

Nutrient, water, pest- disease management in orchard

Overview

Young orchards need regular fertilizing, irrigating, pruning and spraying. Irrigation is not available in all countries, but is recommended for new plantings. Pruning should be carried out in young orchards to improve tree structure, minimize wind damage and to increase fruit bearing area. Young trees can be infested with a number of insect pests and broad-leaf weeds and grasses growing through the leaf mulch also need to be controlled.

Traditionally, orchards were planted at low densities of 100 to 200 trees per ha, and the trees thinned out when they began to crowd each other. Other crops were planted between the rows to make use of the land during the early life of the orchard. Many countries are now adopting high-density plantings with 300 to 1,500 trees per ha. These orchards may have double the returns of other plantings, but must be pruned every year after harvest to keep the trees small. Growers also need to pay close attention to watering and fertilizing. Research in Australia has shown that small trees are just as productive as large trees, when yields are expressed per unit of canopy surface area.

Nutrition generally has a small impact on production, unless trees have a deficiency or excess of one or more nutrients. Trees take a long time to respond to fertilizers, with new leaves, flowers and fruit dependent on reserves in the tree rather than on fertilizer applied to the soil. On the other hand, once nutrient concentrations fall below critical values, it may take several years for tree health and production to fully recover. Leaf standards have been developed from surveys of high-yielding trees in Australia, and have application in other environments. Responses to some nutrients have been reported, whereas the time of fertilizer applications has little effect on yield or fruit quality. Nutrients are best applied to the soil rather than to the leaves as foliar sprays.

Most orchards in the Region are dependent on regular rainfall, with irrigation either too expensive or not available. Research has shown that drought can affect growth and fruit production in South Africa and Australia, but its importance in Asia has not been measured. Mulching and cover crops can assist water conservation, however, it is recommended that new orchards be irrigated if possible. In the absence of irrigation, an annual rainfall of 1,200 to 1,500 mm is required for regular production.

Synthetic auxins were used in the 1950s and 1960s to control growth and flowering in Florida and Hawaii. There were many instances where the treatments increased yield, however, often the responses were unpredictable. More recently, Australian horticulturists showed that ethephon could be used to control early red leaf flushes when applied in May or June in sub-tropical areas. Girdling or cincturing can be used in the same way as the auxins or ethephon to improve flowering. However, it cannot substitute for cool weather at the time of flower initiation. Chemicals applied at this time are also not likely to increase flowering unless followed by cool

weather. Growth regulators and girdling have also been used to improve fruit retention, but the long-term effects of these treatments on tree health are unknown.

6.1 Care of young orchards

6.1.1 Fertilizing

During the first three years, fertilizers are used to promote rapid tree growth. Do not apply fertilizer until the trees produce their first leaf flush. A suggested programme from Australia is indicated below. Amend your nutrition applications to suit local situations. Many areas in Asia use greater quantities of organic fertilizers.

In year one, apply 30 g of urea or equivalent every month, 30 g of mixed fertilizer every three months and a little organic matter in spring (8 litres of fowl manure or equivalent). Increase the urea and mixed fertilizer to 40, 60 and 80 g in subsequent years, along with some organic matter in spring. In frost prone areas, do not apply fertilizer during autumn or winter, and do not exceed the recommended rates. Excessive amounts of organic or inorganic fertilizers can kill trees, especially on shallow, poorly drained soils. Keep fertilizers at least 20 cm away from the trunk to avoid tissue burn. Apply the fertilizer evenly under the canopy and out to a point 30 cm past the dripline or edge of the canopy. Water in well or apply during rain.

6.1.2 Irrigating

Not all orchards in Asia have access to irrigation, however, supplementary watering during the first few years will assist tree establishment. The timing and quantity of water applied varies with tree size, soil, weather and time of year. The following offers a guide based on evaporation in southern Queensland. Some areas in Asia such as India may be drier. In year one with a canopy diameter of 0.5 m, apply 3 litres per tree in winter. This increases to 12 litres, 30 litres and 60 litres in years two (canopy diameter of 1.0 m), three (canopy diameter of 1.5 m) and four (canopy diameter of 2.0 m). Rates in spring (x 2), summer (x 2.5) and autumn (x 1.5) are higher than those in winter. Maximum water use in year four in summer would be 160 litres per tree. Irrigate two to three times a week in sands and one to two times a week in heavy clays. Mulching can assist water conservation, particularly in the absence of irrigation.

