



# Operation KP

A production guide for mango  
growers in northern Australia

Edited by Sam Blaikie and Peter Cavanagh

# **Operation KP – A production guide for mango growers in northern Australia.**

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## Acknowledgements

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## Foreword

This manual draws together established information about mango management in northern Australia and combines it with recent research information, some of which has not yet been published elsewhere. By sourcing material in this manual from recent research carried out by TropHort partners and incorporating the knowledge of experienced, successful growers associated with Northern Territory Horticultural Association (NTHA), the information should provide a solid framework against which individual growers can adapt or extend the recommendations to suit their own situation. As with any crop there is no simple recipe for management that can be applied by all growers in all situations. Assistance in interpreting the information to suit the situation on individual properties is available through TropHort partners and the NTHA. The focus of this manual is on mango grown in Australia's tropical regions around Darwin, Katherine and Kununurra.

The Australian mango industry is dominated by the cultivar Kensington Pride (KP) which accounts for 80 % of the trees and 90 % of the value of production. The remainder are a mixture of local and exotic varieties which are grown to meet export and other niche market opportunities. Given the predominance of KP the information in this manual relates mainly to this variety. However, comparisons are drawn between KP and other varieties where appropriate.

This manual is written for prospective or experienced growers with established orchards. A characteristic of mango production in the north of Australia is that the trees generally do not follow a predictable pattern of growth and production from year to year. This makes it very difficult to manage the trees according to a routine. The pattern of growth and production of the trees from one year may be entirely different to what occurs in other years. Since the performance of mango trees can vary so much from year to year, the information that is presented emphasises the need for the managers of mango orchards to spend time in the field observing and assessing the trees. Most good management decisions will be linked to either (i) an observation of tree growth, such as bud development or insect damage to leaves/flowers or (ii) a measure of the environment in which the tree is growing, such as a soil test. Growers in the region who have a successful record of achieving high yields also use such information to assist with their decision making. This manual aims to make this approach to mango management, together with the most up to date technical advice, available to all growers. It is hoped that readers will find information within this manual that they can use as part of their own management plan to maximize the productivity of their mango trees.

Sam Blaikie and Peter Cavanagh August 2003

## Introduction

### **Mango production in northern Australia**

Mango (*Mangifera indica* L.) is native to tropical Asia but is now grown commercially in many countries. World production is about 23 million tonnes with Australian production estimated to be about 60, 000 tonnes. The Australian industry is young, having grown rapidly since the mid 1980's. Currently valued at about \$100 m (farm gate) per annum, Australian mango production is based principally in coastal Queensland, the Top End region of the Northern Territory and the Kununurra region of Western Australia. While many of the principles of mango management are in common across all regions, aspects of flowering management and nutrition, in particular, vary depending on whether the trees are grown in the tropical or sub-tropical climates.

The demographics of the mango industry in northern Australia have changed in recent years. Pioneering mango growers in the late 1980s and early 1990s enjoyed quite high economic returns for very little input. In fact, a characteristic of the early mango industry is that for many growers it was based on relatively small holdings (hundreds of trees) with inputs only provided when time off from the 'regular job in town' permitted. Factors that may have made such a scenario possible include

- (i) natural fertility of previously virgin soils meant that nutrition was not a major problem that needed intensive management;
- (ii) there were relatively few growers and a relatively large demand;
- (iii) mangoes from northern Australia were first on the market each season;
- (iv) choice of exotic or tropical fruit in southern domestic markets was limited; and
- (v) consumers were not familiar with quality attributes of tropical fruit and were therefore prepared to disregard defects/deformities and pay relatively high prices for mangoes.

Since these highly profitable early years many new growers have entered the industry in the hope of achieving similarly lucrative economic returns.

However, the current economic conditions are quite different, partly as a consequence of the arrival of new participants in the industry. It is estimated that there are now close to 1 million trees planted in the Northern Territory alone. An emerging trend is for much larger orchards (thousands of trees) with a range of full time employees responsible for specific tasks.

The increased supply has greatly reduced the possibility of achieving high prices in the early part of the season. If high prices are achieved it is not for long. Most fruit are sold through the main supermarket chains that have implemented stringent quality control standards. Fruit that may once (in markets 10 years ago) have achieved 1<sup>st</sup> grade prices are now being downgraded and receive prices that can be well below the cost of production.

With economic margins quite small the pressure is on growers to operate at maximum efficiency. In particular, growers must achieve maximum returns from agronomic inputs. Average yield is around 20 kg fruit per tree (around 3 trays, of which at least one tray will be Class 2) and has not improved as the industry has grown over the last

10-15 years. This average productivity level is exceptionally low compared with the yield achieved in some other parts of the world where yields of 10 - 20 t/ha (equivalent to about 100-200 kg/tree) or more are recorded. However, some well managed trees in northern Australia do consistently produce yields of this order, showing that it is possible to achieve economically efficient production levels of about 70 kg/tree (10 trays/tree) or more.

### **Mango physiology and growth**

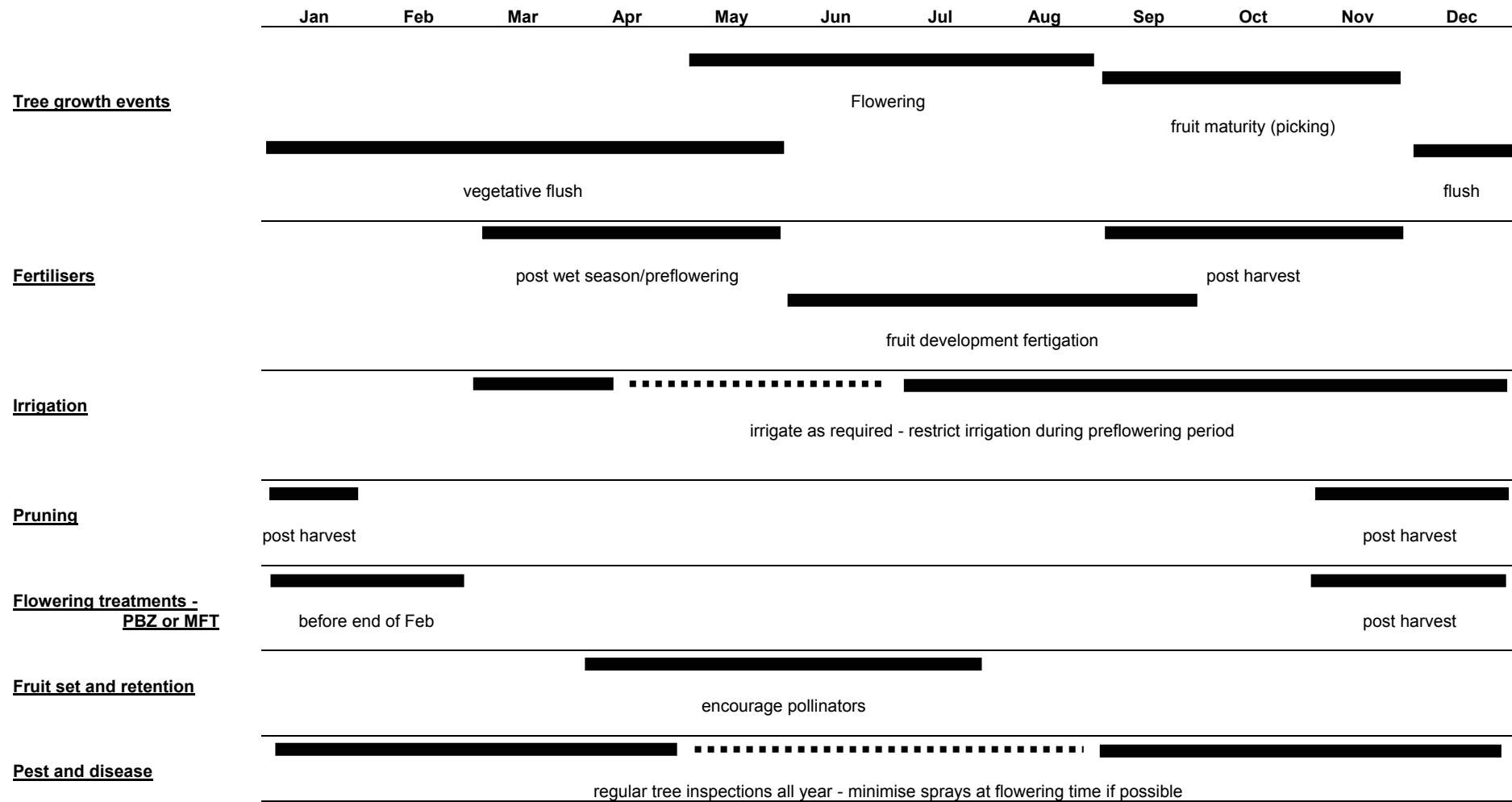
Mangoes are evergreen perennial trees and can be propagated from seedlings or by grafting. It is generally accepted that grafted trees have a shorter juvenility period and are more productive. Also, a traditional viewpoint of the Australian industry is that rootstock effects on mango productivity are unimportant. However, scientific evidence supporting these contentions is not available. In fact, recent observation suggests that the choice of rootstock could greatly influence the final tree size. The reality is that established trees in the industry usually have unknown genetic heritage in terms of the original seedling source or the rootstock-scion combination. It may be that the diversity that undoubtedly exists in the genetic heritage of established trees across the industry explains some of the variability that exists within and between orchards in which the management is otherwise uniform. Further research will be required to address these issues.

Regardless of genetic heritage, the growth of mango trees occurs in periodic bursts of activity known as flushes. Each flush arises from the terminal bud and can result in either vegetative (leaves) or reproductive (flowers) growth. Although vegetative growth predominates in young trees, within 3-5 years of planting, the expectation is that trees grown in tropical regions will have the potential to flower and produce fruit. In the tropical climate warm, humid conditions favour vegetative growth and the priority for growers is to manage these flushes. The objectives are to maintain canopies at a reasonable size for effective spraying and picking operations while optimising the number of healthy, active terminals that are produced and, therefore, potentially capable of flowering and producing fruit.

The calendar of operations (see next page) shows that management input is required throughout the year. Also, coordinating management with the growth cycle of mango trees can be complicated, often requiring that many operations occur simultaneously. The issues associated with this management are complex, but recent work by TropHort partners investigating the use of flowering treatments, irrigation, nutrition and pest control have provided useful new information and growers should now have reasonable confidence in their use and limitations. By implementing or adapting these practices on their own orchards growers who consistently achieve high yields, in excess of 100kg fruit/tree, have demonstrated that these management strategies are effective.

An important feature of management by the most successful growers is that they do all things well. This is important because the final result, measured in terms of the yield of first quality mango, can be affected by the whole range of management factors. For example, the best fertiliser program will be useless if inattentive pest checking during July allows a caterpillar outbreak to ruin the flowering panicles.

## Typical annual calendar of events associated with a mango orchard in northern Australia.



Flowering treatments will be greatly devalued if an inefficient irrigation system causes the premature drop of fruit. There are many other examples of ineffective management in one area compromising the value of management in all other areas. Based on the experience of the most successful growers, the key to achieving excellent management in all areas is directly related to the amount of time spent in the orchard. Regular contact with the trees is required to identify potential problems and to enact remedial or preventative measures in a time frame that will not compromise the overall viability of the crop.

This manual attempts to draw together the key elements of the management practices developed by TropHort partners and the most successful growers with high yielding mango crops. The aim is to provide growers across the north Australian mango industry with **'best-bet'** options to try and replicate the effective management practices on their own farms. In doing so it is hoped that yield and profitability on these farms will improve.



## Nutrition

### Summary – key action points

*Aim to maintain soil nutrients in the following range (mg/kg except for pH):*

<b>Element</b>	
pH	6.5
P	70
K	100-150
Ca	1000
Mg	90-120
S	12-20
Zn	2-5
Cu	2-3
Mn	4-50
Fe	5-60
B	1-2

**Note:**  
*If levels are not in this range it may be necessary to take action. Seek advice if unsure of the correct rates of fertilizers to apply. This will vary from orchard to orchard.*

**Note:**  
*The level for B will be dependent on method of analysis. Check this first.*

#### **To make informed judgments about fertilizer additions:**

- *Observe and account for where and when roots are active. Consider age and size of trees and effects of irrigation wetting pattern.*
- *Gather information about effects of soil type.*
- *Collect soil samples for analysis at least twice a year – before flowering and during the final few weeks of picking.*
- *If unsure, seek advice to interpret the soil test results.*
- *Decide whether to apply fertilizers as in the granular form or by fertigation.*
- *Time fertilizer applications according to the growth stage of the tree or crop.*
- *Apply N soon after harvest.*
- *Implement foliar applications as a supplement to the soil-based fertilizer program where necessary.*

## Nutrition

The objective is to maintain the soil with adequate nutrition to supply the needs of the trees as they grow throughout the season. To do this effectively requires the integration of knowledge from several sources including:-

- Location and activity of the roots
- Soil type
- Soil test result
- Growth stage of crop
- Age/size of trees
- Fertiliser application method

### Location and activity of the roots

The mango root system is a combination of fine (about 5 mm diameter or less), highly-branched surface roots and large (diameter up to several cms), occasionally-branched sinker roots. The fine, surface roots play an important role in both nutrient and water uptake while the larger roots, which can grow many metres deep, mainly anchor the tree in the soil and take up water. In general, growers should be considering the surface roots when developing their fertiliser strategies. Beneficial soil microorganisms, such as mycorrhizal fungi, may also play a role in nutrient availability. These microorganisms are likely to be present in greatest numbers near the soil surface.

