to reduce the impact of diseases like melanose.

7.3 Preparing for sale and transport

7.3.1 Hardening

The way container trees are handled between the nursery, the point of sale and the farm has a significant impact on their survival and long-term health. Before sale, trees should be fully sun-hardened in the pot at the nursery to avoid sunburn and transplant shock.

Hardening involves exposing the plant to regular sunlight, and reducing the frequency of watering. This must be done gradually, over a period of a few weeks, so that the plant can respond to the changing environmental conditions. During hardening, avoid putting plants directly on the ground outside, where they could experience extremely low temperatures.

The changes that take place in trees during hardening-off are described below.

- Physiological changes occur in the leaves to help them tolerate increased exposure to light.
- Plants become acclimatised to increased water stress, reduced humidity and increases in temperature that otherwise would cause leaf and bud drop. To achieve this, it is important to reduce water gradually.

7.3.2 Transporting plants

Moving trees over long distances must be planned carefully. For example, certain quarantine issues may restrict the movement of potting mix into different districts. In this case, prepare the trees according to quarantine guidelines. This may need certification.

Before transporting the trees to another location, consider how long they may go without water and the potential for temperature extremes during transport. Water availability alone would not be enough to overcome the extreme temperatures that may occur during transportation, particularly in enclosed containers.

- Water the trees thoroughly just before leaving the nursery.
- Shade the trees from excessive sunlight.
- Transport the trees at night during the summer.
- Do not allow trees to dry out during transport.
- Cover the foliage in plastic to reduce water loss by transpiration.
- Keep the trees upright.
- Do not allow potting mix to spill out of the pot and expose the roots to dry air.
- Cover up the foliage to protect it from wind damage.
- Water trees thoroughly on arrival at their destination.

7.4 Planting grafted trees in the field

Advanced trees that are to be planted out in orchards should be hardened before leaving the nursery by exposing them to full sun for two to three weeks and reducing the amount of water they are given (see above, Section 7.3.1). This will help them to cope with field conditions.

The trees should be planted out in late winter or early spring, avoiding the risk of frosts but before daytime temperatures become too high. Trees planted outside of this season have a higher risk of failure. Maintain adequate water to the field stock to avoid root death, slow establishment and plant death.

7.4.1 Planting

The trees should be watered immediately after planting; a tractor mounted water tank is highly recommended for this task. The way the planting hole is dug can affect drainage. If the hole is dug with a round, mechanical auger, it may create a barrier to water and roots (especially in clay soils) that will restrict tree growth. Roughen the sides of the hole with a crow bar to encourage water to drain away from the hole.

- The planting hole should be at least 40 x 40 cm across and 50 cm deep.
- The poly-bag or pot should be removed completely before planting (Figure 7.4a).
- Any remaining grafting tape should be removed at the time of field planting.
- The graft union must not be covered with soil. It should remain at the same level as it was in the container.
- Backfill and firm the soil around the tree to remove air pockets; water and allow to settle; complete the backfilling (Figure 7.4 b).
- Lightly mulch (to about 10 cm), but not too close to the seedling stem, to avoid attracting insects and fungal spores.
- Regular watering is needed for establishment.

Figure 7.4a Trees are easily cut away from poly-bags without damaging the roots.

Figure 7.4b Plant the tree in a hole larger than the plant roots and fill in with a shovel.

7.4.2 Watering

Watering at planting

The trees should be watered immediately after planting; a mobile water tanker is highly recommended.

- At planting, backfill and firm the soil around the tree to remove air pockets.
- Water with 5–10 litres of water. Newly-planted trees do not need a large volume of water but enough to maintain a humid environment around the roots. As little as 5 litres per tree will largely eliminate any planting stress and settle the soil around the root system. Allow the soil to settle.
- Exposed roots and over-sunken areas that show up after watering should be re-covered with soil while maintaining a slight depression around the tree.

Watering schedules after planting

Repeat watering as required for the first few weeks after planting. It is important that the roots from container-grown trees do not dry out before they have grown into the surrounding soil.

After the initial watering-in, the weather will determine when further irrigation is necessary. In hot weather this may be after 24 hours, while in mild weather the trees may not need to be watered again for a few days.

Drip irrigation is an efficient way to make sure the trees have enough water, without wasting large quantities by using a hose. Drip emitters, micro-jets or micro-sprinklers connected by a system of PVC piping is an effective way to deliver water. Each tree is watered with a single drip emitter.

Find further information in *Chapter 11—Managing water*.

7.4.3 What to avoid

Field planting is a critical stage in which poor root and tree management can easily result in tree death, or infection with diseases that limit production (Figure 7.5).

Avoid root damage. During field planting utmost care must be taken not to disturb or damage the roots of the tree when removing the pot or poly-bag and placing the tree in the hole (Figure 7.4a).

Avoid stem and graft damage. During field-planting, avoid putting stress on the stem and grafted area by rough-handling or excessive bending. This type of damage can cause grafts to fail and create entry points for diseases. If windy, support the trees by tying to a supporting stake.

Avoid poor irrigation practice. Soil- and water-borne disease can spread in water and enter tree roots and damaged tissue. Drip or under-tree sprinkler irrigation is best practice. Furrow irrigation (flood irrigation confined to channels called furrows) may be used to minimise the impact of flood irrigation but take care not to let water pond around the trunk. Where flood irrigation is used, a circular bund around the tree will prevent surface water reaching the tree trunk, while allowing water to soak into the root zone. See Figure 7.5a and *Chapter 11—Managing water*.

Avoid cultivating too close to trees. Wounds caused by machinery are major points of entry for disease microorganisms. This is a major source of infection for mango sudden death disease. Keep cultivating machinery outside the canopy drip-lines and hand-weed closer to the trees (Figure 7.5b).

Avoid planting in extreme temperatures. Avoid planting at extreme hot or cold times of the year.

Avoid post-planting stress. After planting, make sure trees are protected from pests, diseases, weeds, water stress, extreme temperatures, and saline water (i.e. with a high electrical conductivity (EC)).

Figure 7.5a Avoid poor irrigation practice.

Figure 7.5b Avoid damaging trees with machinery—wounded roots and stems create an entry point for disease to enter your trees.

8 Nursery hygiene

This section is about setting up and managing the nursery to avoid problems with diseases, pests and weeds. Preventing pests, diseases and weeds is always more cost-effective than managing them when they are established. Measures for managing diseases, pests and weeds that are introduced to the nursery are outlined in *Chapter 9—Managing diseases, pests and weeds.*

Pests, diseases and weeds can reduce productivity; good nursery hygiene can prevent them from being introduced into the nursery.

Good hygiene practice begins at the nursery planning stage and involves all the different activities carried out by staff, from establishing seedlings to managing equipment and preparing trees for distribution. The principle of nursery hygiene is to keep pests, diseases and weeds out of the nursery, use clean planting material, clean water, clean potting mix, clean equipment, clean tools and clean work surfaces.

What to consider

8.1 Setting up to avoid problems with pests, diseases and weeds

The risk of pests, diseases and weeds becoming problems can be reduced by designing the nursery appropriately. Find more information in *Chapter 2—Setting up a nursery.*

8.1.1 Locating and designing the nursery

Position the nursery away from mature trees. Do not position the nursery underneath or near mature mango or citrus trees, especially if they are known to have mango malformation or citrus canker. It is well recognised that diseases can spread to young trees from established orchards. Disease spores can travel with wind and rain over great distances. Nurseries should be positioned as far away as possible from orchards, on the up-side of prevailing winds.

Establish a cleared 'buffer' zone. A cleared area around each greenhouse or production area will create a barrier to weeds, pests and diseases. Maintain at least a 5–10 metre, weed-free buffer zone around the production area and keep it completely cleared of all plants. A sealed surface is best, but a satisfactory solution for small areas between nursery structures is to cover the ground with gravel, weed matting or mulch (Figure 8.1).

Windbreaks. If possible, establish a windbreak around the nursery to reduce the risk of pests, diseases or weeds blowing into the nursery. Make sure the windbreak doesn't shade the nursery. Choose the type of plant carefully; for example, do not use citrus or mango trees as windbreaks in nurseries growing the same crop.

Seal ground surfaces. Nursery floors, pathways and roads should be sealed wherever possible. Bitumen and concrete are better than gravel because they are easier to keep clean. They should be kept free from plants, soil and other waste. Make sure that wastewater drains away properly. See Figures 8.2, 8.3 and 8.4.

Maintain good drainage. Nursery floors, pathways and roads should have an appropriate slope so that they drain adequately to minimise algal growth or ponding (water-forming pools). See Figure 8.4. Find more information in *Chapter 11—Managing water*.

Positioning trees. Make sure that young mango and citrus trees are not grown near orchards that have high levels of disease. Raise pots above the ground to keep them away from diseases that may be carried in drainage water (Figures 8.2 and 8.3).

Figure 8.1a Nurseries positioned close to mature trees or orchards can be easily infected with diseases.

Figure 8.1b Establish a 'clear zone' around the nursery production area.

Figure 8.2 Creating a gravel barrier to soil and raising trees off the ground helps to keep trees away from potential diseases.

Figure 8.3 Trees grown in direct contact with the ground are at greater risk from pests and diseases.

Figure 8.4a Poor drainage spreads disease.

Figure 8.4b Good drainage in the nursery prevents water from pooling.

8.2 Routine hygiene practice

Good nursery hygiene optimises productivity and profitability by:

- reducing the incidence and impact of pests and diseases
- reducing new introductions of pests and diseases into the nursery.

8.2.1 Healthy stock trees

Source healthy tree stocks. Many diseases can establish before any symptoms appear. Sometimes the appearance of disease symptoms is delayed for up to several years; or the scion or rootstock variety may be infected but tolerant, without expressing symptoms. Diseases can be spread from infected trees even if the tree appears to be healthy. It is important to source budwood and rootstock seed from trees that have been tested for diseases, to avoid supplying trees to growers that are infected with incurable diseases (Figure 8.5).

Figure 8.5a This tree is not healthy enough to be used as mother stock.

Figure 8.5b Always use healthy budwood and planting material when propagating nursery trees.

Quarantine and inspect new stock. New stock trees should be segregated and monitored carefully before adding them to any established nursery stock. Remove any weeds and damaged plant parts from the pot.

Maintain regular health inspections for all nursery stock (Figure 8.6, and discussed in *Chapter 9—Managing diseases, pests and weeds*).

Keep the surrounding area clear of weeds. Weedy areas harbour pests and diseases, so mow the area surrounding the buffer zone regularly. This will keep the grass short and discourage broadleaf weeds. Knockdown herbicides should not be used routinely because chemicals can run-off, remain in the soil and affect trees.

Figure 8.6 Inspect plants for pest and diseases regularly.

8.2.2 Controlling access and activities

It is important to manage the movement of people and vehicles around the nursery. This can be done with a few simple rules.

Managing vehicles and machinery

Clean all vehicles entering the nursery site. If vehicles from off-site enter the site, they should be brushed down and pressure-cleaned before bringing them onto the nursery site (Figure 8.7) into clearly defined parking areas. If possible, make a car park available off-site so that vehicles do not enter the nursery at all. The car park should be situated so that water from the car park does not drain towards the nursery.

Keep machinery on site. Where practical, vehicles and machinery used on the site should remain permanently on the site; this will reduce any risk of introducing new pests, diseases or weed seeds.

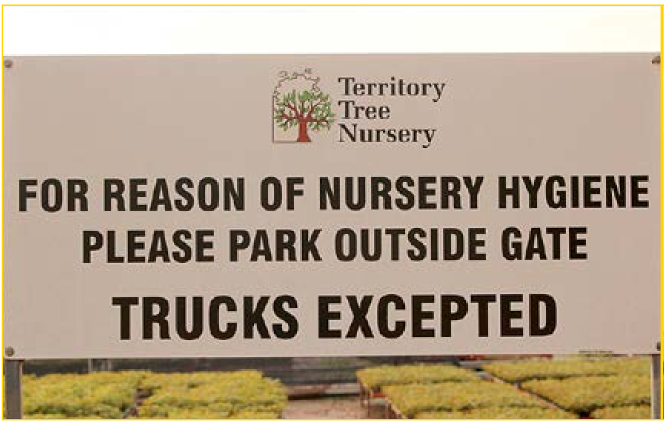


Figure 8.7a Use signs to keep traffic and people away from restricted areas.

Figure 8.7b Clean all vehicles entering the nursery site.

Managing people

Only allow essential access. Access to greenhouses and propagation facilities should be given only to essential staff and should be restricted for non-essential staff. Whenever possible do not allow visitors to enter your plant houses.

Limit walk-through. Do not allow propagation areas to be used as thoroughfares by staff or for materials that are not related to propagation.