6.1.3 Pruning

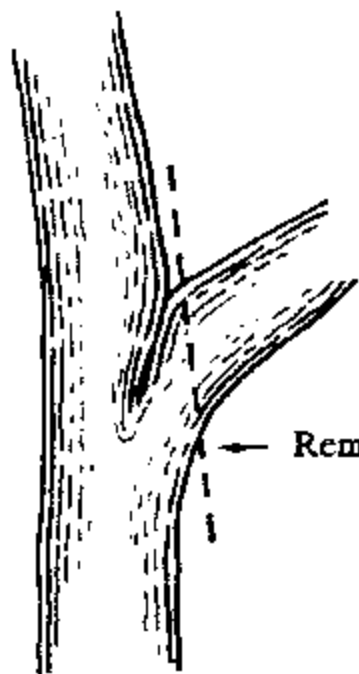
Young trees are pruned to provide a strong structure, minimize wind damage and increase fruit bearing area. Wind damage is an important issue for some cultivars. Cultivars with long branches such as “Fay Zee Siu” and “Tai So” are susceptible to branch splitting, while others with short dense crowns such as “Wai Chee” and “No Mai Chee” can break off at the ground.

Trees should be inspected regularly during the first four years and the following action taken where necessary. Remove branches with weak, narrow crotch angles where the bark is folded into the crotch (Figure 12). On susceptible cultivars such as “Tai So” and “Kwai May Pink”,

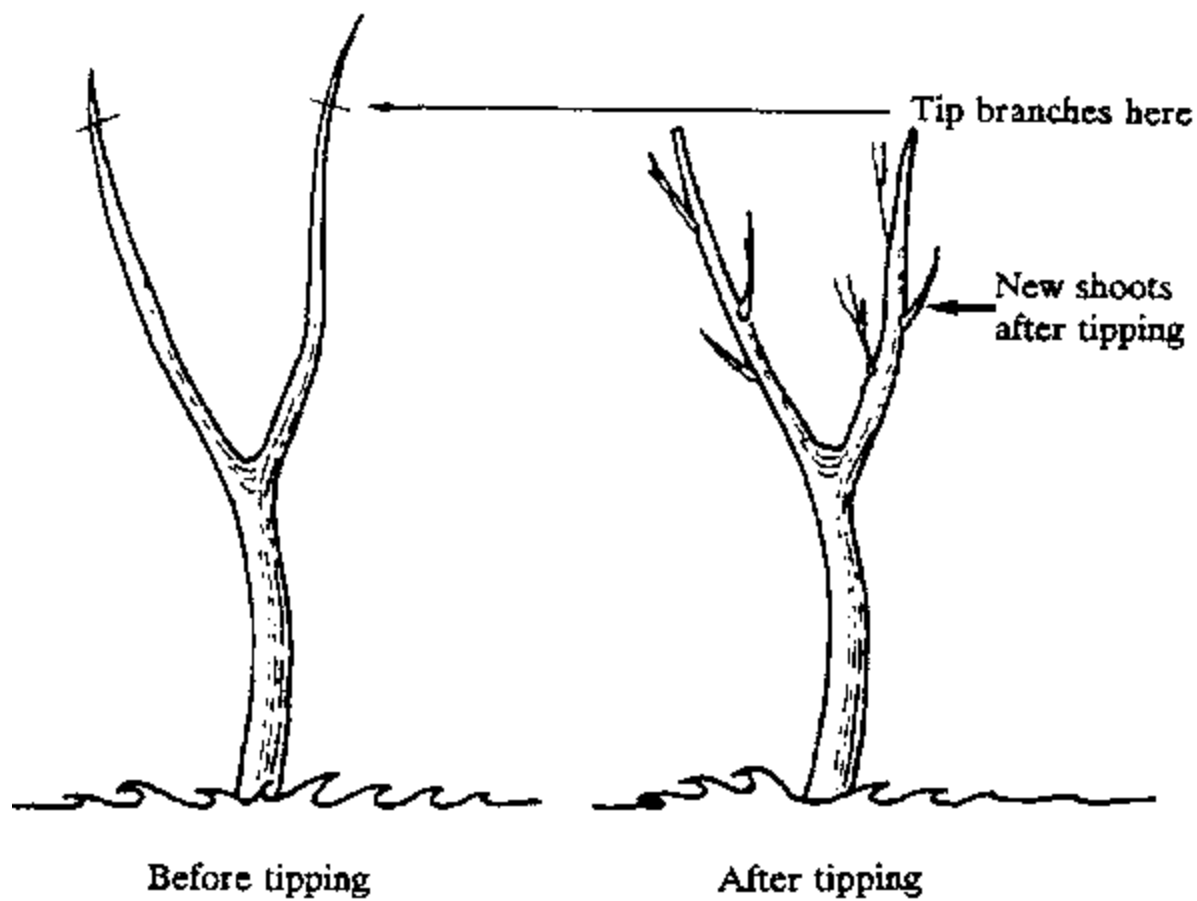
these branches can later split away from the trunk and destroy the tree. Don't remove branches until the trees are at least one year old.