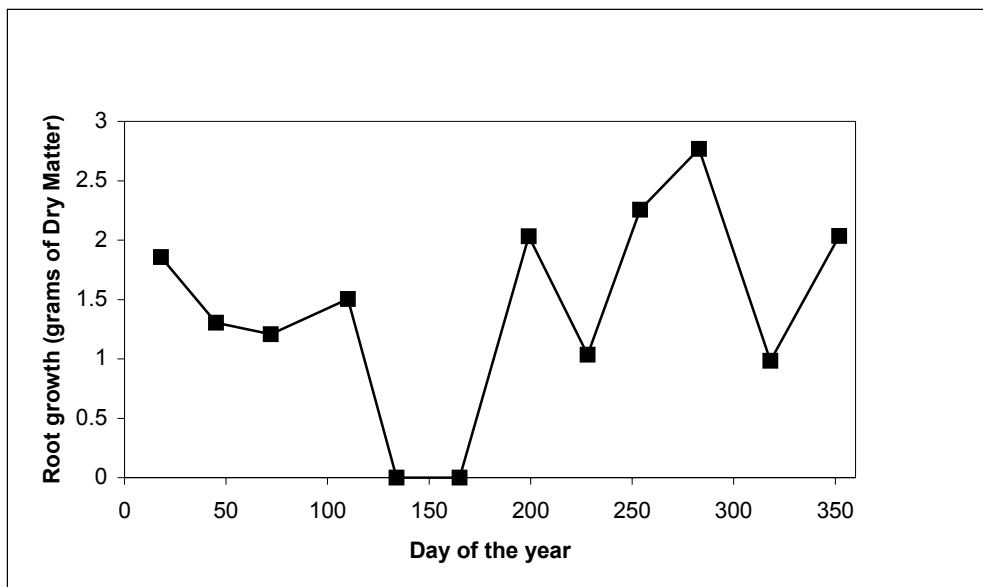


**Figure 1.** *Root system typical of mango with fine roots near the soil surface and much larger, 'sinker' roots that can extend well over 1 m deep. Small divisions on scale represent 10 cm. The top border of the picture corresponds with the level of the soil surface.*

The fine, surface roots usually grow within the top 30 cm of the soil profile and, within that zone, most roots occur within the top 10 cm. Nutrient uptake requires live, healthy roots to transport the nutrients from the soil environment through the root surface into the tree. A good supply of soil water, usually from irrigation or rain, is required to support the uptake processes and ensure that nutrients are in solution. In addition to the role of a good water supply in the uptake process, the proliferation and branching of the fine roots will be encouraged in moist soil. This further improves the capacity of the tree to intercept and take up nutrients from the soil.

It is important to recognise that root growth is not random. As a general rule of thumb, fine roots associated with nutrient uptake will proliferate in the regions of soil that provide the most favourable environment for root growth. So soft, well-fertilised, moist soil will have more root growth than hard, dry soil that is not fertilised. The practical extension of this is that the area of soil that is wet at irrigation is the best place to apply fertilisers. Similarly, it is of limited value to apply fertilisers if the soil has been allowed to dry to encourage flowering. If the soil is dry the roots will not be active, the fertilisers will not be in solution and tree water uptake is likely to be very low.

Fine, surface roots are known to grow in bursts of activity or ‘flushes’ comparable to the shoot flushes that produce new leaves. A recent experiment by TropHort partners in which root flushes were monitored throughout the year demonstrated that a main period of root growth occurs around harvest time (about day 250-300 of the year). In the early Dry season around day 150 of the year, when irrigation was withheld from the trees, root growth did not occur at all. Fertiliser applications should therefore be timed to coincide with periods of active root growth where possible.



**Figure 2.** *The variation in growth of new, fine roots of mango during the year. Fine roots, about 2 mm diameter or less, are important for the uptake of nutrients from the soil. In the middle of the year preflowering drought caused the production of new roots to cease. After flowering at about day 150, irrigation was commenced and supported the growth of new roots*

### **Soil type**

The soil type on mango farms in northern Australia can vary considerably, from farm to farm and within different areas of the same farm. To best understand the fertiliser requirements of their soils it is important that growers conduct soil surveys to determine soil type. Growers will probably need professional assistance to classify their soils but it is likely that they will fall into one of the four following categories:-

- Loam
- Sand
- Loamy sand
- Alkaline clay (eg in Katherine region)

Loams are characterised by having higher clay and silt content, while sands have a low content of these fine particles. Differences in soil type have many important influences on tree management but with regard to nutrition the main consideration relates to the ability to 'hold' nutrients in the soil profile.

Soils with a high proportion of fine, colloidal particles (eg loam) are able to attract and hold nutrient elements far better than coarser textured soils (eg sand). This is related in part to the soil chemistry and in part to the physical characteristics. Water from rain or irrigation usually enters and percolates through sands at high rates which means that the nutrient elements, which are not strongly held by chemical bonds to the sand particles, are easily leached to a depth where the mango roots cannot access them. Leaching also occurs in loamy soils but is far less of a problem.

It is therefore necessary to modify fertiliser practices depending on the soil type involved. To maintain reasonably constant supply of nutrients, loams may require less frequent application of larger amounts of fertiliser compared with sands where a strategy of applying small amounts (sand particles only hold small amounts of nutrient) at frequent intervals (to continually replace what is taken up or leached) may be more appropriate. Where soil type varies across a single property this means that different fertiliser strategies will be needed for each distinct area. For all soil types, extended periods of heavy rain following the application of fertiliser will result in significant losses, so the peak period of the Wet season should usually be avoided.

### **Soil test result**

Decisions on fertiliser application rates should be based on accurate soil test records. Testing should be carried out regularly – at least twice per year. It is generally accepted that a soil test near the end of the harvest period in September-October will be important because large amounts of nutrients are removed from the farm when fruit are picked and it is important to replace these nutrients. This time of year also correlates well with the period of active root growth (see above) and usually allows the tree enough time to take up the applied fertilisers before Wet season rains become too sustained. A rule of thumb is to take this soil sample in time to get the result back and the fertiliser applied by the time harvest finishes, although nitrogen should not be applied until immediately after harvest. TropHort partners can direct growers to various soil analysis laboratories that provide a turnaround time of about 2 weeks.

Another common time for sampling is around late March, when the Wet season is drawing to a close. A test at this time of year will take account of leaching and other

losses over the preceding rainy months and allows sufficient time to build nutritional status before the critical phases of flowering and fruit development begin.



**Figure 3.** *Basic equipment is all that is required to collect a soil sample. The auger shown on the right is useful but not essential. A meaningful sample can be collected with a plastic bucket and a spade or shovel.*

The soil test result will be most valuable if the samples have been collected from a representative area and well mixed. Among TropHort partners there is wide experience in collecting soil samples and growers with no prior experience should seek guidance before sampling. Simple equipment is all that is required. In summary, the principles for collecting meaningful soil samples are as follows:-

- Identify areas with different soil types and collect separate samples from each.
- **Within each area of a given soil type**, collect samples from areas where the roots are likely to be present. For mango, this is usually a matter of collecting samples from within the zone of soil that is usually wet by the sprinklers at irrigation.
- Scrape away leaf litter and any granules of fertiliser that may be left over from previous applications.
- For each tree, collect a few hundred grams of soil from the top 10 cm into a plastic bucket using a small spade or auger.
- Sample from as many trees as possible, moving at random throughout the orchard and avoiding trees with abnormal growth or end rows.

- Once the bucket is full, carefully mix the soil and then collect a small subsample (approx 500g) into a plastic bag - excluding large root pieces. Date and label the bag so that you know where and when the sample was collected.
- **Repeat these steps for other soil types** if necessary.
- Send the samples away for analysis. Usually, it is worth having acidity (pH), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe), and boron (B) analysed.

The cost of soil analysis is typically about \$80-100 per sample. This is very low compared with the cost of fertilisers.

### **Interpreting the test result**

The following critical levels have been developed by TropHort partners based on information published in other areas and on personal observation in the north Australian industry. They are expressed in mg/kg dry soil, which is equivalent to ppm (parts per million).

#### **Soil acidity – pH**

This should be about 6.5. In northern Australia, soil pH tends to be lower than the critical level, resulting in the reduced availability of some soil nutrients. In such situations the soil has become more acidic, a problem that can be rectified by the addition of lime. Large amounts of lime may be required to correct low pH. To raise pH from 5.0 to 6.5 requires 3.6 t/ha of lime. In this situation, a sensible approach is to apply the amount in several split applications, say at 1-2 monthly intervals.

Lime should not be applied at the same time as nitrogen fertiliser because the high pH may cause loss of the nitrogen through volatilisation – allow two weeks between the application of lime and nitrogen fertilisers.

Some soils in the Katherine and Kununurra regions have high limestone content which is associated with pH in the range 7-8. For these soils lime applications should be avoided and, where possible, the sulphate form of fertilisers should be used. High pH will reduce the availability of zinc and iron making foliar applications of these elements more important.

Other points to note:

- Adding lime will also influence soil Ca levels.
- One form of lime, dolomite, contains Mg and care should be taken to avoid this if extra Mg is not required.

#### **Phosphorus – P**

This should be about 70 mg/kg and once achieved the level should be quite stable.

#### **Potassium – K**

This should be about 100-150 mg/kg. The K level can fluctuate as a result of uptake by trees and leaching. Particular attention to K fertiliser during the period of fruit development has been associated with larger fruit at harvest. If flowering is particularly intense then adding extra K could be warranted.

**Calcium – Ca**

This should be at least 1,000 mg/kg, with some evidence that levels as high as 2,000 mg/kg or more can be beneficial. The advantages of maintaining soil Ca at levels above 1,000 mg/kg remain to be proven.

**Magnesium – Mg**

This should be about 90-120 mg/kg to maintain healthy plant growth. At higher levels it is associated with green skin colour and poor blush of the fruit at maturity. Also, an imbalance in the Ca:Mg ratio can interfere with Ca uptake. Aim to keep the Ca:Mg ratio about 8:1. If irrigation water is drawn from a dolomitic soil, Mg levels may be high, particularly during the irrigation season. In this situation, very high levels of Ca may be required to maintain the Ca:Mg ratio around 8:1.

**Sulphur – S**

This should be about 12-20 mg/kg. S will be applied as part of other fertilisers that contain sulphates and will generally not need special application.

**Zinc – Zn**

This should be about 2-5 mg/kg.

**Copper – Cu**

This should be about 2 mg/kg. Copper sprays are often applied as part of a fungicide program that provides adequate Cu for the trees. In such situations the copper reading may be much higher than 2 mg/kg but is not likely to be a concern.

**Manganese – Mn**

This should be at least 4 mg/kg although rates as high as 50 mg/kg will do no harm.

**Iron – Fe**

This should be at least 5 mg/kg although rates as high as 60 mg/kg or more will do no harm. Lateritic soil can have high Fe levels.

**Boron – B**

For the most common method of analysis, this should be 1-2 mg/kg. However, an alternative method used by at least one laboratory gives lower levels with an optimum range of 0.05-0.75 mg/kg. To interpret the B result it will be important to determine which method is used by the laboratory conducting the analysis.

**Molybdenum – Mo**

This is not usually part of a soil analysis. It is required in minute amounts and is commonly included in trace element pre-mixes. If not, then a foliar spray of sodium molybdate at 0.5-1.0 g/L once or twice per year will be sufficient.

**Nitrogen – N**

There are no clear guidelines for nitrogen fertilisation. This is because there are many forms of nitrogen in soil and a measure at any one time may not accurately reflect the amount of N that is available for uptake by the tree. Also, N application is associated with stimulating new vegetative growth, the development of dark, dense canopies and green fruit with thin, easily damaged skins and little or no blush at harvest.



However, N is a vital nutrient for healthy, productive trees. A characteristic of highly productive orchards in northern Australia is that the growers regularly apply N. The rates vary and are based on personal experience. So new growers must use personal experience to develop the specifics of their nitrogen fertiliser program. Some rules of thumb are that growers who successfully achieve high yields commonly apply their N fertiliser in the period immediately following harvest. Apart from providing an early opportunity for the trees to replenish N supplies, it also minimises the possibility that high levels of soil N will carry over to the following flowering/fruiting season and cause problems with green skin colour of fruit. This is because Wet season rains will leach any soil N that is not taken up by the trees. Depending on tree size, 50 g (5 year old trees) to 500 g (15+ year old) N per tree may be required. TropHort partners are currently conducting further experiments with N fertiliser and should be able to provide advice to growers who need assistance in selecting the best N rate to apply.



**Figure 4.** *Pale foliage showing general yellowing, typical of nitrogen deficiency.*

The test results in Figure 5 show that the levels of soil nutrients can be quite variable. Generally the issue for growers is to overcome deficiencies but in some cases the nutrient levels can be quite high. This is usually not a problem and may reflect the recent application of a fungicide spray containing, for example, copper or manganese. However, boron can be toxic to mango at high levels and care should be taken when applying this fertiliser to adhere to the recommended rate. High quality fertilisers, with detailed analyses of their content, should be used to ensure that accurate amounts of nutrient are applied.



Laboratory name and contact details												
<b>Laboratory Job No</b>	JNo123											
<b>Project</b>	Soil various											
<b>Order number</b>	ONo1098											
<b>Notes</b>	Date Sampled:21/08/02											
<b>Report For</b>	TropHort											
<b>Contact</b>	Bloggs											
		<b>pH</b>	<b>P</b>	<b>K</b>	<b>Ca</b>	<b>Mg</b>	<b>S</b>	<b>Zn</b>	<b>Cu</b>	<b>Mn</b>	<b>Fe</b>	<b>B</b>
	<b>Unit</b>	pH					mg/kg					
	<b>Detection limit</b>	0	5	25	25	25	0.5	0.1	0.1	0.1	1	0.2
<b>Sample Identification</b>	<b>Lab No</b>											
Young mango - west	ymw	5	40	140	656	135	17	1.4	0.7	3.6	22	0.4
Young mango - east	yme	6	89	331	515	88	22	2.4	0.4	5.7	11	1.4
Big seedlings	bs	6	110	288	647	98	9.5	4.7	0.4	2.3	24	1.7
Old grafted	og	7	52	165	1997	736	3.5	1.8	20	4	24	1.4

**Figure 5.** A typical soil analysis result sheet in which four areas of the farm – Young mango-west, Young mango – east, Big seedlings, and Old grafted – have been sampled. The top part of the form gives all the standard identification information while the lower section provides the important information about soil nutrient levels in each of the sampled areas. In this example soil acidity is measured in pH units and all the nutrient elements are expressed as mg nutrient/kg dry soil.