Separate activities between clean and dirty areas. Where practical, staff members should not move from a 'dirty' area to a 'clean' area on the same day. This will reduce the risk of cross-contamination with pests and diseases. Mites, insects, microorganisms and weeds can spread on clothing and shoes. If it is necessary to return to a clean area after working in a dirty area, clean and disinfect all tools and equipment and change clothing. If footwear may have been contaminated, clean and disinfect the footwear, OR change footwear before entering a different work station.

Manage double doors. When the greenhouse has a double door entry, make sure that only one door is open at a time: do not open both doors at the same time.

Use a footbath. If possible, install and maintain a footbath at the entrance to each greenhouse so that staff and visitors can clean their footwear (Figure 8.8).

Keep hands clean. Workers should wash their hands with soap and water before and after working in a greenhouse. It is essential that nursery workers have access to hand-washing facilities. Soap, nail brush and water are sufficient, although a hand-washing biocide may be needed in some situations. The spores of several important plant diseases are easily transmitted to trees by dirty hands, particularly when pruning, which creates wound sites for the disease particles to enter (Figure 8.8).

Use gloves. If suitable washing facilities are not available, use disposable gloves and change them frequently.

Wear sensible footwear. Waterproof, non-slip footwear should be worn by all staff working in the nursery.

Keep trees off the soil. Do not work on bare dirt. Instead, work on raised benches or work on a layer of plastic that can be sterilised.

Use non-porous work surfaces. Work benches should be made from non-porous materials or covered with non-porous materials. For example, wooden benches can be covered with plastic. The benches should be cleaned or disinfected between new batches of mix or plants.

Figure 8.8 Maintain strict hygiene for staff and visitors by installing footbaths (left) and providing facilities for washing hands (right).

8.2.3 Clean work areas and equipment

Keep all the work areas and equipment as clean as possible.

Managing mess and waste

Clean up mess. It is important that a high standard of hygiene is maintained in the nursery. The staff member responsible for making a mess is responsible for cleaning up the mess (Figure 8.9a).

Sweep floors regularly. Concrete floors are particularly easy to keep clean using a pressure cleaner (Figure 8.10).

Keep greenhouse doors closed. Do not prop doors open when cleaning the floors of the greenhouses. Closed doors help to prevent pests, diseases and weed seeds from entering the nursery.

Clean up plant waste. Do not leave plant debris or discarded plants on the floor (Figure 8.9b). Plant clippings and potting mix that have spilled onto the floor of the greenhouse should be swept up and placed into garbage bins. The garbage bins should be removed from the greenhouse on the same day that the work was performed and not left in the greenhouse overnight (Figure 8.10b). Discarded plants should be taken out of the greenhouse as soon as possible.

Figure 8.9a Make sure staff clean up after spills.

Figure 8.9b Dispose of old soil and plant matter.

Figure 8.10a Keep the nursery floor and benches clean and remove leaf litter regularly.

Figure 8.10b Untidy and unhealthy plants spread diseases.

Cleaning and disinfesting equipment

Keep disinfestation methods compliant. The disinfestation methods used should comply with health regulations.

Keep equipment clean. Keep tools and pots clean and remove dirt by scrubbing before sterilising them.

Sterilise work surfaces, pots and tools. Use a chlorine (sodium hypochlorite) solution to sterilise work surfaces, tools, pots and trays. A solution of 2% sodium hypochlorite will sterilise plastic and steel surfaces in one minute. Soak pots and tools in a tub of solution, then rinse in clean, disinfected water (Figure 8.11a). Rinsing will reduce any corrosion caused by the chlorine. Allow the chlorine solution to stay on bench tops or work areas for one minute. Find more information about disinfesting potting mix in *Chapter 3—Potting mixes*.

Disinfect cutting tools. Cutting tools must be disinfected between each tree, and tools must be disinfected between batches of mix or after using them (Figure 8.11b).

Use clean water for chlorine solutions. Chlorine solutions will be more effective if they are made up with clean water that doesn't have any organic matter in it; ideally, filter the water first.

Make fresh chlorine solutions. Use a fresh solution of chlorine every few hours because it does not store well.

Choose relevant disinfectants. In mango nurseries, other disinfectants that may be used include ethanol (70%), quaternary ammonium chlorides (2,000 ppm) or heat. In citrus nurseries, the only disinfectant recommended for disinfecting cutting tools is bleach (1.25% or 12,500 ppm sodium hypochlorite solution).

Figure 8.11a Keep equipment and pots clean between uses.

Figure 8.11b Clean tools, like the secateurs shown here, before using on each new plant.

8.2.4 Storing pots and potting mix

Use clean potting mix. Using clean, disease-free potting mix is essential practice in every nursery. Discussed in *Chapter 3—Potting Mixes*.

Store potting mix in a clean, dry area. Store pasteurised potting mix away from any potential sources of contamination (Figure 8.12). Do not store potting mix on bare soil; instead, store it on clean plastic or a cement floor. Plastic bins make good storage containers for small amounts of pasteurised potting mix. It is best not to store potting mix outside, or anywhere exposed to wind, rain or surface water, or near waste material.

Store potting mix away from water. Do not allow stored potting mix to be contaminated by the run-off water from rain or irrigation.

Pasteurise potting mix again before re-using it. If the potting mix is re-used, it must be pasteurised again using either steam or solar heat.

Store pots in a clean area. Store sterilised pots and tools away from dirt and organic matter. If there is nowhere to store sterile pots, then sterilise just before they are used.

Figure 8.12 Store pots in a clean and dry environment (right).

8.2.5 Clean water

All the water used for irrigation, cleaning and cooling should be clean and not contain disease-causing particles. The water supply may need to be filtered or treated for pH and diseases, depending on the source (Figure 8.13).

Treating and testing water. Water obtained directly from the mains, deep bores or clean rainwater catchments may not need to be treated. If there is any chance that the irrigation water could be contaminated by water-borne disease organisms (either at the source or during storage), it should be treated in a holding tank by either:

- filtering through sand (e.g. slow flow sand filtration)
- adding chlorine
- ultra-violet radiation.

Find more information about using clean water in *Chapter 11—Managing water*.

Figure 8.13a Stagnant, dirty water can harbour disease.

Figure 8.13b Clean water can be pumped from deep wells.

8.2.6 Managing waste

Plant clippings and mix that have spilled onto the floor of the greenhouse should be swept up and placed into garbage bins. The garbage bins should be removed from the greenhouse on the same day that the work was performed and not left in the greenhouse overnight.

Discarded plants should be taken out of the greenhouse as soon as possible (Figure 8.14).

Figure 8.14 Dispose of all nursery waste properly, so that it can be removed from the nursery.

9 Managing diseases, pests and weeds

Keeping pests, diseases and weeds under control is essential for running a successful plant nursery. Allowing any of these to get out of control could result in reduced profits or a failed nursery.

Regular plant checks, including root examinations, will give early warning of any problems and enable early action. This combination of regular checks, early action and preventative hygiene measures (described in *Chapter 8—Nursery hygiene*) will assist the nursery to produce healthy citrus or mango trees to establish new orchards. Regular monitoring and control in the nursery will ensure that trees remain healthy up to the point of sale.

What to consider

9.1 About pests, diseases and weeds

Fungi are often associated with plants; some cause disease (pathogenic), others survive on dead or dying organic matter (saprophytic), and some are a combination of the two. Most disease-causing fungi live in dead organic matter as part of their life cycle, although some can only survive in a living host plant (e.g. powdery mildew and rusts). Other important causal agents of plant diseases in nurseries are bacteria, phytoplasmas, viruses and viroids.

Insects, mites and nematodes can affect plants in different ways: some cause plant damage (pests) and others have a protective function (beneficials). Knowledge of plant protection is therefore essential when making decisions about managing pests and diseases in the nursery.

Many weeds are hosts to pests and diseases that affect mango, citrus and other nursery plants, so it is essential to manage them correctly.

Even if a pest, disease or weed infestation does not appear to cause a major problem in the nursery, supplying a nursery tree that is infected with a disease or infested with a pest or weed seeds can lead to major problems in the orchard that can also spread to nearby orchards.

9.1.1 How pests and diseases become established in nurseries

Pests and disease micro-organisms may come from a number of different sources within the nursery, as well as elsewhere on the farm, or outside the farm.

Disease microorganisms can be introduced into nurseries by wind and water (run-off, wind-driven rain and in water used for irrigation, cleaning and cooling); on infected plant material (seeds, cuttings, budwood, other plants including weeds and plant waste); in infested soil or potting mix ingredients; on contaminated tools, equipment, clothes and vehicles, and by vectors such as insects. Other chapters in this manual provide some guidance for minimising the introduction of pests and diseases into nurseries, in particular: *Chapter 2—Setting up a nursery*, *Chapter 3—Potting Mixes*, *Chapter 8—Nursery Hygiene*, and *Chapter 11—Managing water.*

Figure 9.1 Citrus canker.

Figure 9.2 Mango malformation.

Some mango and citrus diseases can be symptomless (asymptomatic): either the appearance of symptoms is delayed for time periods of up to several years; or the scion or rootstock variety may be tolerant of a disease and infected at very low levels without expressing symptoms. Diseases can be spread from infected trees, even if the tree appears to be healthy. It is important to source budwood and rootstock seed from trees that have been tested and declared disease-free. If this process is followed, plants provided to growers will be healthy and free from incurable diseases.

Many common pests can fly or crawl into nurseries, or they might be carried in by wind or air currents. Like diseases, many pests can also enter nurseries on infested plant material, weeds, plant waste and potting mix or on contaminated tools, equipment, clothes and vehicles.

Weed seeds may be blown in on air currents or enter the nursery in infested soil, potting mix ingredients, plant waste or on contaminated equipment or clothes, particularly on shoes.

9.2 Integrated Pest Management—IPM

IPM is a strategy that uses several, combined methods to manage pests, diseases and weeds. It is a whole-of-nursery system for managing the health of plants and includes routine hygiene practices (see *Chapter 8—Nursery hygiene*), regular monitoring, identifying specific problems early, making targeted decisions and responding with either chemical or non-chemical treatments (Figure 9.3).

Compared with a nursery that only responds to major outbreaks, the net results of IPM are reduced impacts of pests, diseases and weeds, fewer disruptions and reduced costs in running the nursery.

A good IPM strategy uses several preventative and treatment measures that minimise the need to use chemical sprays. The non-chemical methods for managing pests are known as 'cultural' management practices.

The principle of IPM is to reduce the use of chemicals to a minimum as there are many problems associated with using chemical sprays in the nursery. As well as being toxic to people if not managed well, over-use can cause phytotoxicity in the plants, destroy natural control methods (such as beneficial insect predators or beneficial microorganisms) or even build resistance in the pests or diseases you are trying to manage.

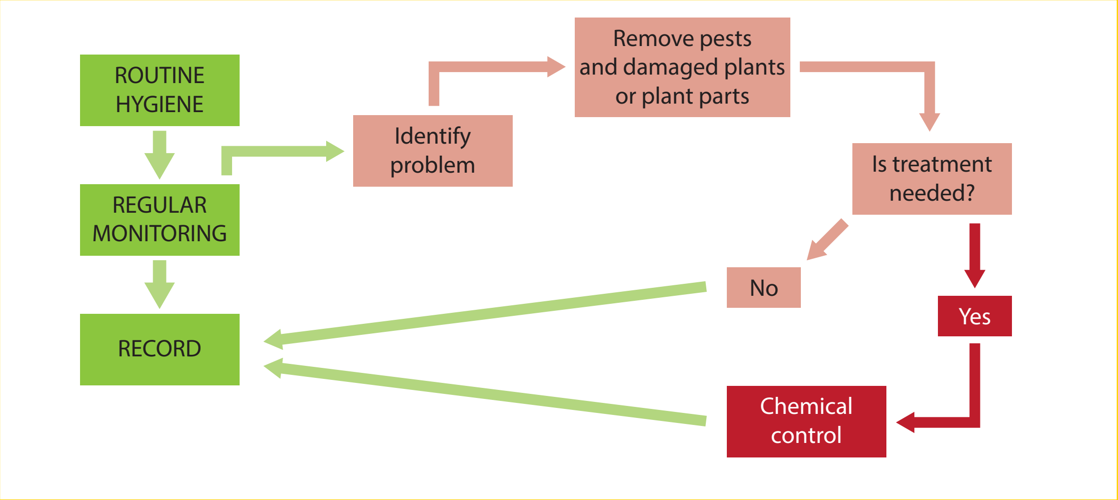


Figure 9.3 Preventative and treatment actions for integrated pest and disease management.

9.3 Managing pests, diseases and weeds

Successful pest and disease management is achieved by always following these general principles:

- Preventative action
  - use healthy plants
  - raise plants in healthy growing conditions
  - practice routine hygiene
  - monitor regularly
  - identify problems early
- Control action
  - use non-chemical methods first
  - use correct chemicals safely—follow 'Handling chemicals—protocols'.