Figure 12. Removing weak crotch angles and tip-pruning long branches.

Bark folded into crotch



Remove branch here



Tip branches here

New shoots after tipping

Before tipping

After tipping

Tip-prune cultivars such as “Tai So” and “Kwai May Pink” which produce long branches or dominant leader branches. Remove approximately 15 cm in spring of year two (Figure 12). This increases the number of growing points and thus provides more flowers and fruit. It also reduces the risk of limbs breaking.

Thin out very dense cultivars such as “Wai Chee” and “Kwai May Pink”. Remove approximately 10 to 20 percent of the branches within the canopy in the third year (Figure 13). You should be able to see broken sunlight on the ground under the canopy when you have finished. This practice allows wind to move through the canopy and reduces the risk of the tree twisting out during heavy winds. Check the trees and repeat each year if necessary.

Skirt trees from the third year onwards by removing all branches and shoots to a height of 50 cm leaving a clean single trunk (Figure 13). Skirting also helps minimize the twisting effect of high winds and prevents fruit and leaves touching the ground. This allows slashing, weeding and fertilizing to be carried out efficiently, without damaging the trees. Ant and scale control is made easier and fewer fruit are damaged by insects and rots.

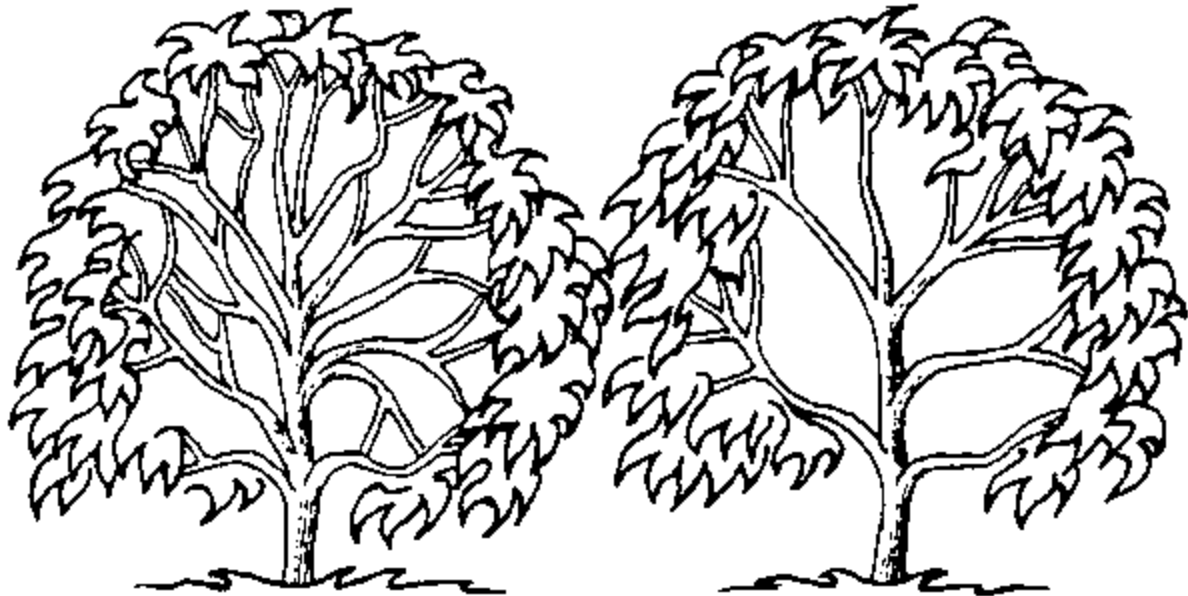
In spite of pruning, some cultivars such as “Tai So” still produce weak crotches that can split. To minimize this risk, growers in Australia have devised a strapping and bracing system using heavy gauge wire to link the main branches (Figure 14). This approach is suitable for similar cultivars in Asia.