Some analyses are reported in meq (milliequivalents)/100g soil. To convert from meq/100 g to mg/kg, multiply by the following factors:-

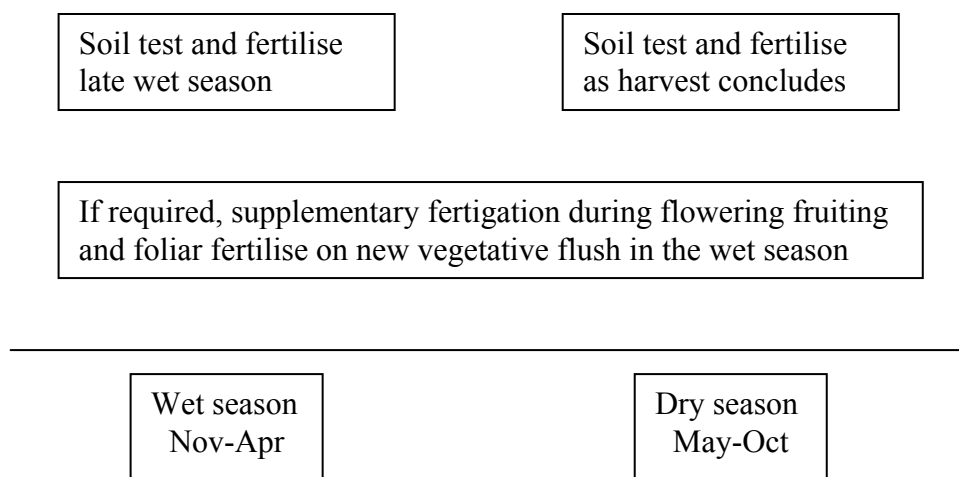
Element measured in meq/100g	Multiply by this factor to give mg/kg
K	391.0
Ca	200.4
Mg	121.6

### Growth stage of crop

The synthesis and storage of carbohydrate occurs by photosynthesis. Photosynthesis is the fundamental way that trees produce fruit. Nutrient deficiencies can limit photosynthesis and, therefore, fruit yield. Thus a major aim of fertiliser management is to maximise the potential for photosynthesis.

Photosynthesis in mango is also highly dependent on the time of year. Rates achieved during the Wet season are many times higher than those during the Dry season, when

flowering and fruiting occur. Recent research by TropHort partners indicates that excess carbohydrates produced in the Wet season can be stored within the tree to be remobilised to help with the production of flowers and fruit later in the year. This highlights the fact that fertiliser practice at one time of year (the Wet season) can have a large influence on productivity (fruit yield) many months later.



**Figure 6.** *The minimum requirement for soil sampling and fertilising is once following the heavy rains of the Wet season and again before the end of harvest. Both these times coincide with large potential losses of nutrient either through leaching in the Wet season or through direct removal in the harvested fruit. If necessary, supplementary fertilisers can be applied at other times of year.*

The objective with postharvest application of fertilisers is to provide conditions that support maximum photosynthesis during the Wet season when the potential for production and storage of carbohydrate reserves is high. If this can be achieved, the reserves that are accumulated during the Wet season will then be used to support high yields later in the season. If trees do not have the opportunity to create large reserves of stored carbohydrate because they are under-fertilised, fruit yield is likely to be limited. Further research by TropHort partners is currently underway to identify more precisely the likely role of stored carbohydrates in determining fruit yield.

As well as the effects on photosynthesis, fertilisers influence a whole range of processes within the tree. If the critical levels defined above are maintained, these processes should not be limited. However, flowering and fruiting are times of peak demand, vital to the ultimate achievement of high yields. Developing flowers and fruit have a particularly high demand for calcium, boron, and potassium. Attention should be paid to ensure that these are well supplied during flowering/fruiting. Extra application of potassium to the soil may be required between fruit set and harvest.

Good results have been achieved when this potassium fertiliser is split into small applications at several (up to five) two-three weekly intervals during fruit development compared to a single, large application early in the period. A fertigation system, where the fertiliser is dissolved and applied with the irrigation water, is used

to apply these split applications. TropHort partners can assist growers with determining the rate and timing of fertiliser applications during the period from flowering to harvest, especially since boron can be toxic if overused.

### **Age/size of trees**

The objective is to maintain a good supply of nutrients to trees, regardless of their size. The amount of fertiliser required is proportional to tree size, so separate fertilising strategies need to be developed for each age/size group of trees on the orchard. While some elements such as N, P and K are mobile within the tree and can be re-used to support the growth of new leaves, flowers or fruits if they are not available from the soil, others such as Ca, B, Mn and Fe are not mobile within the tree. This lack of mobility means that new growth will always require a fresh supply from the soil reserves, which emphasises the need to soil test and apply fertiliser regularly.

Given that the soil area for fertilising is determined by the size of the zone that is wetted at irrigation, it may be appropriate to fertilise large trees, with associated large fertiliser requirements, in a larger number of splits compared with smaller trees. Certainly heaping of fertilisers should be avoided, with even distribution across the wetted zone being preferable. This approach will also reduce potential leaching losses and contamination of ground water.

### **Application methods**

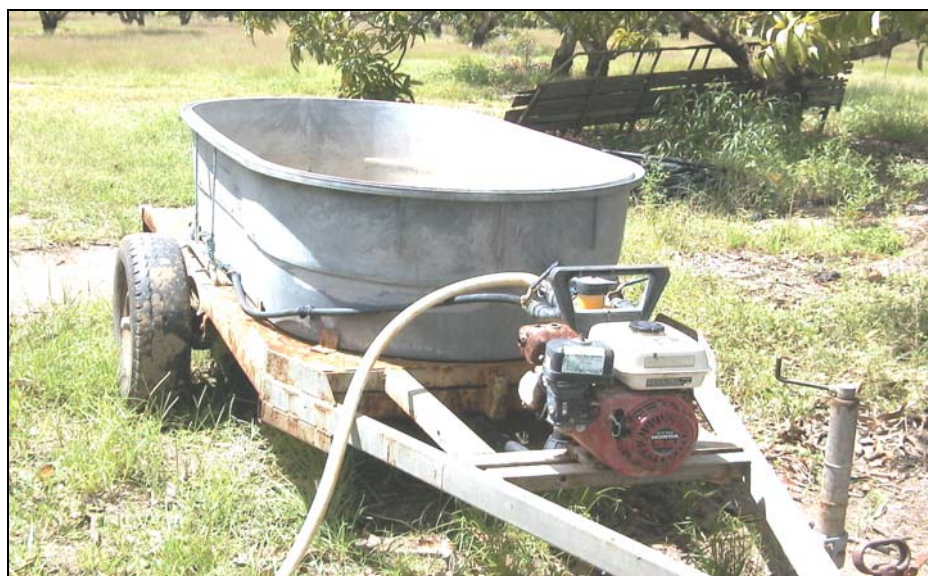
#### **Surface applied granules vs fertigation**

Fertigation is the application of fertiliser in the irrigation water. There has been no extensive, formal comparison of granular fertilisers with fertigation as alternative methods of application. The usual method is to apply granular fertilisers and water them in using irrigation. However, fertigation is becoming more readily available in the industry and features among the tools employed by growers who consistently achieve high yields. Once established, a fertigation system is flexible, requires little labour and can be used for applying a range of fertilisers.

Efficient fertigation requires the use of good quality, pure chemicals and, although they are expensive per kg, they are cost effective on a per tree basis. With fertigation, some chemicals can be mixed together facilitating the application of multiple nutrients in one operation. A list of suitable chemicals and their compatibilities is attached as an appendix. However, when in doubt growers should always test the compatibility of chemicals by mixing a small quantity in a bottle beforehand and watching for cloudiness or the formation of precipitates that could cause blockages in the irrigation lines. When doing such a test, mix chemicals at the same dilution rate at which they would be used for field application. Be sure to wear safety glasses, gloves and other protective clothing during such tests.

The idea with any method of fertilising is to place the fertiliser in the vicinity of the roots that will take up the nutrients. Given that the distribution of roots will be strongly biased towards the area of soil wet at irrigation, fertigation is a means of almost guaranteeing placement of nutrients close to the roots. The loss of nutrients by leaching can occur with fertigation. Although no detailed studies of leaching have been conducted for mango crops in northern Australia, previous experience of

TropHort partners has seen the development of a rule of thumb that recommends injecting the fertiliser into the irrigation water during the last third of the irrigation



**Figure 7.** *A simple fertigation unit comprising a plastic (non-rust) mixing tank coupled to a small injector pump. Trailer mounting allows easy transport to different irrigation blocks.*

period. If large amounts of fertiliser are required then these should be split over multiple applications.

Fertigation systems can be very simple to set up, often requiring equipment that is already available on the farm. For example, a spray unit can be readily used for fertigation by using the tank to mix the fertilisers before injecting into the irrigation line. TropHort partners can provide advice about effective systems that can be put together for little more than the cost of a small injector pump.

### **Foliar sprays**

Foliar fertiliser applications are occasionally useful as a means of ‘topping up’ on some nutrients at critical times. Studies of foliar fertiliser applications have demonstrated that young leaves and developing flower panicles are effective at taking up nutrients. However, the amounts of nutrient taken up are small and their effects are short-lived. When applied as foliar sprays to mature leaves the nutrient uptake is insignificant.

A good example of the use of foliar fertilisers is the application of trace elements (eg zinc, iron, manganese) to young vegetative flushes during the Wet season when weather conditions (heavy rain causing surface runoff or leaching) may preclude the use of soil-based fertiliser methods. Foliar sprays should be applied in calm weather during a time when rain is not expected for several hours.

By applying fungicide sprays as part of a pest control program, trace elements such as copper, zinc and manganese are also being applied because these elements are the active ingredients in a range of fungicides.

The experience of TropHort partners has been that fertiliser sprays after flowering can lead to skin damage on developing fruit and should be avoided. Also, not all fertilisers are compatible when mixed together. For example copper is not compatible with iron or zinc sulphate. As with all chemical applications, it is important to follow label directions to avoid problems with incompatibility.

Sustained soil nutrient deficiencies cannot normally be rectified by the use of foliar sprays. Previous experience has shown that when such a fertiliser program has been attempted, yield of fruit is low, in contrast to the high cost and effort of applying the foliar sprays. Thus, foliar fertilisers are best viewed as a supplement to, and not a replacement for, a well-planned, long-term soil fertilising program.

## Irrigation

### Summary – key action points

*Aim to understand how the response of mango trees to soil water content can be used to manipulate growth and productivity.*

#### **To carry out effective irrigation:**

- *Adequate supplies of good quality water will be required to meet peak demand during the season. This peak will be during the Dry season when fruits are developing under conditions of low humidity and warm temperatures. Bore, pump and sprinklers need to be checked for their ability to deliver the correct amounts of water – up to 1500 L/tree/week for large trees.*
- *Check the water quality. Bore water will usually be either acidic (pH below 7) with low mineral content, or alkaline (pH above 7) with high calcium and/or magnesium. Water quality can have a large impact on fertilizer management.*
- *It is important to understand how soil water availability is affected by factors such as rainfall, evaporation and tree water use. The supply of soil water will vary, particularly with changes in soil type and tree size, and each grower will need a technique to make estimates for their own orchard. Instruments such as tensiometers and capacitance probes can be used to measure soil water content and are commercially available. A new method, known as FullStop, is currently being evaluated.*
- *A knowledge of the role that a good water supply plays in the process of nutrient uptake will ensure that fertilizers are available to the trees when they are required. Ensure that irrigation is continued after harvest time if Wet season rains are not sufficient to ensure that fertilizers applied at this time of year are available for uptake by the trees.*
- *Mango may require a level of water stress (dry soil) to improve the possibility of achieving high levels of flowering. If no other treatment is used to stimulate flowering, irrigation should be withheld after the Wet season until 60% of the buds on a given tree have started to flower. If a flowering treatment, such as paclobutrazol has been used replacement of a small amount of water (10-20% of evaporation) during the pre-flowering period may be beneficial. As this decision will depend on other factors such as tree size and soil type, it may be best to seek advice before starting a program of pre-flowering irrigation.*

## **Irrigation**

The characteristics of the seasonally wet/dry tropical climate in the mango growing regions of northern Australia mean that a well planned and carefully executed irrigation strategy is a vital component of the grower's objective of achieving high fruit yield. While some general principles of irrigation apply across the region, the variation in soil type and ground water supply that occurs from farm to farm, together with the local and year-to-year variations in climate mean that growers need to be proactive and adaptable in their approach to irrigation management.

In particular, growers will need to determine several features of their irrigation system that is particular to their orchard. These features include:

- Availability of ground (or other) water supply
- Quality of irrigation water
- Soil type
- Capability to measure rainfall
- Method of irrigation
- Technique to measure soil water content

### **Availability of water**

When measuring the availability of water it is important to ensure that the capacity of the system – both pumping rate and aquifer delivery rate - can supply enough water to irrigate the entire orchard at times of peak demand. Ground water supplies are known to rise and fall during the year depending on rainfall in the region. The peak demand will occur when the trees have grown to mature size (from about five years old) and will coincide with the middle of the Dry season, when the availability of water could be at its minimum level for the year. So, calculations of the capacity of the irrigation system should be based on the characteristics measured in the middle of the Dry season. It is better to plant fewer trees and irrigate them all well throughout the year, rather than stretching the water over more trees and running the risk of causing drought stress at critical times during crop development.

Another important aspect of water availability concerns the capacity to maintain supplies of irrigation during the Wet season. The distribution of Wet season rains can be variable from year to year, particularly early (a late start to the Wet) and late (an early finish to the Wet) in the season. The importance of replenishing soil nutrients with fertiliser applications both early and late in the Wet season was described in an earlier section. Rainfall should not be relied on to water these fertilisers in to the soil. A better approach is to ensure that there is the capacity to irrigate or fertigate at any time to ensure timely delivery of water and/or nutrition.

### **Quality of water**

Almost all mango farms in the NT are irrigated from ground water from bores that recharge each wet season. The pH and mineral content of the water should be considered in any nutrition program. In particular, the cation balance of Ca, Mg, K, Na and Al is affected strongly by the water quality.

Bore water in the Top End usually falls between two extremes.

1. Low pH and very low mineral content water. Usually from a shale or quartz based aquifer.
2. High pH and high calcium and/or magnesium content water. Usually from a dolomite or limestone aquifer.

Low pH water (Analysis A) has the tendency to keep most nutrient minerals soluble and subject to leaching. The sandy soils in the Darwin region are naturally acid, which also adds to the mobility and leaching of most minerals in the soils. Consequently acid soils with acid water need to be managed carefully.

Regular applications of Aglime and dolomite are needed to maintain the desired cation balance. Fertigation and split applications of basal fertiliser are used to allow uptake of nutrients by the trees and avoid massive losses from leaching.