These steps are described below and then summarised in a Checklist (Section 9.3.3).

9.3.1 Preventative action

Use healthy plants

Examine all new seed, scion wood and plants entering the nursery. Pests and diseases should be prevented from entering the nursery in the first place. It is important to examine plants (leaves, stems and roots) to check their health status as they enter the nursery. Some plant material may be infected but not showing symptoms (asymptomatic) and this risk is reduced by sourcing plants from a reliable supplier. Use seed or nursery stock that has been tested for diseases or that was taken from source trees already tested for diseases.

Quarantine new plant material, temporarily. Always segregate new plant material from other nursery plants for a period of time; this enables you to check that it is not infected with a disease or infested with a pest. It is important to check roots as well as above-ground symptoms, as root rots are a serious threat in any nursery. It is essential that you remove all infected plants and obtain an accurate diagnosis to help manage the disease in future.

Use healthy trees to source propagation material. Trees used as a source of seed and budwood or scion wood must be disease-free, kept in an insect-proof screen house and monitored continuously to maintain their clean status. A diligent nurseryman will keep an eye out for any unusual plant symptoms that may arise.

Use disease-resistant cultivars. Growing disease-resistant cultivars wherever possible will reduce the risk of diseases becoming established in the nursery. For example, some citrus rootstocks like *Citrus trifoliata* and citrange types are resistant or tolerant to Phytophthora root rots and nematodes.

Healthy growing conditions

If plants are given optimal growing conditions they are more likely to resist pests and diseases. Make sure the plants are given suitable light conditions and adequate ventilation, clean and well-draining potting mix and clean water, avoiding overhead and hand-held watering where possible. Keep the plants well away from soil, which may harbour diseases. Chapter 2 describes ways to set up the nursery to minimise pests and diseases and provide healthy growing conditions. Chapters 3 and 11 describe ways to make sure potting mix and water are clean.

Routine hygiene practice

Hygiene practices. Routine hygiene practice is the key to preventing or minimising disease in the nursery, and is covered in detail in *Chapter 8—Nursery hygiene*. Maintain a high level of cleanliness in all processes in the nursery and provide clean water (for irrigation, cooling and cleaning), potting mixes, tools, equipment, pots, work surfaces and planting material. Provide clean, separate storage areas for clean pots, potting mix and fertilisers.

Control weeds. Weeds can harbor diseases and pests. If diseases and pests inhabit weeds around your growing area, they could colonise your nursery plants.

All working areas in the nursery, including propagation and production areas, must be kept free from weeds. Ensure potting mix components supplied to the nursery do not contain weed seeds. Areas used for storing and preparing potting mix must be kept free of weeds and weed propagules (parts of plants that become detached and can grow into a new plant e.g. seeds, corms, tubers and runners).

Staff expertise. Staff responsible for managing pests and diseases should understand the principles of IPM and be trained to: diagnose and control pests and diseases; conduct routine plant hygiene practices; and use plant protection chemicals safely.

Monitor regularly

Actively monitor for signs of pests, diseases and weeds at least every week and more often where possible.

Monitoring for diseases. Look for any symptoms of disease on stems, leaves and roots. Checking the roots of a random sample of plants is an important part of the monitoring process, particularly at the point of sale. The nursery should not sell any plants with rotten roots. Return new stock plants with rotten roots to the supplier.

Monitoring for pests. Check plants for visible symptoms of pest infestation, either pest presence or damage caused by pests. Collect insects by hanging sticky traps in the nursery or by shaking the plants to collect any pests in the plant canopy. Hold a plastic tray in one hand and shake or beat the foliage over the tray with the other hand. The contents of the tray or traps will help determine the relative populations of beneficial and pest insects and mites that are present. Group the collected insects into categories, so that immature and adult stages can be identified for both the pests and beneficials.

Keep records of monitoring. Keep detailed records of monitoring activities for pests, diseases and weeds and record the outcomes. Accurate records will help to diagnose disease or identify target organisms correctly in the future, without unnecessary use of chemicals that may cause significant damage to the plants.

Identify problems

Look out for the tell-tale symptoms of known target pests and diseases. Remove the insects or plant parts with the disease symptoms and identify them, using Government or University laboratories or extension leaflets.

Target pests and diseases include:

Citrus diseases and pests

- diseases—huanglongbing, citrus canker, citrus scab, citrus viruses and viroids
- pests—Asian citrus psyllid, citrus leaf miner, mites, scale, mealy bugs and aphids

Mango diseases and pests

- diseases—mango malformation disease, mango sudden death disease and bacterial black spot
- pests—mites, scale, mealy bugs, and aphids.

Descriptions and photographs of the symptoms and effects of these important pests and diseases are given in the factsheets at the end of this chapter (Section 9.5).

Ants

Ants can spread diseases and pests from plant to plant in the nursery and may reduce root health if they invade plant pots. It is important to control ants in routine nursery hygiene checks.

Root health

Root rots develop in nursery trees when root systems are exposed to waterlogged environments where there is not enough air for roots to respire and grow (anaerobic conditions). This can happen if pots are over-watered, if the potting mix does not drain well or if water pools around the base of pots for long periods. The affected roots (especially feeder roots) turn black and break down. The diseased roots are no longer able to supply enough water or nutrients so the plant canopy then turns yellow, wilts and dies back.

Avoid root rots by setting up a well-drained nursery site, treating irrigation water before watering plants, creating a barrier between the bottom of the container and the soil (such as gravel and weed mat) and not leaving hose nozzles lying on the ground. Citrus scions can also be grafted onto Phytophthora-resistant or tolerant rootstocks like *Citrus trifoliata,* citrange types or Swingle citrumelo to avoid issues with Phytophthora root rot.

Plant parasitic nematodes are microscopic worms that feed on plant roots. Pest nematode species may be a problem for field nurseries where seedlings are grown in the soil. Problems can occur in container nurseries if infected plant materials or potting mix ingredients are introduced into the nursery. Signs of nematode injury include root galls, excessive root branching and stunted root systems. Avoid nematode problems in container nurseries by using pasteurised potting mix and creating a barrier between the bottom of the container and the soil. Citrus scions may also be grafted onto nematode-tolerant rootstocks like *Citrus trifoliata* and citrange types.

Insect pests such as ants and mealy bugs can invade pots and reduce root health. Ants will develop nests in pots and are known to move scale and mealy bugs on to new plants. Controlling these pests is difficult without first controlling ants in the nursery. Mealy bug infestation is common in potting mix. These infestations become a source for re-infestation in the nursery after other control measures have been taken because they are hidden in the potting mix and protected from insecticide sprays. It is advisable to check pots for insect pests so that infestations can be managed before they become widespread in the nursery.

9.3.2 Control action

Effective control may include either or both non-chemical and chemical actions.

Control without chemicals

- introduce only healthy plants and propagation materials
- maintain healthy growing conditions
- maintain all routine hygiene practices
- monitor regularly and identify problems early
- remove pests, weeds and diseased plants

Control with chemicals

- conduct 'preventative spraying' over a large area only when needed
- when practical, 'target-spray' only plants with symptoms
- minimise drift and contamination
- keep detailed records
- handle chemicals correctly and wear protective equipment
- always follow the guidelines in *Handling chemicals—protocols*

Non-chemical actions

Prompt removal or disinfestation of contaminated plants and other materials can reduce the incidence of plant disease. Remove the damaged or diseased plants or plant parts as cleanly as possible so that diseases aren't spread between the plants. Remove weeds manually. Keep the site free of any materials that are potentially contaminated, including plants, potting mix and crop residues. Many plant protection chemicals cannot achieve this level of reduction.

Chemical actions

If chemical actions are necessary, use the correct fungicide or pesticide spray. It is very important to wear personal protective equipment when using chemicals and always follow the guidelines in Section 9.4 below: *Handling chemicals—protocols*.

Drift and contamination. The method, equipment and chemicals used must all be chosen carefully to minimise drift and contamination. Consider how to reduce the risk of agricultural chemicals escaping from the production site so that the impact on people, animals and the environment is minimal.

Targeted spraying. In some situations, it may be practical to only spray the plants with disease symptoms or pests and not the unaffected plants. The spread of disease from a localised outbreak can be contained by targeted spraying (spot-spraying) with a fungicide that has post-infection activity. Treating a confined area rather the entire nursery can save time and costs. It is important to observe strict guidelines when using chemicals.

Preventative spraying. Often it is necessary to spray the entire plant house or nursery as pests may not be picked up through general monitoring. For example, eggs may not have hatched or pests may be hiding in buds. Another example is when protectant fungicides are sprayed to prevent disease, although it is important to note that protectant fungicides only protect the tissue on which they are applied, and further plant growth will leave fresh tissue exposed and vulnerable to attack.

Keep detailed records. Maintain complete records of the:

- chemicals used
- application rates
- application dates
- approximate volumes (or weights) applied
- section of the nursery sprayed and which plants were treated:
  - name of the spray operator
  - application equipment used
  - safety equipment worn
  - treatment results, including damage.

Remove contaminated materials

Prompt removal or disinfestation of contaminated plants and other materials can reduce the chance of spreading the problem. Many plant protection chemicals cannot achieve 100% control, so it is recommended that problem plants or materials are removed to keep the site free of anything that is potentially contaminated, including plants, potting mix and crop residues.

9.3.3 Checklist for integrated pest and disease management in the nursery

Preventative action see section 9.3.1	**Action helps control:** pests	diseases	weeds
Healthy plants			
▶ examine new plants	✓	✓	
▶ segregate new plants	✓	✓	
▶ use healthy trees to source propagation material	✓	✓	
▶ use disease-resistant cultivars where available	✓	✓	
Healthy growing conditions—see also Chapters 2, 3, 8 and 11			
▶ suitable light	✓	✓	
▶ clean, well-drained potting mix	✓	✓	
▶ clean water	✓	✓	
▶ adequate ventilation around plants	✓	✓	
▶ keep plants away from soil	✓	✓	
Routine hygiene practice—see also Chapters 2, 3, 8, and 11			
▶ restrict access to essential vehicles and staff	✓	✓	✓
▶ clean vehicles entering the site	✓	✓	✓
▶ manage hygiene for all activities:			
– clean hands, footwear	✓	✓	✓
– clean work surfaces	✓	✓	✓
– clean equipment	✓	✓	✓
– clean, separate storage for pots	✓	✓	✓
– clean, separate storage for potting mix and fertiliser	✓	✓	✓
– clean up mess, waste	✓	✓	✓
– use clean water for all activities	✓	✓	✓
Monitoring as regular practice			
▶ monitor weekly (minimum)	✓	✓	✓
▶ look out for symptoms of known, target pests and diseases	✓	✓	✓
▶ check all plant parts including roots for disease and insects	✓	✓	✓
▶ check for weeds in or around the nursery	✓	✓	✓
▶ keep records of the monitoring program	✓	✓	✓
Identify problems			
▶ remove plants or plant parts with disease symptoms and have them identified*		✓	
▶ collect known insect pests or unknown insects or mites and have them identified*	✓		
*use Government or University laboratories or extension leaflets			
Control action see section 9.3.2			
▶ hygienically remove the damaged or diseased parts of plants	✓	✓	
▶ remove all weeds from pots and the ground in and around the plant houses			✓
▶ when necessary, use the correct fungicide or pesticide chemicals, following all safety and recommended protocols**	✓	✓	
▶ keep detailed records of all control measures	✓	✓	✓
**follow the recommendations in *Handling chemicals protocols*			

9.4 Handling chemicals—protocols

Chemicals handled in the nursery may include pesticides, fungicides, herbicides and fertilisers. Although we advise the minimal use of pesticides, detailed protocols must be followed whenever chemicals are stored in the nursery.

Equipment

Calibrate spray equipment regularly and keep it in good working order. Keep records of equipment calibration and maintenance. Staff operating the equipment must have access to adequate measuring devices and safety equipment, and know how to use them properly.

Storing chemicals

Pesticides, fungicides, herbicides and fertilisers should be stored in a locked, fire-proof cabinet. Only trained personnel should be allowed access.

Safety Data Sheets (SDS)

The SDS (previously known as Material Safety Data Sheet MSDS, shown in Figure 9.4) describes the chemical's properties, use, supplier and hazard rating. Ask for a Safety Data Sheet when ordering chemicals or download the current version from a chemical safety website. SDSs should be kept together and be accessible to everyone who uses the chemicals. All users should read the SDS and the label on each product.

Risk assessment

It is important to prepare a risk assessment, also known as a *Safe Work Method Statement*. The recommended six steps enable you to identify and manage any problems that could arise while using chemicals. The six steps are: identify the hazard; identify the risk; assess the risk; control the risk; document the process; monitor and review.