6.1.4 Pests

The most important pest of young trees is erinose mite. The mite causes the leaf surface to blister, while the underside develops a brown felting. If not controlled, the pest can damage trees and reduce flowering and fruit production. The best control is to prevent the mite entering your property by dipping new trees. If symptoms appear, remove and burn infested leaves. If most of the trees are infested, spray each new growth flush with dimethoate or wettable sulphur every 10 to 14 days, from just before the flush emerges until it hardens off. Repeat for each new flush. Stop spraying once the new growth shows no symptoms. Sulphur is less disruptive to beneficial insects and is preferred, except during hot weather when days are above 28°C.

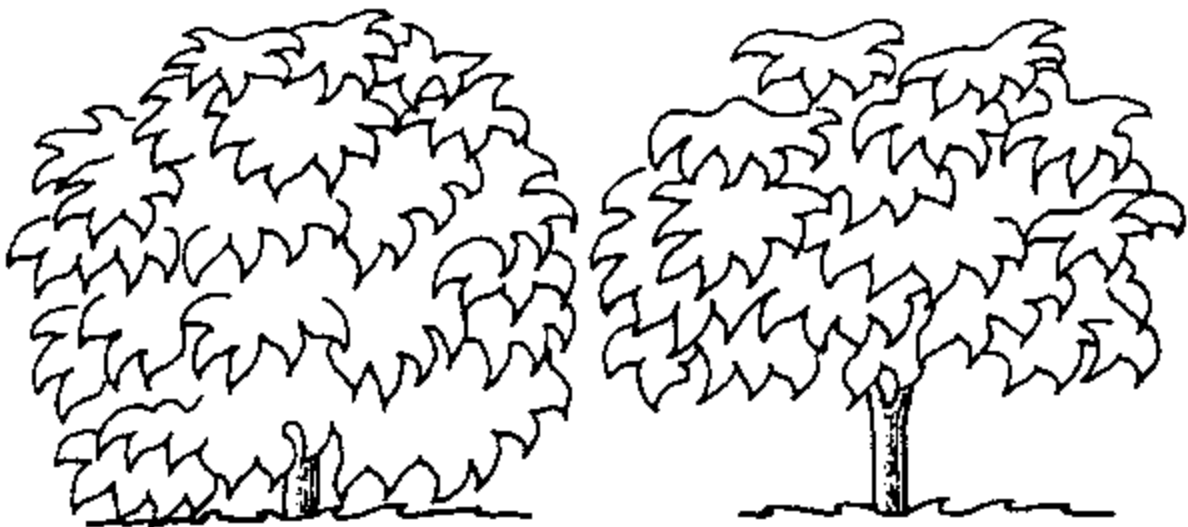
Occasionally, ants, scales, leaf-eating caterpillars, leaf-eating beetles and twig girdlers attack young trees. These can be controlled with registered chemicals (see section on major pests). Borers sometime attack individual branches, although whole trees rarely die. No chemicals are effective against these pests.

Figure 13. Thinning and skirting young trees.