Sample	pH	electrical conductivity ( $\mu\text{S cm}^{-1}$ )	total dissolved solids	Ca Mg bicarbonate		
				(mg L <sup>-1</sup> )		
A	4.7	23	15	0	0	1
B	7.7	319	170	22	27	206

**Figure 8:** *Depending on the source, the characteristics of bore water can vary greatly. The acidic (low pH) water of sample A has no Ca or Mg but irrigating from the bore that provided sample B could influence the availability of both elements to the mango trees.*

For high pH water (Analysis B), the problem is maintaining the Ca:Mg soil ratio at the required 8:1. In these soils Mg tends to accumulate and Ca is quickly used up and/or lost. Large applications of dolomite or gypsum depending on soil pH are the only way to maintain this ratio. Large applications of Ca also tend to increase the cation exchange capacity of the soil and improve soil structure. When water has high levels of bicarbonate it may need to be treated with a water conditioner, such as ammonium sulphate, to avoid the precipitation of fertiliser or other chemicals in solution.

Surface water (rivers, streams or dams) is used by a few growers and should be checked regularly for its mineral content and pH. There are also complications with the amounts of sediment and organic matter found in dams, billabongs and rivers. This can cause blockages of filters and micro-irrigation systems.

### How much to apply

While soil type affects decision making about fertiliser management, it can also have an impact on irrigation strategies. Just as coarser textured sands ‘hold’ less nutrients and are readily leached, they hold less water than finer textured loams. The main effect of this is that sandy soils dry more quickly than loams and will often require more frequent irrigation. Compiling a map of the range of soil types on their orchard will help growers to modify irrigation management accordingly.



Research by TropHort partners has shown that on soil types typical of northern Australia, tree water use – the amount of water actually taken up by the roots - varies considerably from about 100 L/week in young trees (trunk diameter 6 cm) to around 700 L/week in mature trees (trunk diameter 25-35 cm). When other losses of soil water such as evaporation, runoff and deep drainage are taken into account the weekly irrigation requirement to avoid plant drought stress during times of peak demand can be in the range 1,000 –1,500 L for large trees.

As well as soil type, the irrigation requirement is likely to vary with variety grown, tree age, planting density, depth to the water table and other local factors, so the figures need to be interpreted for the individual farm. A general guide to the effects of tree number and size (high canopy cover for large trees) on irrigation requirement is shown in the table below. These figures are a guide only and should be confirmed by soil moisture monitoring at individual farms.

Tree water requirements (L/week)							
Canopy cover m <sup>2</sup> /ha	Tree number per hectare						
	80	100	130	140	160	180	200
1,000	490	390	330	280	250	220	200
2,000	980	780	650	560	490	440	390
3,000	1,470	1,180	980	840	740	650	590
4,000	1,960	1,570	1,310	1,120	980	870	780
5,000	2,450	1,960	1,630	1,400	1,230	1,090	980
6,000	2,940	2,350	1,960	1,680	1,470	1,310	1,180
7,000	3,430	2,740	2,290	1,960	1,720	1,520	1,370
8,000	3,920	3,140	2,610	2,240	1,960	1,740	1,570

**Figure 9:** Average mango tree irrigation requirements (L/week). From NTDBIRD Agnote 234/18.

### Measuring rainfall and evaporation

Measures of rainfall and evaporation, particularly during the transition period between the Dry and Wet seasons, will provide information to guide irrigation management. To fully irrigate trees the recommendation is to replace 70% of evaporation less rainfall. While evaporation is reasonably predictable throughout the year and can be determined from Bureau of Meteorology records, rainfall during the transition period between Wet and Dry seasons is usually dominated by intermittent, localised storms that can vary in intensity and the amount of water they deliver. In this situation the only way to be sure of rainfall at the level of the individual farm is to measure it. Since this period coincides with the main time for applying fertilisers, it is important that irrigation is continued where necessary to supplement water from rainfall.

Similarly, at the end of the Wet season, localized storms can influence the rate at which soil moisture deficit occurs during the pre-flowering period. In this situation measures of rainfall and evaporation collected on the farm will aid the grower in deciding whether or not to commence irrigation, particularly where flowering treatments have been used. TropHort partners can provide advice to growers who

want to use their rainfall and evaporation measurements as a basis for determining an appropriate irrigation strategy.

### **Method of irrigation**

Since the root system of mango comprises fine, spreading, surface roots and deeper sinker roots, the most suitable irrigation method is undertree sprinklers. These sprinklers usually wet a circle of radius 1-2 m and, depending on tree size, one or two sprinklers per tree is/are adequate. Thus, it is not imperative to wet the entire soil area under the tree canopy at irrigation. The area of soil that is wet at irrigation will be where the majority of roots are and will allow adequate area for the effective application of fertilisers.

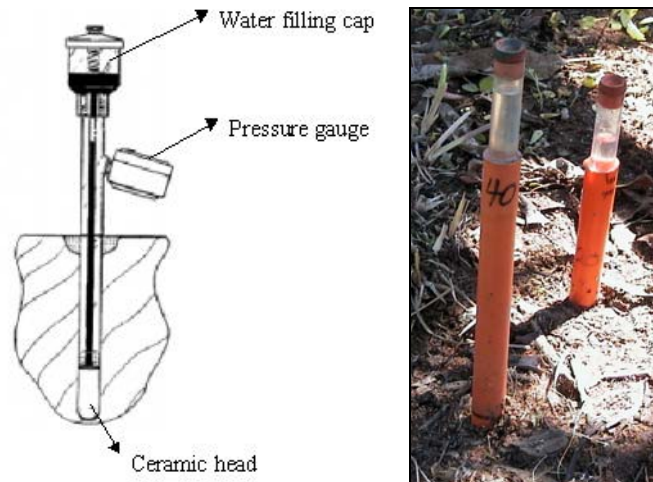
The delivery rate of sprinklers should be sufficient to allow full watering of the trees at the time of peak requirement – in the middle of the Dry season, when crop load is high. At peak demand, large trees may require up to 1,500 L of water per week, so individual sprinklers should deliver about 100-200 L per hour. Growers should calibrate sprinklers so that they can confirm their rated output. Large variation in the delivery rate of sprinklers on the same irrigation line has been observed especially for land on slopes. In this case, sprinklers with different outputs may need to be used to achieve similar water application to each tree along the one line.

### **Measuring soil water content**

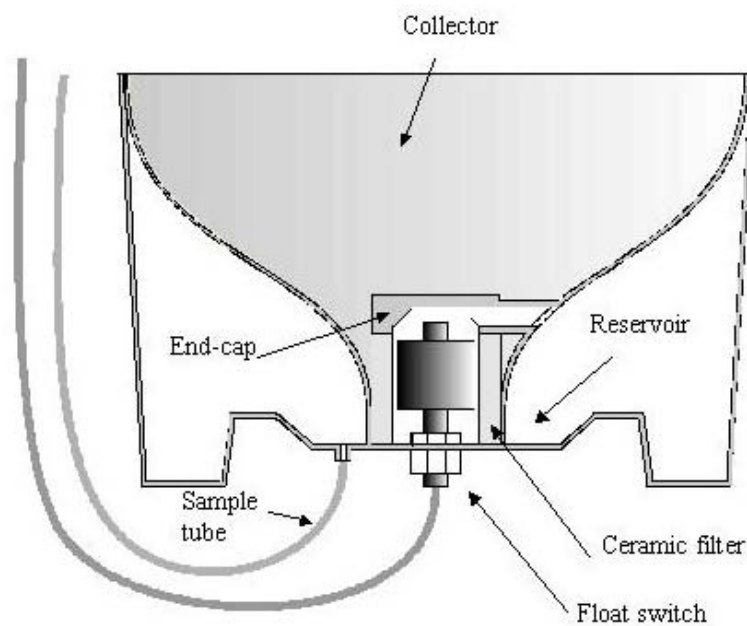
Instruments that measure soil water content also assist irrigation management. Together with the knowledge of sprinkler output, information about soil water content supports the development of a detailed irrigation strategy addressing the scheduling and amount of irrigation to apply through the whole year. Instruments for directly measuring soil water content that have been used by mango growers in northern Australia include the tensiometer and the capacitance probe.

Tensiometers measure soil water suction using a simple vacuum gauge. As soils dry, the suction increases. Tensiometers are simple to install and use and are relatively cheap. Work by TropHort partners has demonstrated that most soil water is taken up from the soil profile between 10 and 90 cm deep. Usually tensiometers are installed in pairs - the first to a depth equivalent to the level occupied by the surface roots (about 20 cm deep); the second near the deeper limit of root activity (about 50-80 cm deep). Depending on soil type irrigation is applied when the upper tensiometer is in the range 20-40 kPa suction and continues until the deep tensiometer reads about 10 kPa suction. During the Dry season weather conditions are reasonably predictable and after a short period growers will become familiar with how quickly the tensiometer readings change over time. In the Wet season tree water use can be high and result in rapid drying of the soil if regular rains do not occur. It is important to continue the use of tensiometers to schedule irrigation until regular Wet season rains commence.

Capacitance probes are expensive and more complex but have the advantage of allowing continuous measurement (computer logging) of soil water content over a range of depths. Although some growers use this technology it is more suited to research applications and large plantations. Commercial agents will provide detailed information about the use of capacitance probes to growers if they elect to pursue this option.



**Figure 10:** *Tensiometers are glass or plastic tubes with a porous, ceramic head on one end and an airtight seal on the other. The tubes are filled with water and, as the soil dries, water flows out of the tube through the porous head creating a vacuum in the tube. This strength of this vacuum can be measured directly with a pressure gauge, the information being used to guide irrigation scheduling. In contrast to the diagram on the left, the pair of tensiometers shown on the right are measured using a portable pressure gauge. Note that the tensiometers require re-filling with water.*



**Figure 11:** *The FullStop is a funnel shaped apparatus that is buried in the soil in the rootzone. After irrigation is applied the water percolates through the soil to the funnel that collects the water and closes a float switch that, in turn, provides the signal that irrigation is complete. As the soil begins to dry again, water is drawn out of the funnel which then resets the device for the next irrigation.*

Recently, TropHort partners have been studying a new, very simple method of irrigation scheduling. Known as the FullStop method, the technique relies on burying a small sensor in the soil profile in the middle of the rootzone. When the wetting front of irrigation water reaches the sensor, a signal at the soil surface indicates that it is time to turn the irrigation off. Although this device does not tell you when to irrigate, the users will soon find out that the more frequently they irrigate, the shorter is the irrigation time. They will quickly develop a feeling about how often to irrigate. TropHort partners can advise growers who are interested in using the FullStop device.

It should be remembered that any automated system must be used in accordance with a program of regular in-field checking. Blocked or damaged sprinklers can occur at any time and they must be checked regularly to minimise the impact of such events on long-term productivity.

Whatever method of measuring soil water is used it will demonstrate that sandy soils require more frequent, smaller irrigation amounts compared with loam or clay soils that will require less frequent, larger irrigation amounts. Research by TropHort partners has demonstrated that soil evaporation represents a significant loss of water from the orchard. This water is not available to the trees and represents an inefficiency.

Mulching under the trees has been shown to reduce this loss of water. There is also some evidence that windbreaks, planted far enough away so that they do not compete with the mangoes for water or nutrients, may also play a role in reducing the evaporative demand in the mango orchard. While no studies have been conducted to evaluate whether there are yield advantages associated with mulching or windbreaks, some growers utilise the techniques to reduce water use. Whether growers use mulch and/or windbreaks or not, it is most important that they base their decisions about irrigation requirements on accurate and regular measurements of soil moisture content.

### **Preflowering water stress**

A special exception to the concept of trying to maintain trees free from drought stress occurs during the preflowering period. Irrigation management during this period is covered again in a later chapter dedicated to outlining the use of a range of flowering treatments.

In summary, a period of controlled soil moisture stress (drought) has been shown to be associated with improved flowering in mango. This stress is usually achieved by withholding irrigation after the Wet season rains cease in March/April until flowering commences. As soon as flowering is observed on a majority of buds (60% of buds in flower is one rule of thumb) it is vitally important to commence full irrigation. This irrigation supports the development of flowers and fruits and also provides a means of applying the fertilisers that are required.

As not all trees will commence flowering at the same date, it is important that growers control their irrigation on a tree-by-tree basis. This can be easily achieved by kinking the 4 mm riser tube that connects each sprinkler to the water supply in each row. The kink can be held in place by slipping a small length (about 1 cm long) of 12 mm diameter polythene tube over the kink to hold it in place. If necessary, divert excess

water pressure. Water flow is restored to each tree by removing the kink in the riser tube as the 60% flowering threshold is reached.

Research by TropHort partners has shown that for trees subjected to flowering treatments (paclobutrazol or cincture+morphactin), it may be beneficial to give small irrigations (10-20 % replacement of evaporation less rainfall) during the period between the end of the Wet season and the time that the 60 % flowering threshold is achieved. However, any irrigation during this period carries with it the risk of inducing an undesirable vegetative flush. In Katherine, where soils can be sandy, irrigation has been applied as late as April-May with no negative effect on flowering. Growers who are considering irrigation in this period should consult TropHort partners for advice.

After reaching the 60 % flowering threshold, the first irrigation will need to be larger in volume than normal because the whole soil profile will be very dry. In some cases the amount of water required may exceed the designed capacity of the system. In this situation it may take several irrigations to fully replenish the soil profile and remove the drought stress. Growers can use their soil moisture measurement apparatus to assist with deciding when the irrigation has been sufficient. A characteristic of successful irrigation systems is that they have sufficient capacity to meet peak water requirements.



**Figure 12.** *Terminals should be inspected from about this stage of expansion (about 2 cm long) to determine whether the new growth will be floral or leafy. The outer bracts (sometimes referred to as scales) can be gently peeled back to reveal whether young floral buds have formed within the new growth. If floral buds are detected in at least 60% of the terminals examined then it is time to start a program of full irrigation.*

It is important that growers examine the buds early in their development when making a decision on when to commence irrigation for the season. When the buds are a centimeter or so long it is possible to determine with the naked eye whether the buds are vegetative or floral. If the majority (60%) of buds on a tree are classified as floral at this stage then growers can confidently commence irrigation without fear of producing a vegetative flush. More importantly, they can relieve the drought stress as early as possible and give the developing flowers and fruit the maximum opportunity to carry through to high yield at maturity.