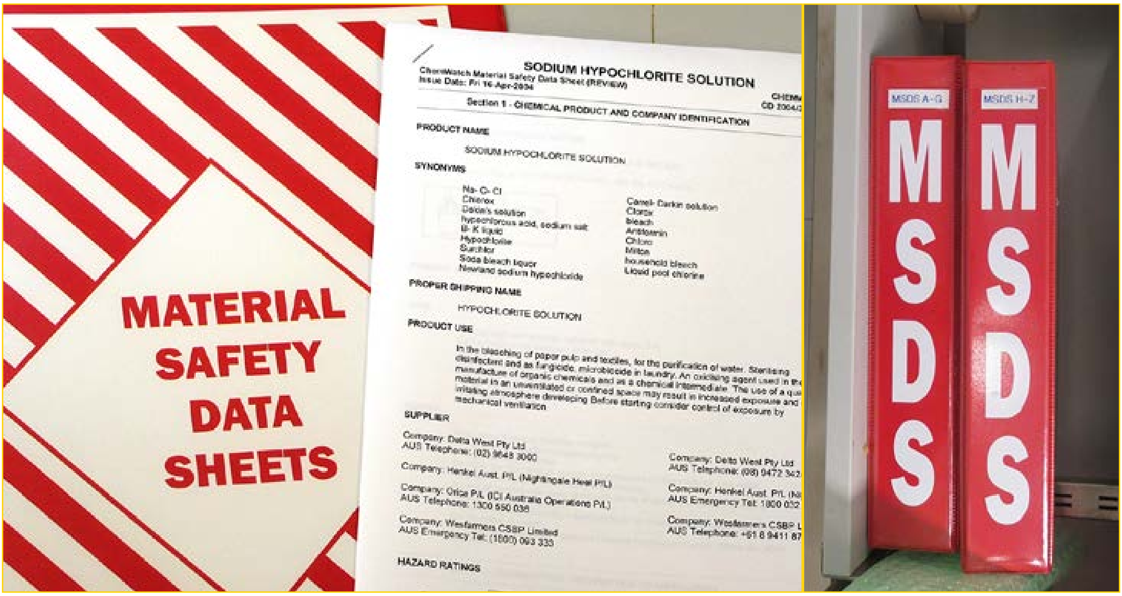


Figure 9.4 SDS—Safety Data Sheets describe chemical properties, use, supplier and hazard rating—previously known as MSDS.

Safe Work Method Statement

Prepare a risk assessment with 6 steps:

1. identify the hazard
2. identify the risk
3. assess the risk
4. control the risk
5. document the process
6. monitor and review.

Hazards and risks associated with using chemicals

The potential risks to workers include: mistakes in mixing and preparation, spills, aerosol droplets when spraying, skin or nasal exposure, poisoning, toxic levels applied to plants, chemical residues on clothing and apparatus, sprayed areas and sprayed plants.

Measures to control the risk

Mixing chemicals. Chemicals should be mixed in a designated area, ideally where there is a concrete catchment area to contain any spills. Undiluted chemicals are at their strongest and most dangerous. When mixing chemicals, always:

- use gloves and other *Personal Protective Equipment* (*PPE*, shown in Figure 9.5a), which should be described in the risk assessment
- consult an up-to-date compatibility chart before mixing more than one chemical in the same spray solution.

Spray equipment. Sprays may be applied using either:

- a sprayer attached to a hand-held or back-pack style tank, shown in Figure 9.5a
- a sprayer attached to a tank mounted on a hand-pushed trolley
- a tractor-mounted sprayer with a large tank.

PPE—personal protective equipment

- fully protective spray suit and eye and head-cover
- breathing apparatus fitted with a filter
- protective gloves and footwear.

Figure 9.5a Correct protection when spraying.

Figure 9.5b Inadequate protection when using chemical sprays.

Spraying. Spraying practice **must** follow these protocols:

1. The volume of spray needed will depend on the number of plants, their size and volume of foliage.
2. Sprays should only be applied by trained personnel wearing appropriate personal protective equipment (PPE).
3. After spraying, the operator should wash off any residues before leaving the nursery site.
4. After each use, rinse the spraying equipment with soap and water in the concrete catchment area.

Entering safely after spraying. Place a sign at the entry to the sprayed area that states the date and time it is safe to re-enter (an example is shown in Figure 9.6). This information is available on the chemical packet and the SDS.

Generally, it is recommended that the sprayed plant house is not entered for 24 hours after it has been sprayed, although for some chemicals a longer period is recommended before re-entry.

Check the SDS and chemical label to determine the appropriate re-entry period. Wear appropriate PPE as described in the SDS.

Handling plants safely after spraying. Check the SDS, risk assessment and the sign at the entry to the sprayed plant house to determine when it is safe to handle plants that have been sprayed recently. It is advisable to wear rubber gloves while handling recently-sprayed plants, even if it is not specifically recommended on the SDS for the specific chemical that was applied.

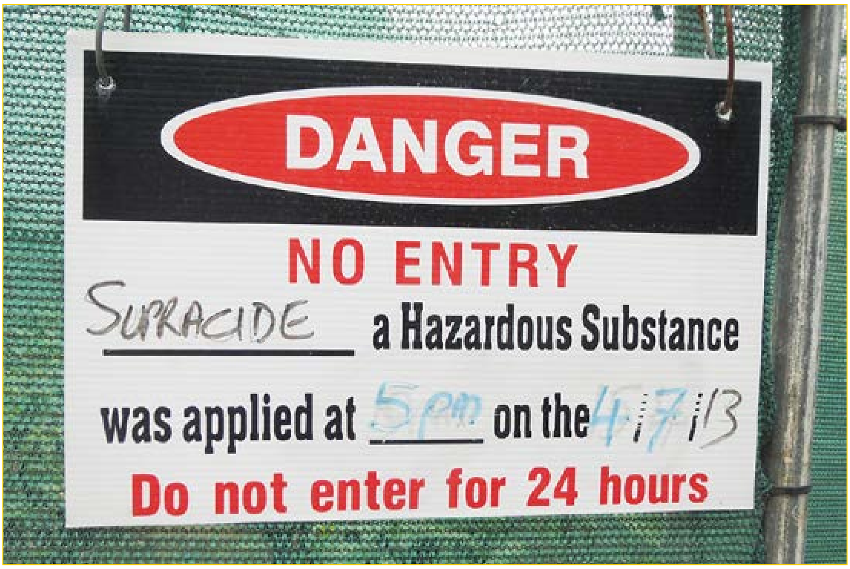


Figure 9.6 Example of an acceptable sign, advising of danger following spraying.

Disposing of chemicals. Waste or excess chemicals should be bagged, tagged and placed in a designated area ready to be collected and disposed of safely.

Chemical spills. Use spill kits to contain any spills that occur when chemicals are being mixed, or transported around the nursery site, or during spraying. Contain large spills with soil transported with a front-end loader. Try to contain all spills or leaks.

Method for cleaning spills

- use personal protective equipment, including gloves, mask, apron and eye shield
- wipe up any solid or excess material
- if the spill is on a hard surface, clean it with an industrial detergent
- dry the surface and dispose of paper products
- clean any mops or buckets that were used.

Chemical poisoning. In the event of chemical poisoning, seek the help of your nearest First Aid Officer and call an ambulance if required.

Spill kits:

- a container for detergent mix and some detergent
- rubber gloves
- face and eye protection
- a plastic apron
- paper towels (high absorbency)
- scrapers (two sheets of cardboard)
- a biohazard bag and hazard sign
- absorbent material (granules) for soaking up spills.

9.5 Target diseases and pests—factsheets

The following factsheets describe the causes and symptoms of important pests and diseases and how to manage them in the nursery.

9.5.1 Citrus diseases

A.	Huanglongbing (HLB)	Figure 9.7 a, b, c
B.	Citrus canker	Figure 9.8 a, b, c, d
C.	Citrus scab	Figure 9.9 a, b, c, d
D.	Citrus viruses and viroids	Figure 9.10 a, b, c, d

9.5.2 Citrus pests

A.	Asian citrus psyllid (ACP)	Figure 9.11 a, b, c, d
B.	Citrus leaf miner	Figure 9.12 a, b

9.5.3 Mango diseases

A.	Mango malformation	Figure 9.13 a, b, c
B.	Mango sudden death	Figure 9.14 a, b, c, d
C.	Bacterial black spot	Figure 9.15 a, b, c, d

9.5.4 Citrus and mango pests

A.	Mealy bugs	Figure 9.16 a, b, c
B.	Mites	Figure 9.17 a, b, c
C.	Scale	Figure 9.18 a, b, c, d
D.	Aphids	Figure 9.19

Huanglongbing (HLB)

Cause

HLB is the most destructive disease of citrus in the world. It is associated with a bacterium that infects *Citrus* species and other members of the Rutaceous plant family, including *Murraya* species. A number of '*Candidatus* Liberibacter species' have been reported in *Citrus*. '*Ca*. L. asiaticus' is associated with HLB in Pakistan.

HLB can be spread by grafting, layering, by parasitic plant species or by insect hosts as they feed on the new leaf flush. In Pakistan, the Asian citrus psyllid (*Diaphorina citri*) is associated with transmitting the Asian form of HLB.

Symptoms

The best diagnostic symptom is an uneven (asymmetric) blotchy mottle on leaves where the pattern of yellow and green is different on either side of the midrib. There may also be yellowing (chlorosis) across the leaf with no green, green islands or chlorotic patterns resembling nutrient deficiency (e.g. zinc). Vein corking may also be seen, where the veins thicken and turn brown.

Infected young trees fail to reach production, so it is critical that orchards are established using healthy, disease-free trees. Infected nursery trees planted into an orchard as 'replants' will introduce the disease and place the whole orchard at risk. Mature trees that are infected with HLB also become non-productive.

Manage in the nursery

Use healthy HLB-free propagation material to produce nursery trees.

Trained staff should detect infection or vector populations early.

Remove and burn diseased trees; use chemical or biological control methods to manage the insect host.

Figure 9.7a Tree decline and dieback.

Figure 9.7b Symptoms of HLB-induced zinc deficiency.

Figure 9.7c Uneven, blotchy mottle.

9.5.1—Citrus diseases: Factsheet B

Citrus canker

Cause

Citrus canker is a serious disease caused by the bacterium *Xanthomonas citri* subsp. *citri*. The bacteria enter the plant through stomata or wounds caused by thorns, insects or wind-blown sand. The disease can affect most species of *Citrus*, although there are differences in susceptibility between varieties.

The disease is spread over short distances by water-splash from wind-driven rain or overhead irrigation (including hand watering). It is spread over long distances by large storms or when transporting infected plant material or equipment.

Symptoms

Canker lesions form on leaves, stems and fruit. The young lesions start as tan-coloured pinpoint spots and become raised as they develop; they appear first on the underside of leaves and then on the top surface. Older lesions are brown or grey, corky and crater-like with a raised margin and sunken centre. Lesions generally have a dark water-soaked margin and a yellow halo surrounding the canker. Symptoms can be exacerbated by the feeding activity of citrus leaf miner.

When infected trees are planted in the orchard, problems with canker will be significant. Severe infection causes leaf- and fruit-drop and tree decline. Internal fruit quality is not affected but fruit showing symptoms are less marketable as fresh fruit.

Manage in the nursery

Reduce spread by planting windbreaks; controlling leaf miner populations and removing heavily infected trees. Copper sprays may be used to protect young leaves against infection but this protection is lost as the leaf grows and new tissue is exposed.

Figure 9.8a Leaf spots (lesions): raised, corky centre and yellow halo.

Figure 9.8b Lesions appear on both sides of the leaf.

Figure 9.8c Lesions as distinct spots (right) and following leaf miner tracks (left).

Figure 9.8d Raised lesions on a stem without a halo. Wind-rub areas may be points of entry.

Citrus scab

Cause

Citrus scab is caused by species of the *Elsinoe* fungus.

The disease is spread short distances by wind and splashing water (rain or over-head irrigation, including hand watering). Scab can spread long distances in infected plant material.

Symptoms

Scab lesions are raised, irregular and wart-like on leaves, twigs and fruit. Lesions are grey to pink and darken over time. Leaf lesions are corky on one side of the leaf with a matching depression on the other side, and often cause distorted growth.

Rootstock seedlings with scab infections are unsuitable for budding.

Manage in the nursery

Remove infected trees and apply fungicide.

Use different fungicides on separate spraying occasions so that single chemicals are not over-used in the nursery. This gives the best chance for controlling the fungus.

Figure 9.9a Scab symptoms on the underside of a leaf.

Figure 9.9b Scab symptoms on leaves.

Figure 9.9c Scab symptoms on stem and leaves showing distorted new growth.

Figure 9.9d Typical scab lesions on a citrus fruit.