Before thinning

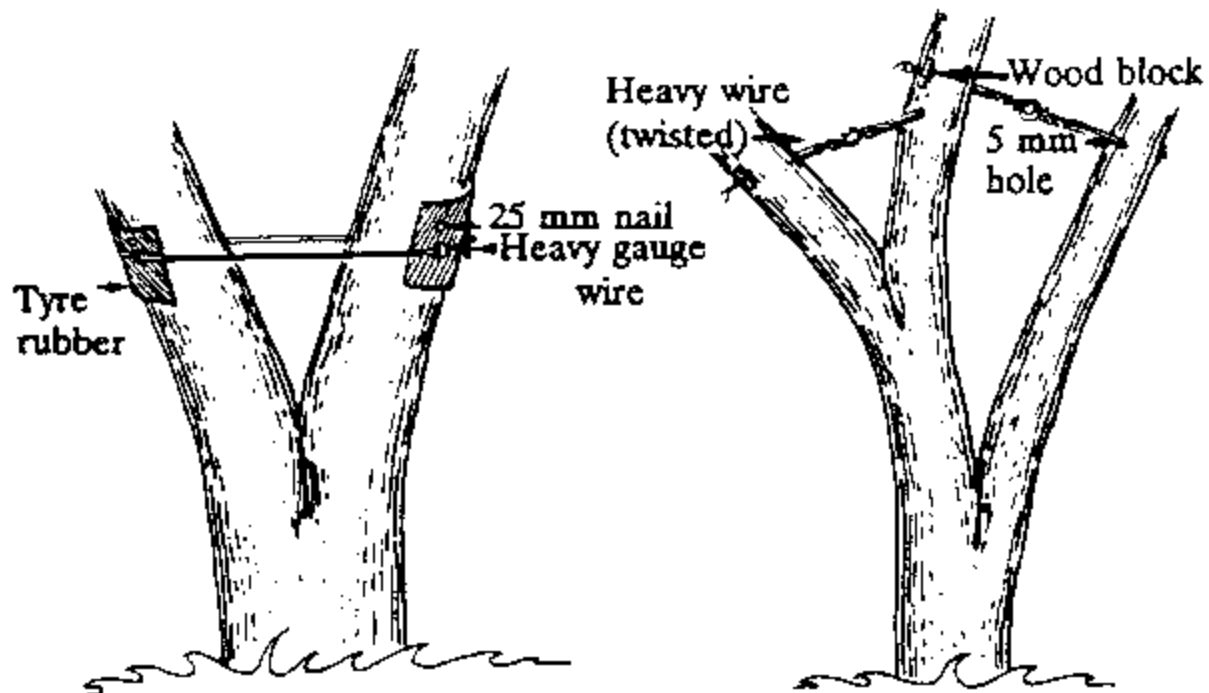
After thinning



Before skirting

After skirting

Figure 14. Braces to support split branches.



6.1.5 Weeds

Weeds compete with the trees for water and nutrients. If allowed to grow, considerable damage to the tree's roots can occur when they are removed. Problems are avoided by maintaining a mown sward of mixed grasses and broadleaf species or cover crops between the rows. Weeds under the trees can be controlled by mulching, chipping and spot-spraying with herbicides.

Mulches used include wheat, barley or rice straw, hay, sorghum stubble and similar materials. Reduce costs by growing mulch material between the rows for later slashing. Renew the mulch as it breaks down. Keep it well away from the trunks as collar rots may develop. Mulches also increase soil organic matter, improve soil structure, increase water retention and help reduce fluctuations in root temperature.

Apply herbicides to the border of the mulched area and to individual weeds that grow through the mulch. Use glyphosate at 5 to 10 ml per litre or paraquat at 1 to 6 ml per litre plus a wetter at 1.25 ml per litre to control grasses and broadleaf weeds. Grasses can also be controlled with fluazifop-p (Fusilade 212) at 1.25 to 10 ml per litre. Don't allow the herbicides to contact any green part of the tree, including the trunk. Drift can be minimized by using a shielded, low-pressure fan or flood nozzle, or alternatively, use a rope wick applicator. Herbicides are very expensive in parts of Asia. With relatively low labour costs, chipping is more practical.