## **Pruning for maximum productivity – Canopy management**

### **Summary – key action points**

*Aim to maintain the tree canopy in a form that maximizes its potential productivity.*

#### **To carry out effective canopy management:**

- *Tree growth and fruit production rely on photosynthesis, the process by which carbon dioxide from the air is converted to carbohydrate in green leaves, using energy provided by the sun.*
- *Aim to maximize photosynthesis. Ensure that pruning encourages a large number of healthy buds on the tree, while at the same time providing adequate sunlight to penetrate the canopy and support photosynthesis and growth. If the canopy is too dense, the outer layer of leaves will intercept most of the light and large areas within the canopy will be shaded and photosynthesis will be limited.*
- *For mango, photosynthesis is limited when the humidity of the air is low. Rates of photosynthesis are much higher in the Wet season compared to the Dry season. While the limitation caused by dryness of the air cannot be avoided, it is important to follow recommendations for the application of fertilizers and other inputs to ensure that these potential limitations to productivity are minimized.*
- *Carry out major pruning operations during the period following harvest. The best outcome is for this pruning to be followed by one vegetative flush and for the canopy to then remain dormant until flowering.*
- *Avoid having to remove large amounts of foliage during pruning by implementing a regular pruning program from the outset. Trees that are heavily pruned are likely to respond by producing repeated vegetative flushes rather than flowers in the following year.*
- *Assess the trees as the harvest approaches. If dense foliage is causing problems with shading within parts of the canopy, minor pruning can be carried out at this stage.*

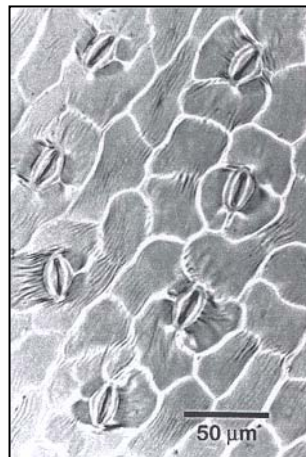
## Pruning for maximum productivity - Canopy management

Mango flowers and fruit develop from terminal buds. The number of terminals on the tree canopy is therefore the primary limit to productivity. Within the constraints of the planting density and tree height, canopy management should be carried out with the aim of maximising the number of healthy buds on the tree. One of the main techniques for manipulating the number of buds is by pruning.

As well as establishing the structural limits of the canopy shape and size, a further objective of canopy management is to ensure that tree photosynthesis is efficient. Pruning can influence photosynthesis by determining the characteristics of light interception and distribution within the canopy. A well managed canopy will also have the benefits of allowing good spray coverage for pest and disease control, with the trees being maintained at a practical size.

### Basics of photosynthesis

Mango generates the resources to grow and produce fruit by using the sun's energy to convert carbon dioxide from the air into carbohydrates, the common carbon-containing building blocks of all living things. The process is called photosynthesis, with the carbon dioxide being taken up through small pores in the leaf, known as stomata. Stomata also allow the exchange of water from the leaf to the air by vapour exchange. Mango has the ability to vary the aperture of the stomatal opening depending on the conditions prevailing at the time. So, when mango is photosynthesising effectively, the stomata are wide open, water is lost from the tree and carbon is gained. Another way of thinking about this is that if water is not readily available (eg the tree is droughted) the stomata may close, limiting photosynthesis.

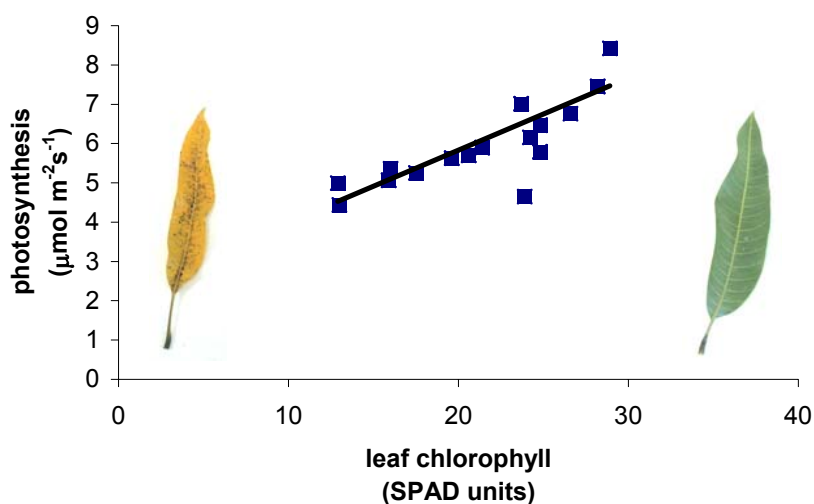


**Figure 13:** *A magnified view of part of a leaf surface showing stomata, the pores through which carbon dioxide and water vapour move between leaf and air.*

Another major factor controlling photosynthesis is the level of chlorophyll in the leaves. Chlorophyll is the green pigment that gives the leaves their colour. In photosynthesis, chlorophyll is directly involved in 'trapping' the energy from sunlight



and converting it to useful energy within the plant that drives the conversion of carbon dioxide to carbohydrate. Thus, yellow leaves, such as those that may be suffering a shortage of fertilisers, are likely to have less effective photosynthesis systems than green, healthy leaves. Care should be taken when interpreting the cause of changes in leaf colour and any possible effects on chlorophyll content should be interpreted in association with a recent soil test. This will help understand which of the nutrients may be causing the effect on leaf colour, eg low P or N causing yellowing or high Mg associated with dark green leaves. TropHort partners will assist growers understand the possible causes of and remedies to variation in leaf colour.



**Figure 14:** Chlorophyll is the pigment that gives leaves their green colour. Chlorophyll is also important for photosynthesis, with green leaves having higher rates than pale leaves.

### Light interception

If growers follow the fertiliser and irrigation recommendations contained elsewhere in this manual the leaves will be well-supplied with water and fertilisers and the main limitation to photosynthesis will be access to sunlight. For example, tree canopies that are allowed to grow large and dense, will have many leaves that are shaded. These shaded leaves have low photosynthesis as a consequence. Studies by TropHort partners have demonstrated that leaves in dense canopies that are in dark conditions add nothing to the photosynthesis of the whole tree. In fact, these leaves can be ‘parasitic’, causing a net loss of carbohydrate. Pruning should aim to avoid heavy shading of leaves inside the canopy by regularly removing unnecessary branches to open out the canopy.

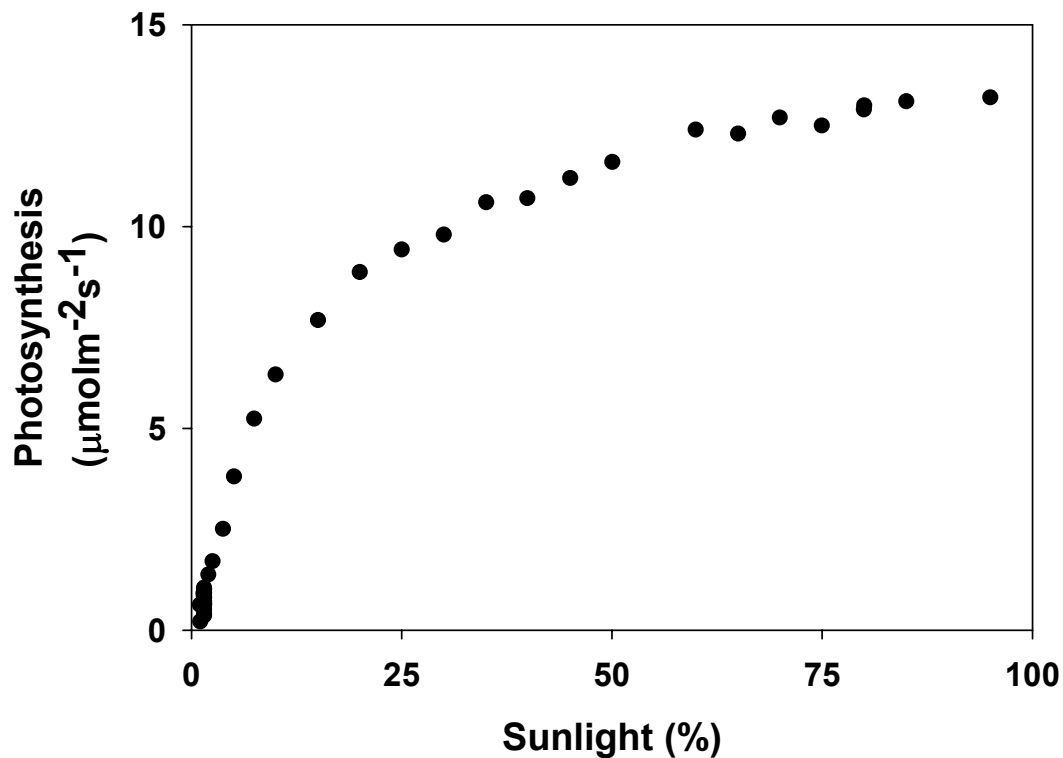


**Figure 15:** *A well-pruned, open canopy such as on the left allows good penetration of light for photosynthesis. Coverage with pesticide or fertiliser sprays is more effective when the canopy is open. A dense, dark canopy such as on the right provides a microclimate that encourages pests and disease and can limit the development of fruit skin colour.*

Although access to light is important, in the mango growing regions of northern Australia, full sunlight can be so intense that the photosynthesis mechanism in the leaves can become ‘overloaded’, resulting in inefficiencies. These periods of excess light usually occur during the middle of the day, when solar radiation is at its peak. Recent research has demonstrated that healthy leaves recover quickly once the period of excess light ends, but stressed leaves (eg droughted leaves) remain unproductive for a longer period. This further emphasises the need to maintain trees according to the fertiliser and irrigation recommendations contained in other chapters of this manual.

Effective pruning improves the interception and use of light within the tree canopy. When light passes through a canopy its intensity is reduced because of the shading and reflection of light that occurs. This means that although the leaves on the edge of the canopy may be suffering from excess light, the remaining leaves will be receiving light of lower, non-stressful intensities. If the outer layer of leaves is too dense, light will be unable to penetrate inside the tree canopy. The challenge is to prune to a level that allows this to occur without (i) removing too many leaves, and thereby limiting overall light interception; or (ii) pruning too lightly and causing heavy shading within the canopy.

Although the details of light relations within mango canopies after pruning are yet to be systematically evaluated, and guidelines for canopy pruning need to be developed by further research, TropHort partners can provide some advice based on previous observation in the north Australian industry. Although the situation will vary from orchard to orchard, depending on planting density, the basic aim of pruning is to maintain tree size such that intermingling with neighbouring trees is avoided and the maximum height is contained to a level that allows efficient picking and spraying operations.

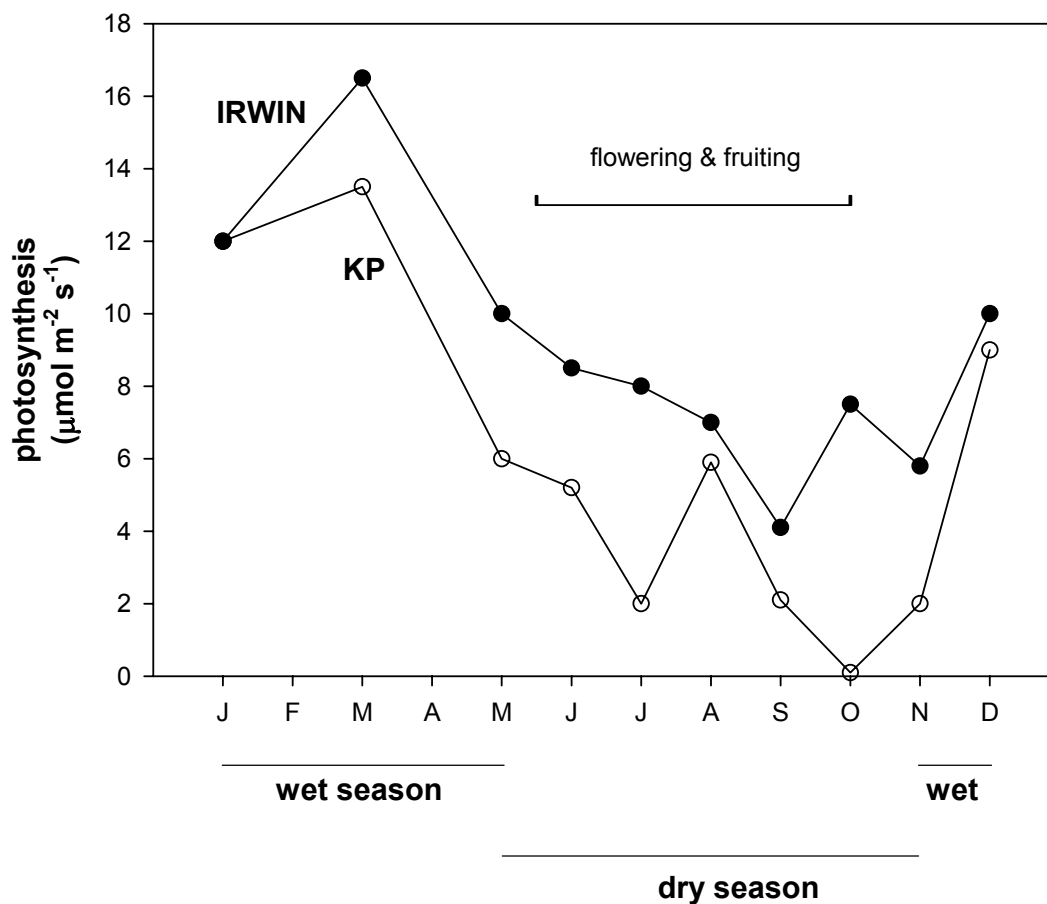


**Figure 16:** *Photosynthesis responds to light. Leaves that are heavily shaded, receiving light levels of 25% full sunlight or less will have much lower capacity for photosynthesis compared with leaves in well-pruned canopies that are well-lit, receiving higher light levels of 50-75% full sunlight or more.*

### Climate affects photosynthesis

Regardless of how well fertilised or irrigated mango trees are, their capacity for photosynthesis in full sunlight varies considerably throughout the year. Recent research by TropHort partners has demonstrated that photosynthesis during the Dry season is much lower than during the Wet season. This is explained mainly by the effect of low humidity during the Dry season which causes stomata to close. Although there is some variation in the severity of this effect between cultivars, the general response is common to all. Growers who monitor soil moisture content (see Irrigation chapter) would notice this effect as a reduction in the rate of soil drying at depth in the profile. In more humid times of year such as late in the Dry season and during the Wet season, the open stomata cause soil moisture content to decline more rapidly.