Citrus viruses and viroids

Cause

Graft-transmissible citrus viruses and viroids are a serious economic threat to citrus production. Symptoms may be delayed and therefore they may not appear in trees until after they have left the nursery. Viruses and viroids can also be symptomless in certain citrus varieties, but disease can be spread from infected, symptomless trees to trees of susceptible varieties.

Examples of graft-transmissible diseases that affect citrus include citrus psorosis virus, citrus tristeza virus (CTV), citrus leaf blotch virus, citrus exocortis viroid (CEV) and citrus cachexia viroid.

Diseases can be spread in infected propagation material, on infected cutting tools and during root-grafting between trees in the field. Some graft-transmissible diseases can also be spread by vectors (e.g. citrus tristeza virus). Citrus leaf blotch virus is also seed-transmissible.

Symptoms

Graft-transmissible diseases can cause severe stunting in trees, reduced yield, tree decline, and in some cases, death.

Other specific symptoms include stem-pitting, gum pockets and bark-scaling.

Manage in the nursery

There is no cure for graft-transmissible diseases but they can be managed by preventing them from being introduced to plants.

Use disease-free budwood and rootstock seed; disinfect all cutting tools in bleach (1.25% sodium hypochlorite) and remove infected trees from the nursery.

Do not collect budwood from any suspect trees.

Figure 9.10a Nursery tree infected with citrus tristeza virus (CTV) causing quick decline (left) and a healthy tree (right).

Figure 9.10b Stem-pitting symptoms caused by citrus tristeza virus (CTV).

Figure 9.10c Citrus exocortis viroid (CEV) causing dwarfing in the foreground tree.

Figure 9.10d Citrus exocortis viroid (CEV) causing bark scaling.

Asian citrus psyllid (ACP)

Cause

ACP (*Diaphorina citri*) is associated with transmitting the deadly bacterial disease huanglongbing. It is a sap-sucking insect that also causes curling, notching and distortion in foliage, sometimes leading to leaf fall and shoot death. ACP hosts include all commercial citrus varieties and some non-citrus members of the Rutaceae family (including *Murraya* species).

Psyllids can fly short distances and be carried on winds, including storms and cyclones. They are spread long distances on infested plant material and 'hitch hike' on plant varieties other than their known Rutaceae hosts.

Symptoms

Adult psyllids are 3–4 mm long with a mottled brown body and light brown head. Their fore-wings are mottled with a brown band around the edge of the wings. The eggs are yellow and often found on buds, the tips of new flush or in the folds of new leaves. Nymphs (juveniles) are yellowish orange and can produce white, waxy secretions. When they feed, adult psyllids sit at a 45° angle on the leaf with their heads down.

Manage in the nursery

Trees in the nursery should be regularly monitored for psyllid infestation, particularly during periods of flush growth. There is no cure for huanglongbing so it is very important to manage the psyllid vector to reduce disease spread. Biological control agents (e.g. *Tamarixia radiata*) exist naturally in Pakistan. Psyllid populations can also be managed using insecticides but only use insecticides that have a minimal impact on bees and natural predators.

Figure 9.11a Adult psyllid feeding.

Figure 9.11b Psyllid nymphs are small and yellow-orange.

Figure 9.11c Psyllid damage on a new leaf.

Figure 9.11d Psyllid damage at the shoot gowing tip.

Citrus leaf miner

Cause

Citrus leaf miner (*Phyllocnistis citrella*) is a serious pest of citrus and other members of the Rutaceae family. The adult is a small moth, about 2 mm in length. Eggs are 0.3 mm long, flat and slightly oval, resembling tiny translucent water droplets.

Eggs are laid singly; mainly on the underside of young leaves. After hatching, the larva burrow under the leaf surface creating silvery tunnels (mines) with a thin dark excrement trail along the tunnel.

The length of the life cycle varies with season and climate but leaf miners can produce several generations per year. Populations reduce during the cooler months. Adult insects can fly and all stages of leaf miner can be spread on infested plant material.

Symptoms

Distorted foliage and silvery trails are obvious signs of the presence of citrus leaf miner in the nursery. Severe infestations reduce the growth of nursery plants and newly planted orchard trees. Leaf miner can also exacerbate issues with citrus canker.

Manage in the nursery

Monitor nursery trees regularly, checking flush growth particularly for leaf miner. Prune or remove heavily-infested plants to help reduce pest populations in the nursery.

Petroleum oil sprays are effective for prevention, by deterring adults from laying their eggs on the sprayed leaf surface.

Leaf miner populations can also be managed using insecticides, but only use insecticides that have a minimal impact on bees and natural predators.

Figure 9.12a Leaf miner damage on the topside of the leaf.

Figure 9.12b Damage on the underside of the leaf.

Mango malformation

Cause

Mango malformation is caused by the fungus *Fusarium mangiferae*. The disease can cause serious losses in the nursery because plants with symptoms must be destroyed and never sold to farmers. The disease can cause 50% fruit loss if infected trees are planted in orchards.

Malformation spreads from infected plants to healthy seedlings or trees in nurseries. The fungus is easily spread by grafting infected scions onto nursery rootstock trees. It also spreads in orchards. Bud mites may play an important role in spreading the fungus to uninfected plants.

Symptoms

Disease may remain latent (symptomless) in nursery trees, with no obvious signs of malformation for up to one year.

Mango malformation causes vegetative shoots to thicken at the growing tip (vegetative malformation) and floral parts to become a compact mass of sterile flowers (floral malformation).

Vegetative malformation usually occurs in young seedlings, although it is also observed on mature trees (both grafted and seedling types). Vegetative buds produce misshapen shoots with shortened internodes and small, stubby leaves. If all the buds are affected, the plant will remain stunted and unproductive.

Flower malformation causes flower structures to develop as large, dense, ball-like structures that become woody, heavy and fail to set fruit. They then mummify and produce inoculum that can infect nearby trees. This is why it is so important not to locate nurseries anywhere near orchards or other potential sources of infection.

Manage in the nursery

Plant disease-free seedlings, but if symptoms appear, remove and destroy the affected plants. Select budwood and scions only from healthy trees.

Figure 9.13a Malformation showing brown buds and short leaf clusters (left) and multiple branching and distorted new growth at the plant apex (right).

Figure 9.13b Multiple stem buds are a symptom of vegetative malformation.

Figure 9.13c Symptoms of floral malformation (foreground) compared with healthy inflorescences (background).

Mango sudden death

Cause

The fungus *Cerastocystis fimbriata* is the main cause of the disease. It is a very serious disease that can devastate orchards when it has been introduced by infected plants from the nursery. The main sources are from contaminated soil and infected budwood.

Stressed trees are at risk. The disease is spread within and between orchards by management practices such as flood irrigation and wounding roots by cultivating too close to trees. Bark beetles may also be disease vectors and they cause wounds that become infected.

Symptoms

Symptoms are not distinct in the nursery but become evident in field-planted trees. Leaves become dull and wilting spreads throughout the tree. Gummosis can occur through bark on the trunk and branches and there may be vascular discolouration when the bark is removed. Tree death may occur suddenly following these symptoms.

Manage in the nursery

Make sure the nursery is located remotely from existing orchards.

Do not use soil in the potting mix.

Take budwood only from healthy trees.

Avoid wounding trees and roots during field-planting.

Sterilise pruning equipment.

Use effective methods to control insects, especially bark beetles.

Ensure nurseries supply only healthy trees.

Figure 9.14a Sudden wilting in a large tree.

Figure 9.14b Infected trunk showing dark tissue beneath the bark.

Figure 9.14c Gummosis symptom of mango sudden death.

Figure 9.14d Gummosis symptom of mango sudden death.

Bacterial black spot

Cause

Bacterial black spot is caused by the bacterium *Xanthomonas campestris* pv. *mangiferaeindicae*. The disease causes black, skin-deep lesions on stems, leaves and fruit.

The bacteria are dispersed by rain, water-splash and insects and transferred from infected plant material.

Symptoms

On leaves, slightly raised, angular, black lesions appear. Edges of the lesions are limited by the small leaf veins, giving them their angular appearance. Lesions are often surrounded by a pale green halo. Lesions become darker with age.

On stems the lesions appear as elongated, black lesions with greasy margins.

On fruit, early symptoms are small, irregular spots from which a drop of sap and/or bacterial ooze may develop. Raised black spots with greasy margins develop later. In severe infections the lesions cause splits in the fruit skin.

Manage in the nursery

Bacterial black spot infections can be avoided by not raising rootstocks or grafted trees under infected mango trees, keeping leaves dry by using drip irrigation and by selecting a nursery site that is protected from the wind.

In wet weather, fortnightly applications of a protectant copper fungicide may be needed.

Destroy infection sources by pruning infected stems and leaves.

Bacterial black spot enters through damaged tissue, so avoid leaf- and stem-damage when transporting trees and keep dust off the foliage.

Figure 9.15a Bacterial black spot symptoms on a leaf.

Figure 9.15b Bacterial black spot symptoms on a leaf petiole.

Figure 9.15c Bacterial black spot symptoms on a stem.

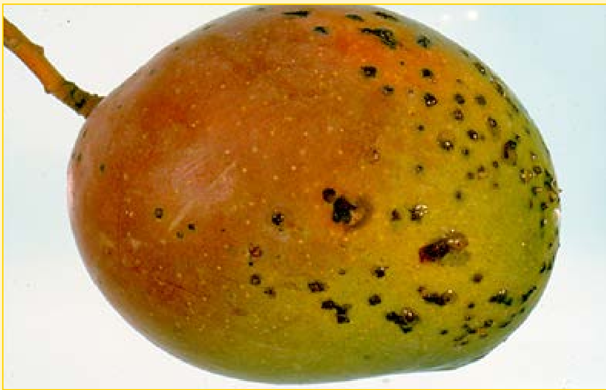


Figure 9.15d Bacterial black spot symptoms on a fruit.

Mealy bugs

Cause

Mealy bugs are soft, oval-bodied insects that are covered with a thin coating of wax. Adults are 3–4 mm long.

Mealy bugs are sap sucking insects that crowd together, feeding on plant tissue and reducing plant vigour.

Symptoms

Large numbers of mealy bugs feeding on plant tissue reduce the plant's overall vigour.

Sooty mould thrives on the sugary, sticky honeydew secreted by mealy bugs. Ants are also attracted to the honeydew.

Manage in the nursery

Nursery plants should be monitored regularly for pest infestations.

Prune or remove heavily-infested plants to reduce pest populations in the nursery.

Manage mealy bugs by conserving their natural enemies (e.g. lady birds) and reduce problems with ants and dust.

Petroleum oil sprays may also be used but monitor rates and timing carefully to avoid toxic effects on plant growth.

Figure 9.16a Mealy bug on citrus fruit.

Figure 9.16b Mealy bug on the underside of a mango leaf.

Figure 9.16c Mealy bug on a young mango stem in a nursery.

Mites

Cause

Mites are nursery pests worldwide. These arthropods range in size from 0.1 to 0.6 mm and are best observed using a hand lens.

Pest mites use their mouthparts to pierce plant cells and suck out the contents.

Predatory mites feed on pest mites and cause no harm to the plant.

Symptoms

Signs of feeding damage can vary with different mite species and include surface scarring, russetting and deforming leaves and fruit. When trees are already stressed, heavy infestations of pest mites can lead to tree dieback and fruit drop.

Manage in the nursery

Nursery plants should be monitored regularly for pest infestations. Prune or remove heavily-infested plants to reduce pest populations in the nursery.

Mites can increase their reproduction on water stressed trees, so good irrigation practices are essential to help avoid problems with pest mites.

Miticides may reduce pest mite populations, but avoid them or use them minimally to encourage populations of beneficial predatory mites or other natural enemies.

Petroleum oil sprays may also be used but monitor rates and timing carefully to avoid toxic effects on plant growth.

Figure 9.17a Two-spotted mite webbing and russetting damage on citrus.

Figure 9.17b Two-spotted mite webbing and russetting damage on citrus.

Figure 9.17c Mite symptoms on a mango leaf.

Scale

Cause

Scale insects are significant pests in nurseries worldwide. These small insects usually have a protective covering or secretion over their bodies. Young scales are mobile and called crawlers; adult males are mobile but short-lived and adult females are wingless and often totally immobile.

Scales may be soft (lacking a separate protective covering) or hard (with a separate thin, hard waxy cover called an 'armour'). Scale insects suck sap through their mouth parts embedded in plant tissue.

Symptoms

Severe infestations can lead to defoliation, fruit drop and tree decline.

Sooty mould thrives on the sugary, sticky honeydew secreted by soft scales. Ants are also attracted to the honeydew.

Manage in the nursery

Nursery plants should be monitored regularly for pest infestations. Prune or remove heavily-infested plants to reduce pest populations in the nursery.

Petroleum oil sprays may also be used but monitor rates and timing carefully to avoid toxic effects on plant growth.