6.2 Canopy management

Plant production depends on the conversion of sunlight into chemical energy, and, for the most part, this process takes place in the leaves. There has been a strong move to improve the

productivity of temperate fruit trees in the past 30 years or so, based on an understanding of the relationship between yield and light interception. Modern apple and stonefruit orchards are planted at high density and trees kept small through the use of dwarfing rootstocks and intensive pruning. These systems maximize the interception of light by the canopy. This philosophy is not well developed in lychee and most other tropical fruit trees, with few dwarfing rootstocks or validated pruning strategies.

6.2.1 Orchard layout

A well-managed orchard should have a long commercial life. Hence, close attention to orchard layout and land preparation will have their rewards for many years. You need to make decisions on row direction, spacings, placement of waterways and drains, mounding, wind protection and all weather access to the block. Your local horticulturist should be able to help you with the layout of your orchard and care of young trees.

Many old orchards in Asia and Australia were planted at spacings of 9 m or 10 m x 12 m or even 12 m x 12 m, equivalent to 70 to 80 trees per ha. Such plantings can have very high yields on a tree basis after 10 or 15 years, but are wasteful of land in the early years. There are also problems with harvesting, spraying, and protection from birds and bats in large trees in some areas.

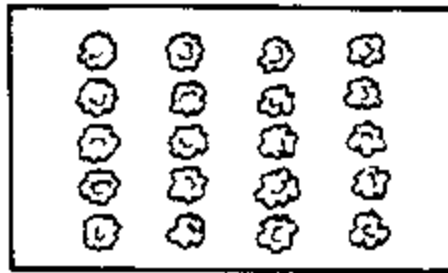
Newer orchards are planted at closer spacings of 6 m x 8 m or 4 m x 6 m or 7 m x 3 m, equivalent to 200 to 460 trees per ha. These orchards require regular pruning to keep the trees small. Otherwise, some of the trees must be removed when they start to crowd each other (Figure 15). There are high-density plantings up to 1,500 trees per ha in southern China, but these are dependent on hand spraying. They are not suited to operations using heavy machinery.

The economics of high-density plantings in Australia and elsewhere have yet to be fully analysed. There is also probably no advantage in very close plantings where the trees start to crowd each other before they begin to bear at year four or five.

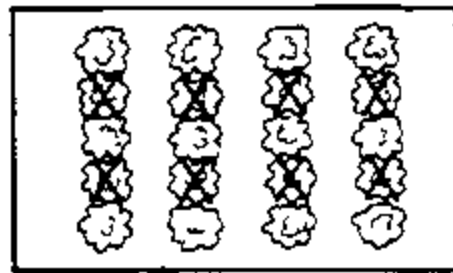
6.2.2 Strategies in different countries

In China, there is no standard layout, although most farmers prefer close plantings of 2.5 to 3.0 m x 3.5 to 4 m (825 to 1,100 trees per ha). They usually plant other crops such as bean, peanut, sweet potato, vegetables, pineapple and papaya in the inter-rows, and thin the orchard to 300 trees per ha after a few years. Some sections of the industry have adopted high-density plantings up to 1,500 trees per ha. These are often based on the popular early cultivar “Fay Zee Siu”, and are dependent on close attention to pruning, girdling, watering and fertilizing.

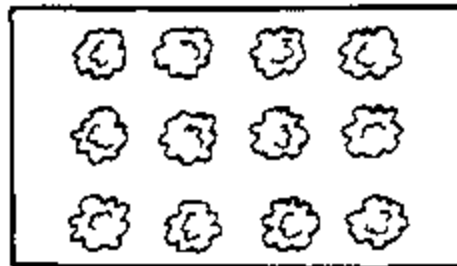
Figure 15. Thinning strategies for close plantings in Australia for upright (top) and spreading cultivars (bottom).