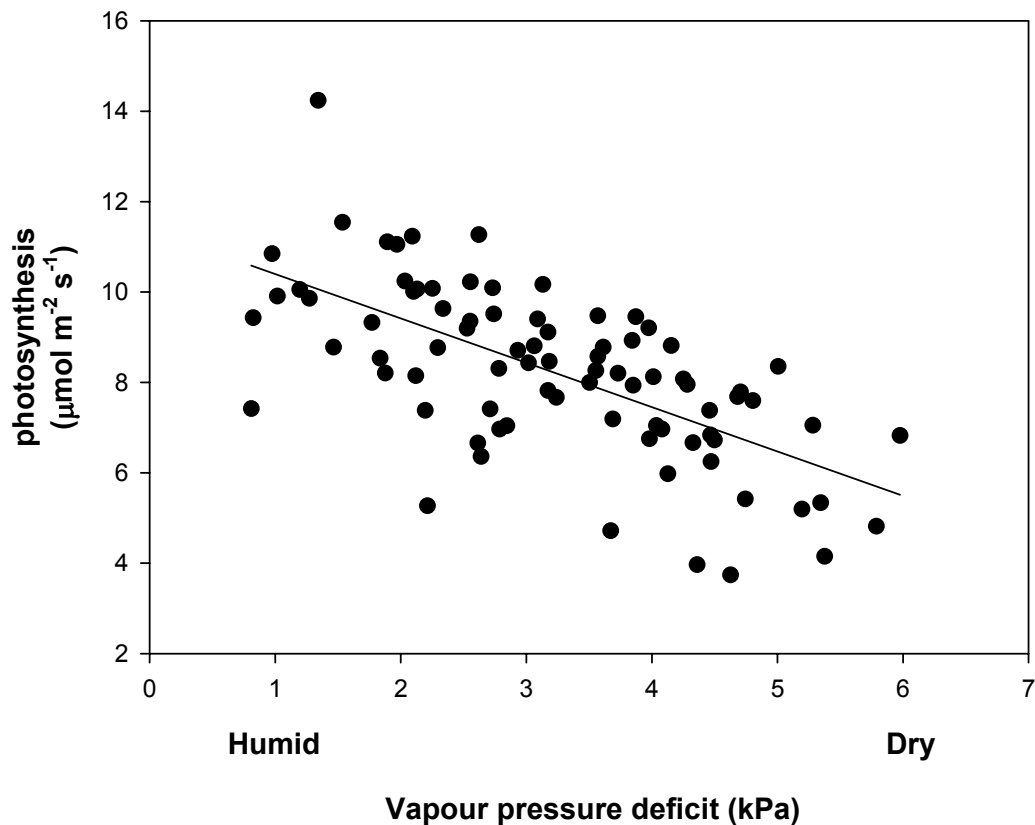
A further study by TropHort partners has shown that a consequence of this climatic limitation to photosynthesis is that flowering and fruiting are likely to rely on stored reserves of carbohydrate from within the tree. On this basis, trees that start the Dry season with high levels of stored reserves are more likely to produce and retain fruit to harvest than trees with low levels of carbohydrate storage. While other factors, such as rootstock, may influence carbohydrate distribution within the tree, management is also likely to play a role. Current research aims to establish a link between the level of reserves and subsequent production of fruit.



**Figure 17:** Low humidity during the Dry season causes leaf stomata to close, limiting photosynthesis. This period of low photosynthesis coincides with flowering and fruiting and probably contributes to the low yield of mango in northern Australia. The cultivar Kensington Pride is more severely affected than others, such as Irwin.

It has been established in recent experiments that there is a large ‘cost’ in terms of stored reserves to produce a new vegetative flush. This is because it takes considerable resources to produce and maintain the new leaf and stem structures. These processes effectively ‘drain’ the stored reserves of the tree. Further, once produced the young leaves take up to six weeks before they reach their maximum photosynthetic potential. Maintaining the young leaves during this period further reduces the tree’s reserves.

Therefore, it is imperative that pruning, which will encourage a new vegetative flush, is carried out as soon as possible after the harvest period. This will allow the new leaves time to fully develop in the Wet season when the potential for photosynthesis is greatest. Also, it will provide an opportunity to rebuild the stored reserves of the tree before the onset of flowering and fruiting, when demand for reserves is high.



**Figure 18:** *Photosynthesis of mango is affected by changes in weather conditions. When the weather is humid, stomata remain open and the opportunity for photosynthesis is high. In contrast, when vapour pressure deficit is high, such as during the Dry season, stomatal closure can limit photosynthesis.*

The carbon/energy cost of producing a vegetative flush also highlights the importance of avoiding more than one flush following post-harvest pruning. For several reasons, such a flush will produce vegetative growth that will not contribute further to the productive potential of the tree. Firstly, the extra vegetative growth will cause excessive shading in the canopy. Secondly, the larger tree canopy will be more difficult to manage effectively - eg for picking, spraying. Thirdly, the extra wood will need to be pruned at the end of the season. Finally, if the vegetative flush is initiated near the end of the Wet season, the period of pre-flowering drought combined with the negative effect of climate on photosynthesis that occurs at this time of year will limit the capacity of the tree to rebuild the stored reserves it has used to generate the flush. This, in turn, will probably reduce the potential yield of the crop.

An important principle of pruning management is to ensure that it is carried out regularly. For young trees this ensures an appropriate canopy shape/structure is achieved. For mature trees it avoids the problem of having to carry out large pruning of overgrown trees. A feature common to all trees is that their shoot and root systems grow together in equilibrium. If this equilibrium is disrupted, then the tree reacts to restore it. If an overgrown tree canopy is drastically pruned, a common response is for repeated vegetative flushing to occur until the shoot:root balance is restored. This

repeated flushing is commonly known to cause large yield reductions in the season following pruning. If the trees are not allowed to get overgrown, but are maintained by pruning only a small amount regularly, then vegetative flushing is more easily controlled without reducing the yield potential in the following season. As a general rule, highly productive trees are less vegetatively active than low yielding trees because the high fruit load competes for the reserves that would otherwise be available for vegetative growth. This emphasises the need to manage the trees in a holistic way. If fertilisers, irrigation, pruning, flowering treatments and pest control are managed to a consistent high level, the growth cycle of the tree becomes a self-sustaining system.

Minor, supplementary pruning may be beneficial in the pre-harvest period. By removing small branches that are not carrying fruit the canopy can be opened up to:

- increase colour of the fruit skin
- facilitate rapid drying if rain occurs during the harvest period
- reduce microclimates that favour insects

## Flowering management

### Summary – key action points

Aim to maximize the number of buds that flower in each year, while maintaining the trees in a healthy condition with the capacity to support large fruit yield.

#### **To maximize the capacity of trees to produce flowers and carry large numbers of fruit:**

- *Adopt a strategy of regular pruning that will limit the likelihood of the trees becoming dominated by repeated vegetative flushes (see previous chapter). The problem for mango growers in north Australia is that flowering is unpredictable. Warm, humid conditions favour vegetative growth rather than flowers. Trees that are not pruned regularly will be further predisposed to produce vegetative growth.*
- *Decide on the use of flowering treatments – paclobutrazol or cincture/morphactin/twine. Selection of trees should take account of local, soil, climatic and other conditions together with a knowledge of the vigour and yield history of the trees. These treatments should be applied during Dec-Jan, about six months before flowering is expected.*
- *Trees should not be treated with morphactin+cincture in successive years.*
- *Use soil drought during the pre-flowering period to further restrict the potential for new vegetative growth.*
- *Developing buds should be carefully inspected during the lead-up to flowering. When 60% of the buds on a tree are floral, full irrigation should commence. If flowering is not uniform it may be necessary to commence full irrigation on a tree by tree basis.*
- *Follow fertilizer recommendations (see Nutrition chapter) to ensure that nutrients are available to support the growth of the developing fruits.*

## Flowering management

The information in this chapter relates exclusively to Kensington Pride, because most previous research has concentrated on this cultivar, reflecting its predominance in the north Australian industry and its erratic flowering behaviour in the seasonally wet/dry tropics. TropHort partners have some experience with flowering management in other cultivars and can provide this information to growers on request.

### The problem

A major competitive advantage for mango growers in northern Australia is that the warm climate offers the potential to produce the first mangoes of the domestic season. Early mangoes that are of high quality attract high prices in the southern markets and avoid potential pests and diseases that can occur after the onset of the Wet season. However, the same climatic conditions that offer the potential for early fruit production can also limit production of Kensington Pride mango. The major limitation arises as a consequence of erratic or late flowering.

Although the precise mechanisms are not understood, flowering in mango is associated with a period of cool weather that induces active buds to commence reproductive development. There is no predictable winter period in the tropical north Australian region and the onset of cooler weather during the Dry season can vary both in timing and duration from year to year. Past experience has indicated that year-to-year differences in flowering time and intensity are a reflection of this variation in Dry season weather conditions.

The trigger for reproductive growth is complex and a simple relationship between cool temperature and the onset of flowering does not exist in the north Australia region. While a period of cool weather, such as often occurs in the Dry season in Katherine, is associated with the onset of flowering it is no guarantee that high levels of flowering will be achieved. In particular, it appears that the level of vegetative flushing will modify the flowering response, with mature terminals that have not flushed recently favouring the development of flowers while young leaves are inhibitory. This effect of vegetative development can modify any positive effects of temperature such that if the terminal bud has recently undergone, or is undergoing, a flush of new leaves when a period of cool weather occurs, then those terminals are far less likely to flower than terminals that have not undergone recent vegetative flushing.

Taking these factors together the grower should aim to restrain vegetative growth during the pre-flowering period to maximize the possibility of inducing flowers, should a period of cool weather occur. A range of treatments that encourage flowering by restricting vegetative growth are available.

### Flowering Treatments

The three treatments for enhancing flowering that are commonly in use in the north Australian mango industry are (i) withholding irrigation during the period between the end of the Wet season and the onset of flowering; (ii) applying paclobutrazol as a soil drench around the trunk of the tree; and (iii) applying morphactin to a trunk cincture (known as mango flowering treatment, MFT). While these three treatments have distinct modes of action, they have the common effect of inhibiting vegetative growth.



*(i) Withholding irrigation*

A drought stress is imposed by withholding irrigation after the Wet season rains cease in March/April until flowering commences. By its nature, this treatment is unpredictable, because the effectiveness will depend on when the Wet season rains finish for the year. Final rains of the year can occur at any time during March or April. Vegetative growth is sensitive to the availability of water, so the sooner that the period of drought is imposed, the sooner the restriction to new leaf growth will occur.

If no other flowering treatment is used, irrigation should not commence until the onset of flowering. However, since flowering is such a crucial stage of crop development, it is imperative that growers relieve the drought stress as soon as possible. For this reason, growers need to regularly inspect their trees to look for floral buds from late May onwards (see Figure 11). As soon as 60 % of the buds on a tree are known to be floral, irrigation should commence. If growers wait until panicles are fully expanded then the irrigation is too late, with the likelihood that drought stress will reduce yield potential by causing flowers or fruitlets to fall early in their development. Also, as noted in the Irrigation chapter, the decision on whether to commence irrigation should be individually made for each tree.

Although drought stress is considered to be favourable, it does not guarantee early or intense flowering. Rainfall late in the Wet season or warm temperatures during the Dry season are likely to encourage vegetative rather than floral growth.

*(ii) Paclobutrazol*

In mango, hormones known as gibberellins are produced by the tree and are associated with the development of new leaves. Paclobutrazol improves the likelihood of flowering because this chemical is an inhibitor of gibberellin synthesis and therefore restricts the vegetative growth. Research by TropHort partners has clearly demonstrated the potential of paclobutrazol to improve flowering.

Paclobutrazol is best applied once each year during December – January as a soil drench around the trunk of the tree with the dose rate proportional to tree size. A rule of thumb developed by TropHort partners is to calculate the dose of paclobutrazol (grams of active ingredient, g ai) using the formula

$$\text{Dose (g ai)} = 1.25 \times [\text{tree height (m)} + \text{canopy width (m)}] / 2$$

For a tree that is 4 m tall and with 4.5 m width of canopy,

$$\begin{aligned} \text{Dose} &= 1.25 \times [4 + 4.5] / 2 \\ &= 1.25 \times 4.25 \\ &= 5.31 \text{ g ai per tree} \end{aligned}$$

The commercial product often contains 250 g active ingredient per litre, which means approximately 21 ml (ie 5.31 x 4) of the commercial paclobutrazol would be required per tree.

If the trees are pruned prior to application then use the pre-pruning dimensions of the tree to calculate the paclobutrazol dose. The required dose is mixed with about one litre of clean water before application. After applying the soil drench growers should

ensure that rainfall or irrigation prevents the soil surface from drying for at least several days to allow uptake of the active ingredient.

The rate of paclobutrazol required may also vary with soil type, trees growing in sandy soils needing less than trees growing in heavier clay or loam soils. Monitoring tree performance over several years will assist growers to make this decision. In the first instance the formula shown above should be used.



**Figure 19:** A syringe can be used to measure the dose of paclobutrazol which is then mixed with about 1 L of clean water. The solution is then poured onto the soil around the trunk of the tree. The soil should be kept moist for several days following application to ensure adequate uptake of the paclobutrazol.

It is recommended that soil drought between the end of the Wet season and the onset of flowering should be applied together with the paclobutrazol treatment. Unlike the situation where drought alone is used as a flowering treatment, trees that have been treated with paclobutrazol may benefit from small irrigations (10-20 % replacement of evaporation) during the period between the end of the Wet season and the time that the 60 % flowering threshold is achieved. The justification for applying these small irrigations will vary from year to year and growers who are unsure can seek the advice of TropHort partners beforehand.

Although of great potential benefit, recent research by TropHort partners has demonstrated that if the climatic conditions during the Dry season are dominated by warm temperatures, then paclobutrazol is far less effective compared with years in which cool temperatures accompany flowering time. This response probably explains the variable response to paclobutrazol that is reported by growers in tropical regions and represents a significant risk for growers. They must commit to the expense of

applying paclobutrazol in December-January with no knowledge of the likely climatic conditions at the next flowering time. However, this risk is generally accepted as being less than the risk of relying on soil drought alone as a flowering treatment.