Insecticides may reduce scale populations but avoid or use pesticides minimally to encourage populations of beneficial predatory mites or other natural enemies.

Heat waves reduce the activity of natural enemies enabling scale populations to increase.

Figure 9.18a Hard wax scale on citrus.

Figure 9.18b Leaf symptoms of common soft scale on mango.

Figure 9.18c Scale on a mango stem.

Figure 9.18d Scale on mango leaves.

Aphids

Cause

Aphids are soft-bodied insects that feed on plant sap with their sucking mouth parts.

Aphids may also carry virus diseases and infect nursery plants as they feed. For example the brown citrus aphid (*Toxoptera citricida*) is a serious pest of citrus, not only because of feeding damage but also because it can transmit *Citrus tristeza* virus.

Symptoms

Aphids feed on young shoots, distorting their growth.

Sooty mould grows on the sugary, sticky honeydew secreted by aphids. Ants are also attracted to the honeydew.

Manage in the nursery

Nursery plants should be monitored regularly for pest infestations. Prune or remove heavily-infested plants to reduce pest populations in the nursery.

Pesticides may reduce aphid populations, but avoid them or use them minimally to encourage populations of natural enemies like ladybirds.

Control ants as well because they protect aphids from their natural enemies.

Extreme heat and frost will reduce or kill aphid populations.

Figure 9.19 Brown citrus aphids on a citrus plant.

10 Nutritional disorders

Nursery trees that are supplied with adequate nutrients for optimum growth are healthier, faster-growing and have a better chance of survival when planted in the field.

What to consider

10.1 The key nutrients for mango and citrus nursery trees
10.2 Nutrient deficiency and toxicity symptoms
- 10.2.1 Mango—nutrient deficiency symptoms in nursery plants
- 10.2.2 Mango—nutrient toxicity and frost symptoms in nursery plants
- 10.2.3 Citrus—nutrient deficiency symptoms in nursery plants
- 10.2.4 Citrus—nutrient toxicity symptoms in nursery plants

10.3 Fertiliser application in the nursery
- 10.3.1 Types of fertiliser
- 10.3.2 Adding fertiliser to potting mix
- 10.3.3 Fertilising the growing nursery trees

10.1 Key nutrients for mango and citrus nursery trees

Nutrient	Importance for nursery plants
Nitrogen (N)	Component of chlorophyll and protein. Nitrogen is the main driver of growth. Nitrogen is easily leached out of pots and must be supplied regularly in small amounts.
Phosphorous (P)	Cell division and growth, formation of sugars and starch, energy and transport.
Potassium (K)	Formation of proteins, carbohydrates and fats, cell division, maintains the balance of water and salts in plant cells. Potassium is very mobile within the tree.
Calcium (Ca)	Component of cell walls and membranes, contributes to cell division, growth of shoot tips and root tips, tissue strength and protection against toxins.
Sulphur (S)	A component of photosynthetic proteins, DNA and fatty acid metabolic proteins.
Magnesium (Mg)	Synthesis and function of chlorophyll and proteins.
Zinc (Zn)	Chlorophyll formation, metabolism, growth hormones.
Iron (Fe)	Chlorophyll formation, enzyme activation, photosynthesis.
Manganese (Mn)	Chlorophyll formation, cell elongation, nitrate assimilation, respiration.
Copper (Cu)	Photosynthesis, enzyme function, tissue strength (lignin formation).
Boron (B)	Cell elongation, tissue strength, sugar transport, growth of shoot tips and root tips, pollination.

10.2 Nutrient deficiency and toxicity symptoms

The characteristic symptoms of nutrient deficiencies in nursery trees can be used to diagnose the deficiency.

10.2.1 Mango—nutrient deficiency symptoms in nursery plants		
Nitrogen (N)	Appears as a yellowing of the oldest leaves, progressing to the younger leaves. N deficiency will slow tree growth.	
Phosphorous (P)	Deficiency symptoms appear in older leaves as marginal or tip necrosis with brown or red-purple taints, leaf fall and stem dieback.	
Potassium (K)	Appears in older leaves first. Symptoms include yellow spots and brown necrosis of leaf margins extending to tip, non-necrotic leaf areas are dull yellowish brown to light green.	
Calcium (Ca)	Necrosis of young, actively growing shoot tips.	
Sulphur (S)	Deficiency is uncommon in mango. Appears as lateral necrotic spots and deep green leaves that drop prematurely.	
Magnesium (Mg)	Appears on older leaves first as light green mottling of leaf margins, with leaf veins remaining green. The chlorophyll may appear 'washed out'.	

10.2.1 Mango—nutrient deficiency symptoms in nursery plants		
Zinc (Zn)	Appears in immature, coloured leaves first as a thickening of the leaf and a failure of the leaf to fully expand. Leaves are often stunted on one side, causing them to be sickle-shaped. Fully mature leaves are thick and brittle and light green with olive green veins on the upper surface.	
Iron (Fe)	Often found with Zn deficiency. Symptoms appear on young leaves as pasty, dull yellow/green leaves that don't reach full size. Chlorosis develops from the leaf tips in more severe cases and symptoms are often first seen in cool weather.	
Manganese (Mn)	First seen as light green necrosis between the main veins of the middle and younger leaves, which become necrotic with age.	
Copper (Cu)	Symptoms appear as long, strap-like leaves curling downward, compact and stunted growth.	
Boron (B)	Expressed in rapidly expanding tissues (such as shoot tips) as uneven, lopsided growth, producing sickle-shaped leaves with deformed margins. Apical dominance can be lost. In older leaves, symptoms appear as small holes within the leaf surrounded by a light green halo ('shot-hole').	

10.2.2 Mango—nutrient toxicity and frost symptoms in nursery plants

Sodium (Na) and Chloride (Cl)	Leaf burn (chlorosis) starting at the margins of the leaf-tips, defoliation, dieback. Symptoms are seen in highly saline soils and when watering with salty water with a high electrical conductivity (EC). These chlorosis symptoms on the leaf margins are also seen when pots are over-fertilised.	
Boron (B)	Leaf symptoms appear as a block of necrosis (or leaf-burn) starting at the leaf margins and spreading throughout the leaf.	
Sulphur (S)	S toxicity inhibits photosynthesis with no visible leaf symptoms. It appears in areas of high pollution (near brick kilns) where acid rain falls.	
Phosphorus (P)	P toxicity is occasionally seen in nursery stock where too much press mud is used in the potting mix. Symptoms appear as stunted seedlings and bronzed leaves.	
Manganese (Mn)	Pale green/yellow mottle between the main veins in the middle and younger leaves, later becoming necrotic. Buff-coloured spots appear on the primary leaf veins and margins.	
Frost	Frost damage can be common in unprotected nurseries in winter. Small trees should be protected.	

10.2.3 Citrus—nutrient deficiency symptoms in nursery plants		
Nitrogen (N)	Most important nutrient for citrus. Symptoms of deficiency include yellow leaves, poor growth with small leaves and leaf fall.	
Phosphorous (P)	Deficiency symptoms are rare. Leaves turn a dull, bronzed green, and are easily shed.	
Potassium (K)	Symptoms differ with season, but they are most prominent in spring with brown, irregular patches and yellowing near the apex of leaves, small leaves, slow growth and leaf-fall.	
Calcium (Ca)	Stunted roots.	
Sulphur (S)	Leaves pale green/yellow with lighter veins, stunted growth of younger leaves.	
Magnesium (Mg)	Yellowing of leaves, a green triangle remains at the base of older leaves.	
Zinc (Zn)	Yellow leaf blotches with green veins, small and narrow leaves, shows in young leaves first, stunting of leaves and shoots.	

10.2.3 Citrus—nutrient deficiency symptoms in nursery plants		
Iron (Fe)	In young leaves, all the tissue between the veins becomes light green/yellow.	
Manganese (Mn)	Pale green/yellow mottle between the main veins, green band bordering the veins.	
Copper (Cu)	Dark green leaves, weak S-shaped shoots, gum pockets on young stems, dieback. The image shows a gum pocket in a stem.	
Boron (B)	Young leaves have yellow veins, stumpy roots.	

10.2.4 Citrus—nutrient toxicity symptoms in nursery plants		
Sodium (Na) and Chloride (Cl)	Leaf burn, defoliation, dieback.	
Boron (B)	Yellow/brown leaf tips, followed by mottled yellowing of leaf apex and leaf fall.	
Phosphorus (P)	Excess P can induce Cu deficiency and associated symptoms.	
Manganese (Mn)	Yellow margin of older leaves, with dark brown spots (3–5 mm) on leaves.	

10.3 Fertiliser application in the nursery

Fertiliser is needed because potting mix does not contain enough nutrients for optimum plant growth. Some fertiliser is usually added when the potting mix is prepared. Additional fertiliser can be added to trees in the nursery as they grow to maintain continued, healthy growth. The quantity and type of fertiliser applied depends on what was originally added to the mix, the properties of the mix, water quality and tree age, size and variety. Fertiliser may come in solid or liquid forms and be organic or inorganic.

10.3.1 Types of fertiliser

Organic fertilisers are derived from animal or vegetable matter, such as manure and compost. Naturally occurring organic fertilisers include animal wastes from meat processing, peat, manure, slurry, and guano. Inorganic fertilisers are extracted from minerals (e.g. phosphate rock) or produced industrially (e.g. ammonia). More information about organic and inorganic fertilisers is given in *Chapter 3—Potting mix*.

10.3.2 Adding fertilizer to the potting media

Solid fertilisers can be added to the potting mix with the other ingredients. Lime or dolomite can be added to balance the pH of the potting mix if it is less than pH 5.5. pH testing of potting mix is described in *Chapter 3—Potting mix*. Macro and minor elements are added to boost seedling nutrition and early growth.

Do not over fertilise. Over-fertilisation is the most common cause of seedling death, so it is advisable to be cautious with the quantities of macro elements added to potting mix.

When potting mix is pasteurised with heat or steam, macro-nutrients that were added as fertiliser are made more available to the tree. This can cause toxicity by over-fertilisation, so use caution when calculating the amount of fertiliser to add to the mix if it is to be pasteurised.

Check the pH. When lime or dolomite is added to non-sterilised potting mix, the effect on pH should be measured several weeks after adding it, to give it time to work. On the other hand, in heat-pasteurised potting mix, the effect of adjusting pH is accelerated and can be measured a day or so after pasteurisation. As the potting mix ages and the organic components begin to break down, their physical and chemical properties will change. This change must be monitored by testing the pH in randomly-selected pots every six months.

10.3.3 Fertilising the growing nursery trees

Over-fertilisation is the most common cause of seedling death and so only fertilise in small amounts. One of the safest ways to fertilise nursery trees is to apply slow-release or soluble fertilisers as liquids.

Slow-release fertilisers are coated with plastic and designed to release fertiliser gradually, each time the trees are watered. Slow-release fertilisers are designed to last for 3, 6 or 9 months.

Soluble fertilisers dissolved in water at about 1% w/v can be applied regularly to nursery trees. Soluble fertiliser may be sprayed directly onto the foliage, poured onto the potting media or applied with the irrigation water (fertigation).

Foliar sprays are only suitable for some nutrients. For citrus, it is recommended that foliar sprays of **magnesium** (magnesium nitrate or magnesium sulphate) be applied each year during late spring. It is also recommended that sprays of **zinc** (zinc sulphate) and **manganese** (manganese sulphate) be applied each year to the spring flush when leaves are two thirds expanded (i.e. before they reach full size). **Copper** and **boron** may also be applied by foliar spray. Citrus is sensitive to excess boron so apply boron fertiliser only if test results show that your plants are deficient.

In mango, it is common to apply foliar applications of **nitrogen**, **potassium** and trace elements such as **zinc** and **iron** in the nursery. These can be applied to the pot or to the foliage. When applying to the foliage, target the young, undeveloped leaf stage for the best uptake. **Boron** is rarely used in the mango nursery but if needed it should be applied as a pot drench as it has limited mobility and will not be taken up by mature leaves.

Fertigation by drip irrigation is the most costly system to set up but it is the most efficient way to apply fertiliser. This is because the application rates can be adjusted quickly to suit plant needs and fertiliser applications can also be split over several irrigations to reduce the amount of fertiliser that is lost through leaching (where fertiliser runs through the bottom of the pot before root uptake). Nutrients are best applied towards the middle of the irrigation period and should stop shortly before the irrigation is finished so that the fertiliser is flushed from the lines. Nitrogen and potassium fertiliser are best suited to fertigation. It is recommended that phosphorous fertiliser is not applied by fertigation, as phosphates can react with calcium and magnesium and block the irrigation lines.

11 Managing water

In Pakistan, water is in short supply and competition for water use is increasing due to increased population, urbanisation, industrialisation and agricultural production. Some areas are drier than others, but even in rain-fed regions, water is unevenly distributed throughout the year. Agricultural research in Pakistan is developing innovative methods and technologies for conserving and using water, including water-saving and efficient irrigation systems that are appropriate for citrus and mango nurseries.

A well-functioning nursery needs a reliable supply of good quality water and a watering or irrigation program tailored to the trees being grown.

What to consider

11.1 Water availability

The nursery must be located near a reliable water supply. Growing nursery trees successfully depends critically on having access to a secure and reliable water supply. In Pakistan, a secure water supply may be a permanent spring, harvested rainwater, a deep bore, a canal, a tube-well, or sometimes sourced from open storage or town supply. See Figures 11.1, 11.2, 11.3, 11.4 and 11.5.

It may be appropriate to dig a well (12 m deep and 3 m diameter) and install a kerosene pump-set (2.0 HP) with accessories to deliver water to the nursery. See Figures 11.3 and 11.5.

Figure 11.1 Water used in nursery irrigation often comes from canals.

Figure 11.2 Filling a tanker to transport water to the nursery.

Figure 11.3a Tube wells access water from the water table.

Figure 11.3b Inside a tube well showing the lined wall and pump.

11.2 Water quality

While some areas in Pakistan have adequate supplies of good quality water, many others access poorer quality water supplies. Water quality is reduced when contaminated with plant disease organisms, salts and sewage. Animal and human sewage contains water-borne disease organisms. Salts and nutrients in irrigation water should be considered in the nursery nutrient budget. The quality of the water supply can change over time; it may be good quality initially, but can change to a borderline quality and then unusable in just a few months.

The water supply may need to be filtered or treated to adjust the pH and manage diseases, depending on its source.

Figure 11.4 Water supplies for nursery irrigation are often shared with many other uses.

Figure 11.5 Water flow to the nursery can be controlled by gates in water channels (left) and drawn through hand-pumps or irrigation pipes (right).

11.2.1 Treating and testing water

Managing water-borne disease organisms

Water obtained directly from suburban systems, deep bores or clean rainwater catchments may not need to be treated. If there is any chance that the irrigation water could be contaminated by water-borne disease organisms (either at the source or during storage), it should be treated in a holding tank in the nursery (Figure 11.6) by either:

- filtering through sand (e.g. slow flow sand filtration)
- adding chlorine
- ultra-violet radiation.

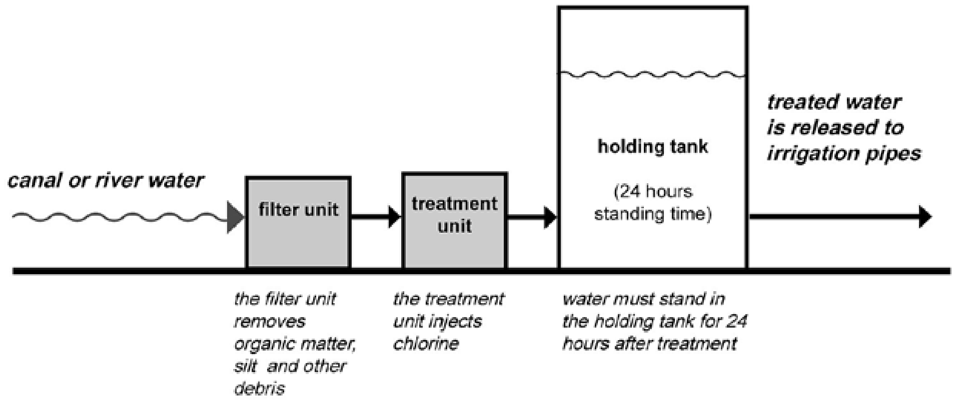


Figure 11.6 A common treatment process for water sourced from rivers and canals.

Managing pH and salinity

Tree growth is severely restricted if the pH and salinity levels in the irrigation water are not within an optimum range.

- The pH affects the availability of some nutrients and it also affects the solubility of some chemicals used in the nursery for controlling pests and diseases. Low pH can be treated by adding an alkaline solution (sodium hydroxide or lime). High pH can be treated by adding an acid solution (citric, phosphoric or sulphuric acid). The nutrient content of the substance used to adjust the pH of irrigation water must be included when calculating how much fertiliser to apply to trees.
- The salinity of irrigation water is determined by the quantity of dissolved salts and a value for total soluble salts is measured as the electrical conductivity (EC) of the water. When dissolved salts like sodium and chloride are present at high levels, they can be toxic to trees and impede water uptake.

pH and salinity (EC) can be measured using readily available kits that include a pH meter and an EC meter. If salinity levels are too high (greater than 1600 µS/cm or 1.6 dS/m), the water should not be used. See *Chapter 3—Potting mixes* for more information about pH and EC.

Regular checks. The pH and EC of all irrigation water should be checked regularly, at least once a month.

11.3 Irrigation systems

Trees may be watered by hand-held hoses, overhead sprinklers or drip irrigation systems.

11.3.1 Overhead sprinklers

Overhead sprinklers are easy to manage (Figure 11.7) but they use more water than drip systems. Good drainage is needed to drain all the run-off water away from the work area. A variety of low-pressure sprinklers are available. The commonly-used under-tree sprinklers can be turned upside down and screwed into PVC pipes and work very efficiently.

It is important to space the sprinklers correctly to give a uniform coverage of the whole nursery area to be irrigated. Trees that are in corners not covered by overlapping sprinklers will not receive enough water; unfortunately, these trees tend to be exposed to drier conditions and wind, and will have the highest demand for water. In larger plant houses, low pressure sprinklers spaced 1.5 m apart give adequate coverage. In smaller plant houses, fewer, lower-capacity (micro) sprinklers will cover the area effectively. Irrigation can be automated (using a time clock and a solenoid) to control the frequency of watering.

Overhead irrigation should be used in the morning or late afternoon, to avoid 'leaf-burn'.

Note:

In Pakistan, overhead sprinklers are not recommended where the irrigation water is saline. Water that has a high EC will cause salts to accumulate on the leaves over time, resulting in 'leaf-burn' and death.

Figure 11.7 Overhead sprinkling is a cost-effective way to deliver enough water to trees in the nursery.

Figure 11.8 Controlled drip irrigation uses water efficiently.

11.3.2 Drip irrigation systems

Potentially, drip irrigation systems use water more efficiently than other systems (Figure 11.8). Drip irrigation applies water directly to the trees (individual pots) through emitters (holes) located along plastic tubing. It applies water directly to the trees' root zone by water emitters operated under low pressure. Timing is controlled and set to the trees' needs.

The system of PVC pipes and drippers can be connected to a tap or automated using a pump and control head unit. The cost of installing a drip irrigation system can be recouped within one or two years.

While drip irrigation is suitable for young trees in the plant-house, the related bubbler irrigation system delivers water to mature trees in the orchard.

Drip and micro-sprinkler irrigation systems designed for nurseries in Pakistan are described by The Pakistan Agricultural Research Council [www.parc.gov.pk/index.php/en/caewri-rshprog/caewri-awmp].

11.4 Using water efficiently

Water is scarce, so it must be used efficiently. Ways to improve water-use efficiency include saving and storing water, and irrigating efficiently.

11.4.1 Saving water—rain water harvesting

Rainfall is often scarce and distributed unevenly throughout the year, and rainwater may be lost through runoff. Roof-top rainwater harvesting increases the amount of water available to the nursery. It also enables water to be used more efficiently.

Rooftop water harvesting. In the nursery, rooftop water harvesting collects rainwater in tanks, wash tubs or drums where it is stored until needed. It can be distributed around the nursery using pumps (which can be solar-powered) or by gravity feed.

Collecting and reusing nursery irrigation water is not recommended as it can be source of disease contamination.

11.4.2 Irrigating efficiently

Use drip or sprinkler systems. Drip or sprinkler systems are potentially the most efficient ways to water nursery trees. Drip irrigation applies water directly to the trees through emitters (holes) located along plastic tubing. Drip irrigation distributes water uniformly and large areas can be watered with much less water loss compared with hand-held hosing.

Overhead sprinkler systems can be regulated to deliver the correct amount of water at the correct rate. Note that in Pakistan, overhead sprinklers are **not** recommended where the irrigation water is likely to be saline.

Potting mix. Use a good quality potting mix that holds sufficient water to supply trees and drains well to avoid water-logging and tree death (see *Chapter 3—Potting mixes*).

Mulching. Mulching nursery trees with organic mulch will reduce the rate of evaporation from the pot. Avoid plastic because it will increase soil temperatures in the root zone.

How much water to use?

It is important to give the nursery trees the correct amount of water; under- or over-watering will lead to poorer growth or even tree death. Ideally, the irrigation system applies water evenly and can be controlled to allow flexibility that matches climatic variations.

The amount of water needed for the nursery depends on the layout and structure of the nursery and the type of irrigation used. Daily water use will depend on which trees (mango or citrus) are grown, their stage of growth, and the type of pots and growing media used.

Water should be applied evenly and at an appropriate rate, irrespective of the irrigation system used.

- If water is applied too quickly or unevenly, dry patches will develop, resulting in poor tree quality or even death.
- If too much water is applied, excess water can pool on greenhouse floors and paths, creating an environment for algae, mould, weeds and disease organisms to thrive.
- If the sprinkler pressure is too high, the water droplets become too small, causing misting. In extreme cases, the mist will drift away from the trees, so they will be under-watered and the water will be wasted.

Efficient sprinkler or drip irrigation

The irrigation schedule. Develop an irrigation schedule that delivers the correct frequency and duration of watering. Distribute water uniformly across a group of trees or within the greenhouse. Check the trees' water status daily. Water requirements may change with the tree growth stage and the season.

Checking performance. It is important to know how the irrigation system works and how to keep it at maximum performance. Drippers and sprinklers need to be checked daily to ensure trees are receiving sufficient water. The main polyethylene pipes should be flushed twice a year to prevent spray or drip irrigation heads from clogging. Clean the in-line filters monthly.

Keep records of water use. It is essential to keep records of daily temperatures and rates of water use. This helps you to plan the annual nursery irrigation schedule and make changes related to variations in the weather.

11.5 Water requirements for field planting

Preparing for field planting

Maintain adequate water supplies to all nursery stock to avoid root death and slow establishment or even tree death. Consistent, adequate watering is important all year but particularly during the warmer months in the nursery.

Container nursery trees as well as field-grown trees should be transplanted into the field in late winter or early spring, before day temperatures get too high, but after the risk of frost has passed, to minimise stress on the trees. Transplanting (field planting) outside this season increases the risk of tree failure.

The type of planting hole that is dug can influence the way water drains away. Planting holes dug with a mechanical, round auger may create a hard barrier to roots and water at the edge of the hole (especially in clay soils) that can restrict tree growth. Roughening the sides of the planting hole with a crowbar will improve drainage (See *Chapter 7—Managing advanced trees in the nursery, during transport and field planting*).

Watering at planting

The trees should be watered immediately after planting; a tractor-mounted water tanker is highly recommended for this task.

- At planting, backfill and firm the soil around the tree to remove air pockets.
- Water with 5–10 litres of water. Trees do not need a large volume of water but enough to maintain a humid environment around the roots. As little as 5 litres per tree will largely

eliminate any planting stress and settle the soil around the root system. Allow the soil to settle.

- Exposed roots and over-sunken areas that show up after watering should be re-covered with soil, while maintaining a slight depression (basin) around the tree, which will direct water to the root zone.
- If there is water stress, cut some shoots back to reduce leaf-mass.

Watering schedules after planting.

Repeat watering as required for the first few weeks after planting. It is important that the potting mix (from container-grown trees) does not dry out before the roots have grown into the surrounding soil.

After the initial watering-in, the weather will determine when further irrigation is necessary. In hot weather, it may be after 24 hours, while in mild weather, the trees may not need to be watered again for a few days.

Drip irrigation is an efficient way to make sure the trees have enough water, and reduces the amount of water wasted when using a hose. Drip emitters, micro-jets or micro-sprinklers connected by a system of PVC piping are an effective way to deliver water.

11.6 Managing wastewater

Irrigating mango and citrus nursery trees generates wastewater that flows to the ground, and if allowed to pool, encourages algae, mould, weeds and disease organisms. Used water should drain away from nursery trees to prevent contamination. Do not re-use wastewater, which may be contaminated with plant diseases and excess fertiliser.

Drainage in the nursery. A series of drains constructed under and around the edge of tree storage areas will direct water away from floors. If plants pots are on the ground, they should be placed on a gravel bed, sloping gently away from the pots.

Managing excess rainwater. Consider diverting and storing excess water from heavy rainfall. Rainfall run-off can be diverted through drains to a collection point and used later.

Do not re-use wastewater. Wastewater may be contaminated with plant diseases and excess fertiliser, so it should not be used to water nursery trees.