*(iii) Mango flowering treatment – MFT*

This compound treatment combines traditional cultural techniques (cincturing and strangulation of the trunk) with the application of a chemical growth regulator (twine soaked in morphactin solution and then tied into the cincture). Experience with other crops has shown that both cincturing and strangulation can be effective in restraining the vegetative growth of the tree. The chemical, morphactin, acts to specifically inhibit the development of new shoots and roots. Recent research by TropHort partners has demonstrated that MFT, which combines all these treatments, is very effective at restraining the growth of mango trees. It also encourages high levels of flowering that are achieved whether the Dry season temperatures are dominated by warm or cool temperatures.

However, by its nature the MFT treatment is ‘stressful’ for the tree and experience has shown that only certain trees are capable of responding well in terms of high yield at harvest. Other trees, which may flower very well, lose yield potential between flowering and harvest as a consequence of premature flower or fruitlet drop or fruit maturing at a size that is too small to market. At worst, tree death has been associated with the use of MFT but the occurrence of this is extremely low. Thus, the grower who uses this treatment must be prepared to carry these risks. Selecting only healthy, vigorous trees and initially ‘testing’ the treatment on only a small number will minimise the consequences of these risks.

**Tree selection and management for MFT trees**

The experience of TropHort partners is that trees responding well to MFT have the following characteristics:-

- They are well-grown, at least five year old and capable of bearing a crop. Generally, the larger the tree, the better the response.
- They are vegetatively vigorous and may be grafted or seedling.
- The treatment can be applied from November to February but is most often applied in December – January, and often encourages a vegetative flush shortly after application.
- Conditions for tree growth are free of other stresses such as those caused by waterlogging, rocky or hard soil.
- Growers manage the trees to avoid stress by following irrigation and fertiliser recommendations outlined in this manual.
- In most situations the severity of preflowering drought is limited by applying irrigation to replace about 10-20% of the cumulative evaporation each week.
- Pests and diseases are controlled, particularly longicorn beetle.



**Figure 20:** *MFT* - a length of twine that has previously been soaked in a morphactin solution is tied tightly into a cincture cut through the bark around the trunk of the tree.

Research by TropHort partners has demonstrated that trees that have been treated with MFT have root growth reduced by about 50 % compared with untreated trees. This probably reduces the ability of trees to take up water and nutrients and growers should consider adding extra fertilisers and irrigation to compensate. Factors such as soil type, tree size and other local factors may modify the response to extra inputs but based on past experience TropHort partners can provide advice to growers.

As for trees treated with paclobutrazol, those treated with MFT may benefit from small irrigations (10-20 % replacement of evaporation) during the period between the end of the Wet season and the time that the 60 % flowering threshold is achieved. Once flowering commences and full irrigations are applied, a foliar spray of low biuret urea (10g/L) + Aquasol<sup>®</sup> will be beneficial.

### **Retreatment with MFT**

Usually a large flowering/fruiting response to MFT occurs in the season following treatment, with the possibility of a smaller, carryover effect during the second season after treatment. However, often the trees behave like untreated trees in the second season after treatment.

There has been little systematic research to define optimal cycles of retreatment, but experience of TropHort partners has demonstrated that reapplying MFT in consecutive years results in tree decline and low yields. At least one year, and possibly longer, should be allowed for the trees to recover between treatments. In any case, it may be desirable to rotate flowering treatments around sections of the orchard

to spread flowering and harvest times. In this way the annual peak in activities will be spread over the maximum period allowing for the maximum utilisation of labour and machinery.

### **Modified MFT**

Recent experiments with modified MFT aimed at developing treatments that can be used more frequently and without the use of the chemical morphactin have demonstrated some positive results. These experiments have examined cincturing and strangulation with twine that has not been soaked in morphactin as alternatives to the usual MFT treatment.

In summary, the results with modified MFT have shown that:

- Cincturing alone during December – January gives little, if any, benefit for flowering or fruiting.
- Cincturing during December – January and strangulation, by tying a length of dry twine into the cincture, generally improves flowering and fruiting compared with untreated trees. While the effect is not as large or consistent as with MFT, there are no apparent negative effects on tree vigour and the treatment should be suitable for annual re-application.

The morphactin component of MFT is relatively new and is not currently registered for commercial use. However, the use of modified MFT based on cincturing and strangulation with dry twine is not restricted.

TropHort partners can provide advice to growers who are interested in using any of the flowering treatments discussed in this chapter.

## **Fruit set and retention**

### **Summary – key action points**

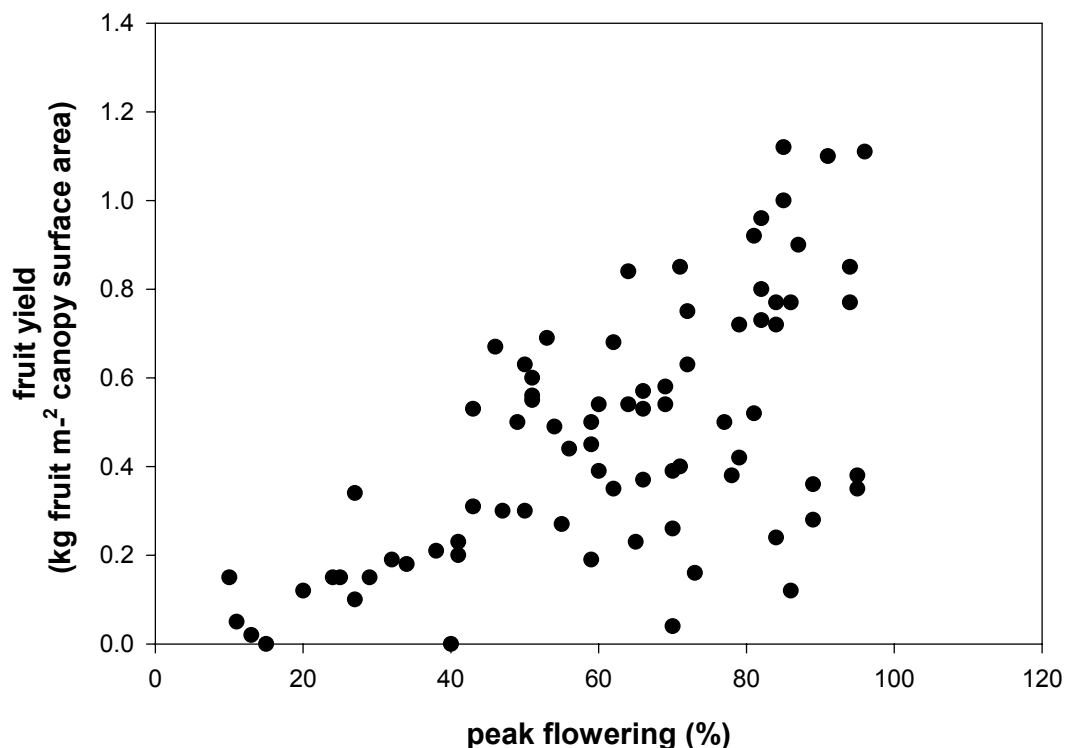
*Aim to maximize the conversion of flowers to high quality fruit.*

**Flowering only offers the potential for fruit production. There are several issues that growers can address to maximize the chances of converting flowers to fruit.**

- *Follow fertiliser recommendations and pay particular attention to ensuring Ca, B and K are available during the flowering and fruit development phases.*
- *Ensure irrigation is commenced as soon as possible after flowering. Treat each tree on an individual basis. Monitor soil moisture to avoid severe soil drought during the fruit development phase.*
- *Encourage pollinators. Blowflies are effective and can be easily encouraged to breed in the orchard by establishing bait stations.*
- *Self-pollination occurs in KP but some observations suggest cross pollination can be beneficial. Plant a few trees of alternative cultivars, such as Nam Dok Mai, in the orchard to encourage cross pollination.*
- *Monitor pests and diseases and implement control measures where required. Spraying at peak flowering and early fruit set can be harmful to flowers and developing fruit and this should be taken into consideration when deciding whether or not to apply a pesticide or foliar fertilisers.*

## Fruit set and retention

While flowering is seen as the major limitation to mango productivity, particularly of Kensington Pride, it is clear that careful management between flowering and harvest is required to ensure the maximum conversion of flowers to fruit. Recent research by TropHort partners on mango farms at a range of locations across the Darwin, Daly River and Katherine mango growing regions has demonstrated that high levels of flowering do not carry any guarantee of high fruit yields. The graph below shows that while high yield requires high levels of flowering, fruit production is very variable at all levels of flowering.



**Figure 21:** *Flowering is a prerequisite for fruit production, however, high levels of flowering are no guarantee of high yield. Excellent management between flowering and harvest is vital to achieve a high efficiency of conversion of flowers to fruit.*

Mango management for high production is a full-time, year round job. However, because of the nature of the flowering process – the potential for flowering and, therefore yield, only arises for a short period each year; the onset and level of flowering are uncertain – growers must be sure to make the most of the opportunity. Several factors that are under the control of growers can affect the efficiency of conversion of flowers to fruit. Some of these, such as those relating to fertiliser and irrigation management, have been dealt with elsewhere in this manual and are briefly

restated here. Others include the management of pollinators (vectors such as insects or wind that carry pollen to the female flower), pollinisers (mango trees with male flowers that produce pollen) and insect or disease attack.

### **Fertiliser and irrigation**

Having achieved flowering it is important to minimise the limits to productivity during the period of fruit set and development. The fertiliser program, outlined in the Nutrition chapter, aims to supply the full range of nutrients required. If in doubt seek advice about fertiliser recommendations. In particular, the flowering and fruit production period may require applications of potassium (K), calcium (Ca) or boron (B). These elements are important for the development of flowers and fruit and Ca and B need to be in ‘fresh’ supply because they cannot be remobilized from other areas within the tree.



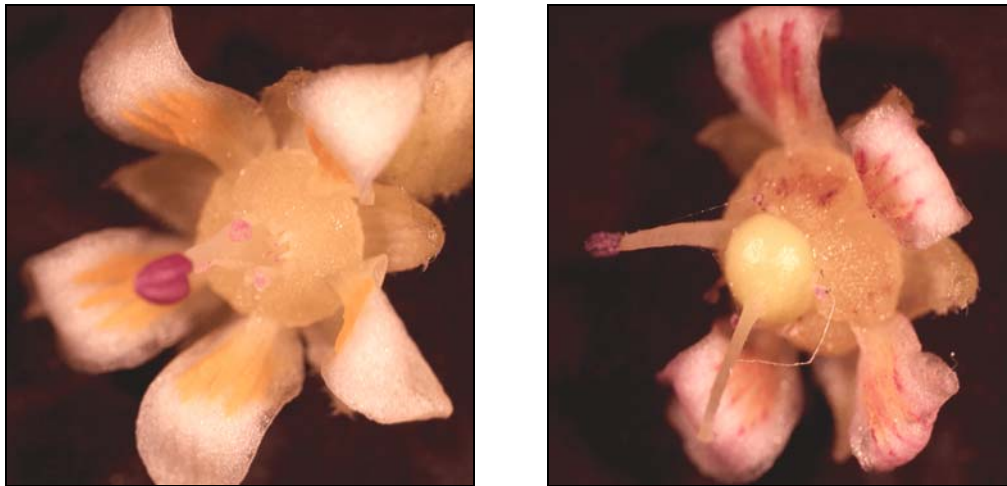
**Figure 22:** *Excellent management will be required to convert flower buds to fruit.*

Growers will need to decide about re-starting irrigation after flowering occurs. As outlined in the Irrigation chapter, this decision should be made individually for each tree. The most important consideration is to inspect the buds as they start to emerge so that irrigation commences as soon as possible. When 60% of these buds on a tree are confirmed as floral, full irrigation of that tree should start. Flowers and developing fruit are particularly sensitive to drought. If the re-start of irrigation is delayed, the risk of drought causing premature flower and fruit drop increases. Once underway, soil moisture should be regularly monitored to ensure that irrigation continues to keep the tree well-supplied with water during the period from flowering until harvest.



### **Pollinators and pollinisers**

Mango panicles contain a mixture of male and hermaphrodite (with both male and female reproductive structures on a single flower) flowers. Fruit can only arise from the hermaphrodite flowers. Although the ratio of male to hermaphrodite flowers can vary, research has shown that most hermaphrodites are produced early in the season. Late season flowers are often virtually all male. It is also important to recognise that pollination only occurs during the period between dawn and noon each day. After this time the flowers are not receptive to pollination until the next day.



**Figure 23:** *Mango flowers can be male (left) or hermaphrodite (right). Large purple anthers can be seen on the male flower, while the hermaphrodite flower shows both purple anthers and an obvious, bulbous carpel which contains the ovary.*

The mango flowers are usually pollinated by insects and research by TropHort partners has indicated that a range of species is effective. Of these, blowflies can be easily encouraged and do not cause any problems with other aspects of fruit production. Blowflies are particularly active during the mornings when flowers are most receptive to pollination. They also remain active in cool weather. European honey bees are not favoured because they are too large for the mango flowers and are not active early in the day. A range of techniques to support blowfly breeding in the orchard has been examined and TropHort partners can provide advice to growers seeking to use blowflies as a source of pollinators. Interestingly, observations of blowfly breeding stations indicate that the flies remain localised in the orchard near the breeding station. For this reason, multiple stations are required within each orchard and/or stations need to be moved around the orchard regularly to ensure an even distribution of flies throughout. Fly breeding stations can be simply established by placing a protein source, such as pet food or other meat scraps, in an open container and ensuring that the station is kept moist.

Mango is receptive to self-pollination and many trees in uniform Kensington Pride orchards in northern Australia must be self-pollinated because there are no alternative varieties present in the orchard. However, observations in orchards where alternative varieties are available suggest that cross pollination can occur and may be beneficial

to Kensington Pride. To be effective the polliniser must be in flower at the same time as the main crop variety. Although no systematic evaluations have been carried out, observations suggest that Nam Dok Mai and Kensington Pride are compatible pollinisers for each other northern Australia.

### **Pests and disease**

While pest and disease management is important throughout the year, it is even more vital at flowering time, when the annual yield potential is set. The best approach is to ensure a regular program of pest and disease monitoring is carried out in the orchard, particularly during the period leading up to and including flowering and fruit development. Fungal or insect attacks at this time can completely destroy the flowers and young, developing fruit. Guidelines for identifying and controlling these pests are contained in the Pest and Disease Management chapter.