12 What makes a high quality tree for sale?

This chapter describes the characteristics of a high quality nursery tree. This information can be used by the nursery operator to judge the quality of his trees and compare their quality with other nurseries. The information is also useful for the tree buyer when assessing the quality of trees for sale.

A high quality nursery tree at the time of sale must be ready for field planting and should be true-to-type, free from pests and diseases, and of an age and height to withstand transplanting into the field.

What to consider

12.1 Tree age
12.2 Tree height
12.3 Rootstock variety
12.4 Scion variety
12.5 Pests and disease status
12.6 Nutritional status
12.7 Condition of the graft union
12.8 The root system
12.9 Hardening
12.10 Labelling
12.11 Checklist

12.1 Tree age

Trees between 12 months and 2 years old are generally suitable for sale. The age of the tree at the time of sale is important because trees that are too young will not acclimatise well. They will be more likely to fail during field transplanting, due to a poorly developed root system or unhealed graft union. Young trees tend to be less sturdy and can bend more easily when transplanted.

Trees older than the recommended age can be sold as advanced trees but they must be re-potted into larger pots several months before sale. Older trees in their original pots may have pot-bound roots that will not develop into good tree root systems after transplanting.

12.2 Tree height

Height is an indicator of the age and growth of nursery trees. For transplanting mangoes in the field, the ideal height of the tree above the potting mix is between 0.6 m and 0.9 m. For citrus trees, the ideal height above the potting mix is between 1 m and 1.2 m. A shorter plant may indicate stunted growth, growth problems or it may be too young.

Taller and spindly plants can be difficult to handle and transport and they are more vulnerable to wind damage after transplanting in the field. See Figures 12.1 and 12.2.

Tree age and height

Figure 12.1 Citrus

Figure 12.2 Mango

12.3 Rootstock variety

All rootstocks should be from mother trees of known varieties (true-to-type) and certified (or inspected) and declared to be free from pests and diseases of concern, especially those diseases that can be spread through rootstocks such as mango malformation.

In mango, polyembryonic cultivars are preferred for rootstock uniformity; this is because polyembryonic seed produce genetically similar rootstocks (see Figures 12.3 and 12.4; *Chapter 5—Germinating and growing seedlings* and *Chapter 6—Grafting*).

Rootstock variety

Figure 12.3 Citrus

Figure 12.4 Mango

12.4 Scion variety

The scion material used for grafting should be selected for the variety, the health status of the mother tree and compatibility with the rootstock. Scion budwood should only be taken from trees that have been tested and/or declared free from graft-transmissible diseases that can be spread by infected budwood e.g. citrus viruses and viroids, citrus huanglongbing or mango malformation (see Figures 12.5 and 12.6; *Chapter 5—Germinating and growing seedlings* and *Chapter 6—Grafting*).

Scion variety

Figure 12.5 Citrus

Figure 12.6 Mango

12.5 Pests and disease status

Nursery trees must be free from pest and diseases. Trees infested with pests (for example scale, mites, aphids) and diseases (for example mango malformation, bacterial black spot, huanglongbing, citrus exocortis viroid—see *Chapter 9—Managing diseases, pests and weeds*) may have stunted growth and poor vigour in the field and will not produce healthy and high-yielding orchards. All seed, rootstock and scions entering the nursery must be inspected and quarantined for pests and diseases. Pests and diseases must be managed throughout the nursery life of a tree to keep the trees healthy and growing vigorously. Do not neglect root system pests such as ants and mealy bugs, which can either impede root activity or emerge from the potting mix to infest the canopy. See Figures 12.7 and 12.8. Raising healthy plants is described in *Chapter 8—Nursery hygiene* and *Chapter 9—Managing diseases, pests and weeds*.

12.6 Nutritional status

A good quality nursery tree for sale should not be showing any nutritional disorder or toxicity symptoms. This is only possible if tree nutrition has been balanced throughout its life-time growth in the nursery. There should be no symptoms of leaf yellowing, mottling, dry leaf margins, necrosis, darker or lighter leaf veins, or leaf curling. See Figures 12.7 and 12.8. For a full range of symptoms see *Chapter 10—Nutritional deficiencies*.

Pest and disease status and nutritional status

Figure 12.7 Citrus

Figure 12.8 Mango

12.7 Condition of the graft union

In a good quality nursery tree for sale, the graft union should be fully-healed and healthy, showing good growth of callus in the join between the rootstock and scion. There should be no signs of sooty mould or other fungal infections. In citrus, a yellow ring under the bark would indicate that the scion and rootstock are either incompatible or infected with a disease. The thickness of the stem above and below the graft should be similar. See Figures 12.9 and 12.10. A guide to grafting mango and citrus trees is given in *Chapter 6—Grafting*, and to pests and diseases in *Chapter 9—Managing pests, diseases and weeds.*

Condition of the graft union

Figure 12.9 Citrus

Figure 12.10 Mango

12.8 Root system

High quality nursery trees have healthy, well-formed root systems. A well-formed and healthy root system will make the tree more resilient to transport and transplant shock, allowing the tree to become established and continue growing sooner after field planting. A healthy root system should fill the pot and hold all the potting mix in place when the tree is removed from the pot. An overgrown or pot-bound root system is identified by a mass of roots circling the pot. The roots of pot-bound trees will have difficulty growing in the soil after transplanting into the field and they often have knots in the tap roots that may strangle the tree in time.

Healthy root systems are established in the nursery by using suitable potting mix and containers and healthy growing conditions (see Figures 12.11 and 12.12; *Chapter 3—Potting mixes, Chapter 4—Plant containers* and *Chapter 7—Managing advanced trees in the nursery, during transport and field planting*).

Root system

Figure 12.11 Citrus

Figure 12.12 Mango

12.9 Hardening

A good quality nursery tree for sale will have been hardened environmentally, so that it can tolerate transport, storage and transplanting into the field without too much shock. Trees should be sun-hardened by moving them gradually from the shade of the plant house to the full sun. They can be water-hardened by gradually exposing them to longer and longer periods between watering. During hardening, trees should not be exposed to extreme, dangerous conditions. Hardening is essential for nursery mango trees to minimise losses during transplanting (see Figures 12.13, 12.14 and *Chapter 7—Managing advanced trees in the nursery, during transport and field planting*).

Hardening

Figure 12.13 Citrus

Figure 12.14 Mango

12.10 Labelling

A high quality tree for sale should be labelled clearly with the names of the scion and rootstock varieties, the age of the tree and statements indicating the source and health status of the source rootstock and scion materials. The label should be securely tied. Good labelling will also give the name and contact details of the nursery producing the trees. This information can be provided on tree labels or displayed in a prominent place for buyers to read. See Figure 12.15.

The tree buyer will be looking for visible signs that the plant is healthy and growing vigorously with a full root system. They will check that there are no signs of disease, pest damage, or nutritional disorders. The buyer will also be interested in the height of the graft union (citrus) and the height of first branches (mango), and if the trees are sun-hardened and ready for immediate field-planting. See Figures 12.16 and 12.17.

The nursery can add to their stock quality by supplying information, guarantees and health records for the variety and sources of seed and scions. It is also important to display information about the varieties as clearly as possible on tree labels or posters around the sales area of the nursery.

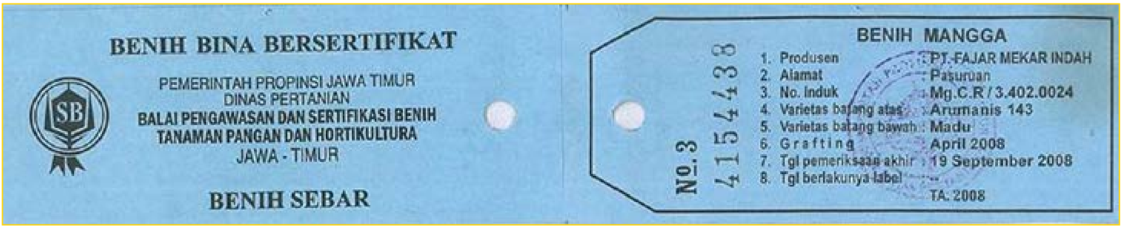


Figure 12.15 Nursery businesses world-wide use labels provided by the industry to describe their trees for sale. This example is from an Indonesian nursery.

Figure 12.16 Select plants carefully.

Figure 12.17 Plant varieties should be labeled clearly.

12.11 Checklist

The checklist of the key characteristics of good quality nursery plants (on the next page) is a guide for both nursery managers and for farmers buying trees.

Checklist

Features that buyers are looking for in high quality nursery trees

Tree age—an age that can be field-planted with minimal transplant shock.

Section 12.1 Figures 12.1 & 12.2	Mango and Citrus: grafted trees from 1 to 2 years old.	

Tree height—not stunted; not tall and spindly.

Section 12.2 Figures 12.1 & 12.2	Mango: 0.6–0.9 meters above the potting mix.	Citrus: 1–1.2 meters above the potting mix.

Rootstock variety—from a known, clean source with the name written on the label.

Section 12.3 Figures 12.3 & 12.4	Mango: a named, polyembryonic variety with evidence that the seed came from a mother tree that was malformation-free.	Citrus: evidence that the seed came from a tree declared free from diseases that can be spread by infected seed.

Scion variety—from a known, clean, true-to-type source with the name written on the label.

Section 12.4 Figures 12.5 & 12.6	Mango and Citrus: The budwood supply tree was tested and declared free from graft-transmissible diseases that can be spread by infected budwood e.g. mango malformation, huanglongbing, citrus viruses and viroids.

Pests and disease—no signs of stunted growth, pests or diseases on foliage, stem or roots.

Section 12.5 Figures 12.7 & 12.8	Mango and Citrus: free from pests (scale, mites, mealy bug, aphids) and diseases (mango malformation, bacterial black spot, citrus scab or citrus exocortis viroid).

Nutritional status—no symptoms of nutritional disorders or toxicities; growing vigorously.

Section 12.6 Figures 12.7 & 12.8	Mango and Citrus: no signs of leaf yellowing, mottling, leaf margin drying or necrosis, darker or lighter leaf veins, leaf curling.

Graft union—grafting tape and bindings removed; no shoots or leaves below the graft.

Section 12.7 Figures 12.9 & 12.10	Mango and citrus: graft union well-healed and callused on both sides of the stem. There should be no signs of sooty mould. In citrus, there should be no sign of a yellow ring under the bark.

Root System—no signs of the roots being pot-bound

Section 12.8 Figures 12.11 & 12.12	A healthy root system should fill the pot and hold all the potting mix in place when the tree is removed from the pot. An overgrown or pot-bound root system is identified by a mass of roots circling the pot.

Hardening—conditioned for survival outside the nursery.

Section 12.9 Figures 12.13 & 12.14	Mango and Citrus: trees are housed in a sunny position outside the growing nursery having been sun-hardened and root systems conditioned to less frequent watering than in the nursery.

Tree labelling

Section 12.10 Figures 12.15 & 12.17	Mango and Citrus: labels should indicate clearly all of the information in this checklist. They should be tied on securely so they cannot fall off during transport and transplanting. See Figure 12.15.

13 Further reading

1. Atkinson IC (Ed), 1997. Best practice guidelines for the Nursery Industry Accreditation Scheme, Australia (NIASA), 2nd Edition. Nursery Industry Association of Australia, Sydney, Australia.
2. Bodman K and Sharman KV (Eds), 1993. Container media management. Queensland Department of Primary Industries, Brisbane, Australia.
3. Owen-Turner JC and Shaw RG, 1984. Citrus propagation in containers. Queensland Department of Primary Industries Information Series Q184023, Brisbane, Australia.
4. Goss OM, 1983. Practical guidelines for nursery hygiene. Australian Nurserymen's Association, Sydney, Australia.
5. Handreck KA and Black ND, 2010. Growing media for ornamental plants and turf. 4th Edition. University of New South Wales Press Ltd, Sydney, Australia.
6. Aubert B and Vullin G, 1998. Citrus nurseries and planting techniques. Centre of International Cooperation in Agronomical Research for Development, Montpellier, France.
7. Alexander DMcE, 1986. Practical hints for budding and grafting fruit and nut trees. CSIRO Publications, Adelaide, Australia.
8. The Pakistan Agricultural Research Council. Climate Change, Alternate Energy and Water Resources Institute, Agricultural Water Management Program, CAEWRI- NARC, Islamabad. www.parc.gov.pk/index.php/en/caewri-rshprog/caewri-awmp, viewed June 2015.
9. Image resources
    a. Figure 3.1. Adapted from Michigan Tech, Michigan Environmental Education Curriculum-Water. www.techalive.mtu.edu/meec/module06/Porosity.htm, viewed June 2015.
    b. Figure 5.9a. www.instructables.com/id/How-To-Grow-A-Mango-Tree/, viewed June 2015.