A key point to remember is that any spray, including foliar fertilisers and some insecticides, can be harmful to flowers (eg carbaryl) or to beneficial pollinators. Where possible growers should plan their sprays to avoid peak flowering and early fruit set times. This may involve a trade-off between current pest damage to some of the crop and the yield potential of the overall crop. In this situation growers should urgently seek advice from TropHort partners or elsewhere before taking action.

## **Pest and disease management**

### **Summary - key action points**

*Aim to regularly monitor pests and disease and apply control measures when appropriate.*

**Effective pest and disease control strategies are based on a program of regular surveys throughout the orchard.**

- *Regular surveys will identify specific times of year or areas of the orchard that pests or weeds are likely to be a problem.*
- *Experienced pest surveyors will be able to decide when an economic threshold of incidence is reached.*
- *Trees that are well managed with respect to fertilizers and irrigation are likely to be more resistant to pest/disease attack.*
- *Organic mango growers may consider using green ants as part of their pest control strategy.*
- *A recent publication “Pests, Diseases and Disorders of Mangoes in the Northern Territory” is a valuable reference, available through NTHA or NTDBIRD.*

## **Pest and disease management**

A recent publication *Pests, Diseases and Disorders of Mangoes in the Northern Territory* describes in excellent detail the appropriate strategies for identifying, monitoring and controlling insect and disease pests in north Australian mango orchards. Copies can be obtained from Northern Territory Horticultural Association or NT Department of Business, Industry and Resource Development.

As well as the information in the abovementioned manual, it is appropriate to pay attention to some key principles and practices.

- A regular pest/disease monitoring program is essential.

The best way to keep track of pest or disease incursions is to spend time in the orchard making observations on trees selected at random across the whole orchard. By carrying out these pest checks regularly, and keeping a record, it will be possible to identify whether certain pests and diseases are particularly active at certain times of year or with certain stages of crop development. For pests or diseases that occur regularly it will then be possible for growers to predict a likely incursion and to carry out timely protective measures. For example, when the humidity declines during the Dry season, thrips often come into the irrigated orchard. Regular insect pests will usually arrive at a similar place in orchard. Growers should note where incursions originate and take particular notice of these areas when pest checking.

- Pesticide treatments should only be applied when a threshold of incidence is exceeded.

Pest and disease monitoring records will assist in making a judgement about whether a particular outbreak warrants the use of pesticide sprays. This decision will be modified by information about the stage of development of the crop. For example, when new vegetative or floral growth is occurring the potential damage caused by insects or disease will be much greater than at other times.

- Pest/disease management is part of a holistic crop management program.

Trees that are well-managed will likely be more resistant to attack by pathogens. For example trees that are well supplied with calcium fertiliser could be expected to have tougher leaves, while trees receiving excess nitrogen may have softer leaves. Some insects (eg longicorn beetle) are associated with attacking trees that are stressed, such as by excessive soil drought or by waterlogging.

- Pest/disease management may be influenced by weather patterns.

Year to year variations in rainfall or temperature may influence the onset of pest/disease incursions. In particular, the timing and amount of rainfall during the transition between Wet and Dry seasons and the occurrence of cool temperatures during the Dry season are known to vary between years. Both of these factors could influence the build up of pest/disease problems, either by a direct effect on the pest/disease organism or indirectly through an effect on crop development.

- Integrated pest management

Of potential interest to organic mango growers, green ants have been demonstrated to attack the main mango insect pests. However, green ants are known to encourage mealybugs and can cause damage to the fruit when they secrete formic acid. Also, the green ant colonies need to be managed at harvest when they could create problems for pickers. TropHort partners are currently in the process of investigating technologies for the use of green ants in combination with a range of soft chemical or cultural treatment in commercial orchards. While early results are promising, the results will not be finalized and released to industry until the project is completed in 2004.

#### Weeds

Most active mango roots will develop in the well-fertilised, irrigated zone under the tree canopy. Weeds that are allowed to grow in this area will compete with the tree, effectively 'pinching' water and nutrients from the mango tree. It is important that these weeds are removed because they compete with the tree for nutrients. During the Dry season they will also compete for irrigation water.

## **Fruit maturity**

### **Summary – key action points**

*Aim to predict labour and other harvest requirements and pick fruit at optimal maturity.*

#### **A range of techniques can be used to estimate maturity:**

- *Regional heat sums, published in rural newspapers, provide a broad guide.*
- *On farm heat sums, calculated using temperature data from the individual orchard, have been demonstrated to have a high level of accuracy over the last two seasons.*
- *Dry matter (DM) testing of fruit is a proven method. Avoid picking until DM is 14%.*
- *Flesh colour changes from green/white to yellow/orange. Generally, can be used in field as a confirmation of maturity. The change occurs late in development making it difficult to use as a predictor of picking date.*
- *External characteristics. Changes in fruit shape, colour, and skin texture can be used in field as a confirmation of maturity. The changes occur late in development making them difficult to use as a predictor of picking date.*

## Fruit maturity

The issues addressed in this manual are restricted to the 'on-farm' management practices under the full control of growers. In general, it is accepted that a high standard of management during the fruit development phase will be reflected in high quality fruit post harvest. However, at harvest time, the fate of the fruit becomes subject to a range of external factors such as:

- selection and handling in field by pickers
- de-sapping, washing and grading processes
- handling during packing and transport operations
- cooling and the maintenance of a consistent cool chain from the orchard to the point of sale

To ensure a high quality product it will be necessary to implement practices that minimise the influence of these external factors on the fruit.

One pre-harvest factor that growers can control and which has a potentially large impact on the fate and value of their fruit is the selection of harvest time. This involves predicting the date of fruit maturity.

### Predicting fruit maturity

A variety of techniques are used to predict picking time. To organise labour and other harvest requirements needs as long a lead time as possible, so it is best to use the techniques that give the earliest predictions of harvest date.

#### (i) Regional heat sums

The rate of fruit maturity is strongly linked to the temperatures that prevail between flowering (the date at which the flowering panicle is about 3 cm long) and harvest. Temperatures can vary from region to region or from farm to farm. Heat sums are calculated for each location by using the daily average temperature to determine the number of heat units. For each degree that the average daily temperature exceeds 12°C, one heat unit is accumulated. Predictions of picking date are based on a threshold cumulative total heat units (heat sum) of 1600. Experience has shown these predictions to be accurate to within two weeks. Regional heat sum predictions for main mango growing locations are published in rural newspapers.

#### (ii) On farm heat sums and Dry Matter testing of fruit

If growers record temperatures on their own orchard, heat sums that apply directly to the individual crop can be calculated. Such on farm heat sums predict fruit maturity with an accuracy of within two days. For each day after flowering the heat units are calculated from the formula:-

$$\{(\text{Max Temp } (^{\circ}\text{C}) + \text{Min Temp } (^{\circ}\text{C})) / 2\} - 12 = \text{daily heat units}$$

The heat sum is the total over a series of days. Harvest time is indicated when the accumulated heat sum reaches 1,600 heat units.

Dry matter testing can be used to predict fruit maturity during the 3-4 weeks leading up to harvest. Several fruit should be selected at random from the orchard and samples of the flesh weighed fresh and after drying to constant weight. These fresh and dry weights are used to calculate the dry matter (DM) % as

$$\text{DM (\%)} = [\text{dry weight (g)} / \text{fresh weight (g)}] \times 100$$

Fruit should not be picked until DM reaches 14%. The rate of increase in DM is approximately 1% per week. As flowering can occur in several phases it is important that growers estimate the proportion of fruit that will mature from each phase of flowering. Their DM sampling should take these different proportions of the overall crop into account i.e. sample some fruit from each flowering phase.

(iii) Flesh colour

During the last stages of fruit maturity prior to harvest the flesh colour changes from green/white to yellow/orange. This change to cream/yellow can be used as an indication of picking date. At this late stage in maturity the change in colour can occur over a period of only several days and gives very little lead time for planning other harvest requirements. Observations of flesh colour are probably best used on the day of harvest as confirmation that the heat sum or DM predictions are correct.

(iv) External characteristics

In the final phases of maturity the fruit changes shape, becoming rounder at the beak end and with the shoulders of the fruit at the stem end filling out. Accompanying this change in shape, the skin becomes smoother. Also, the background colour of the fruit changes from deep green to a paler green. As for flesh colour, observations of external characteristics are probably best used as confirmation, rather than prediction, of harvest date.

A guide to mature flesh colour and fruit external characteristics is available through the NTHA or NTDBIRD.



## Literature

A range of sources was used in compiling this manual. These include:

- Agnotes. Compiled by various staff of NTDBIRD covering a wide range of topics concerning mango management.
- Pests, Diseases and Disorders of Mangoes in the Northern Territory. An illustrated field guide. (2002). NTDBIRD in partnership with NTHA.
- Annual reports and reports to industry compiled by NTDBIRD and CSIRO.
- Scientific journal and conference publications.
- Unpublished data from ongoing research.

TropHort contacts can provide access to the published information for those who wish to gather more detail than is provided in this manual.

## Appendix

### Fertigation chemicals

List of commonly used fertigation chemicals and their solubility data. (From *Fertigation*. C. Burt, K.O'Connor and T. Ruehr (1995). Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, California, USA). [32°F = 0°C; change of 18°F approximates a change of 10°C]

	Grade	Form	Temp °F	Solubility gm/100 ml
<u>Nitrogen Fertilizers</u>				
Ammonium Nitrate	34-0-0	NH <sub>4</sub> NO <sub>3</sub>	32	18.3
Ammonium Polysulfide	20-0-0	NH <sub>4</sub> S <sub>x</sub>		high
Ammonium Sulfate	21-0-0	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	32	70.6
Ammonium Thiosulfate	12-0-0	(NH <sub>4</sub> ) <sub>2</sub> S <sub>2</sub> O <sub>3</sub>		v. high
Anhydrous Ammonia	82-0-0	NH <sub>3</sub>	59	38.0
Aqua Ammonia	20-0-0	NH <sub>3</sub> H <sub>2</sub> O/NH <sub>4</sub> OH		high
Calcium Nitrate	15.5-0-0	Ca(NO <sub>3</sub> ) <sub>2</sub>	62	121.2
Urea	46-0-0	CO(NH <sub>2</sub> ) <sub>2</sub>		100.0
Urea Sulfuric Acid	28-0-0	CO(NH <sub>2</sub> ) <sub>2</sub> • H <sub>2</sub> SO <sub>4</sub>		high
Urea Ammonium Nitrate	32-0-0	CO(NH <sub>2</sub> ) <sub>2</sub> • NH <sub>4</sub> NO <sub>3</sub>		high
<u>Phosphate Fertilizers</u>				
Ammonium Phosphate	8-24-0	NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub>		moderate
Ammonium Polyphosphate	10-34-0	(NH <sub>4</sub> ) <sub>5</sub> P <sub>3</sub> O <sub>10</sub> & others		high
Ammonium Polyphosphate	11-37-0	(NH <sub>4</sub> ) <sub>7</sub> P <sub>5</sub> O <sub>16</sub> & others		high
Phosphoric Acid, green	0-52-0	H <sub>3</sub> PO <sub>4</sub>		45.7
Phosphoric Acid, white	0-54-0	H <sub>3</sub> PO <sub>4</sub>		45.7
<u>Potash Fertilizer</u>				
Potassium Chloride	0-0-60	KCl	68	34.7
Potassium Nitrate	13-0-44	KNO <sub>3</sub>	32	13.3
Potassium Sulfate	0-0-50	K <sub>2</sub> SO <sub>4</sub>	77	12
Potassium Thiosulfate	0-025-17S	K <sub>2</sub> S <sub>2</sub> O <sub>3</sub>		150
Monobasic Potassium Phosphate	0-52-34	KH <sub>2</sub> PO <sub>4</sub>		33
<u>Micronutrients</u>				
Borax	11% B	Na <sub>2</sub> B <sub>4</sub> O <sub>7</sub> • 10H <sub>2</sub> O	32	2.10
Boric Acid	17.5% B	H <sub>3</sub> BO <sub>3</sub>	86	6.35
Solubor	20% B	Na <sub>2</sub> B <sub>8</sub> O <sub>13</sub> • 4H <sub>2</sub> O	86	22
Copper Sulfate (acidified)	25% Cu	CuSO <sub>4</sub> • 5H <sub>2</sub> O	32	31.6
Cupric Chloride (acidified)		CuCl <sub>2</sub>	32	71
Gypsum	23% Ca	CaSO <sub>4</sub> • 2H <sub>2</sub> O		0.241
Iron Sulfate (acidified)	20% Fe	FeSO <sub>4</sub> • 7H <sub>2</sub> O		15.65
Magnesium Sulfate	9.67% Mg	MgSO <sub>4</sub> • 7H <sub>2</sub> O	68	71
Manganese Sulfate (acidified)	27% Mn	MnSO <sub>4</sub> • 4H <sub>2</sub> O	32	105.3
Ammonium Molybdate	54% Mo	(NH <sub>4</sub> ) <sub>6</sub> Mo <sub>7</sub> O <sub>24</sub> • 4H <sub>2</sub> O		43
Sodium Molybdate	39% Mo	Na <sub>2</sub> MoO <sub>4</sub>	44.3	
Zinc Sulfate	36% Zn	ZnSO <sub>4</sub> • 7H <sub>2</sub> O	68	96.5
Zinc Chelate	5% – 14% Zn	DTPA & EDTA		v. sol.
Manganese Chelate	5% – 12% Mn	DTPA & EDTA		v. sol.
Iron Chelate	4% – 14% Fe	DTPA, HOEDTA & EDDHA		v. sol.
Copper Chelate	5% – 14% Cu	DTPA & EDTA		v. sol.
Zinc Lignosulfonate	6% Zn	Lignosulfonate		v. sol.
Manganese Lignosulfonate	5% – 14% Mn	Lignosulfonate		v. sol.
Iron Lignosulfonate	6% Fe	Lignosulfonate		v. sol.
Copper Lignosulfonate	6% Cu	Lignosulfonate		v. sol.
Lime Sulfur	†	CaS <sub>5</sub> +Ca <sub>2</sub> SO <sub>3</sub> • 5H <sub>2</sub> O		high
Sulfuric Acid	95%†	H <sub>2</sub> SO <sub>4</sub>		v. high

## Fertigation chemical compatability

Compatability of some commonly used fertigation chemicals. (From *Fertigation*. C. Burt, K.O'Connor and T. Ruehr (1995). Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, California, USA).