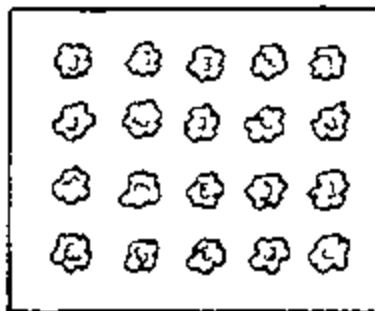
At planting



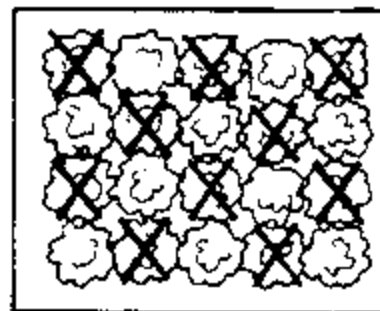
Crowded



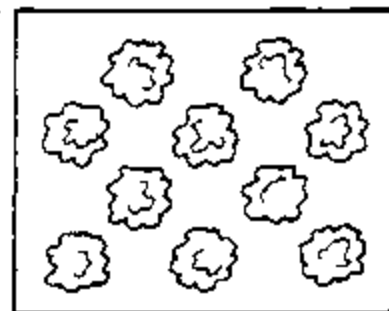
Thinned



At planting

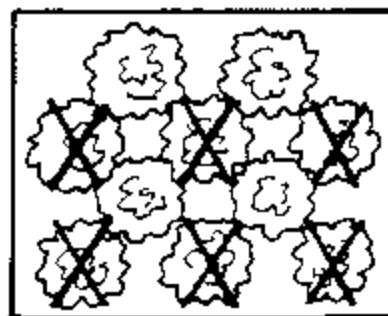


Crowded

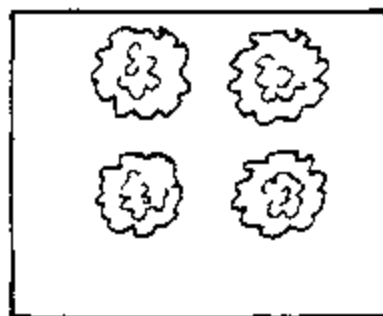


Thinned

First thinning



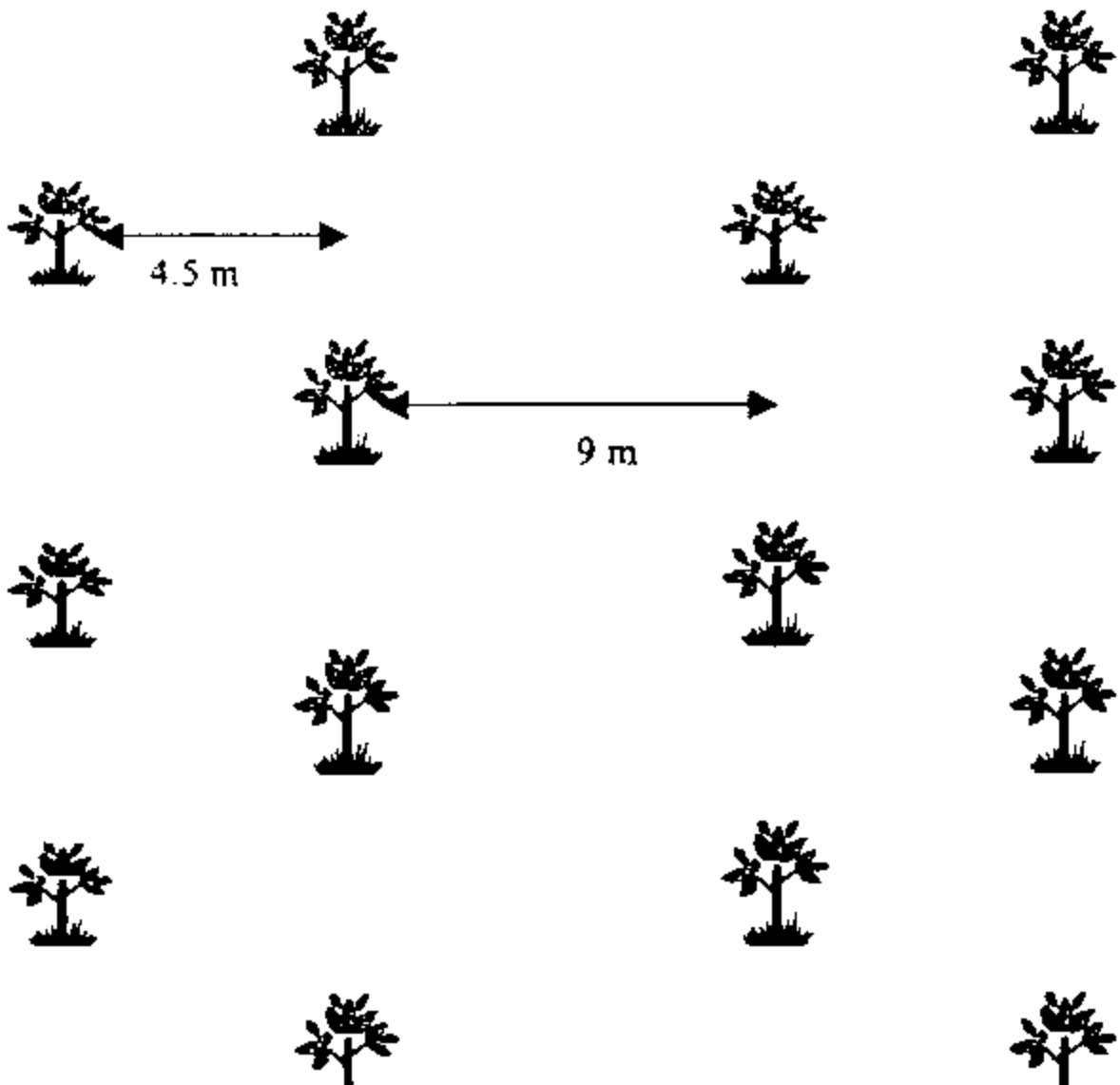
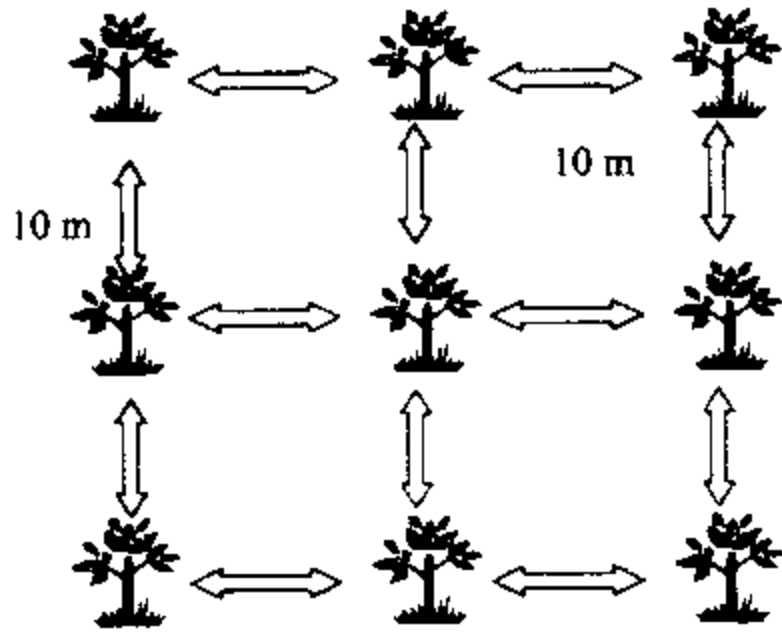
Crowded



Thinned

Second thinning

Figure 16. Plan of orchards in India showing square system for traditional plantings (top) and double hedgerow for closer plantings (bottom).



In Viet Nam, the normal spacing adopted is 7 or 8 m, depending on the fertility of the soil and topography. There are very few high-density orchards. Planting distances in Thailand range from 3 to 8 m, with the closer spacings requiring a higher level of orchard management than traditional plantings.

The traditional growers in India use a spacing of 9 to 10 m, equivalent to 100 trees per ha planted in a square system. Old trees in these orchards may be 10 or 12 m high. There are also experimental plantings at 4.5 m x 4.5 m x 9 m (329 trees per ha), in double hedgerows (Figure 16). The closer plantings provide greater fruit production per hectare, and equally good fruit as traditional plantings. A light pruning is recommended after harvest.

In Bangladesh, old orchards were planted at 7 to 12 m; however, many of the new plantings are spaced at 4 m. Traditional spacings of 10 to 12 m are still used in Nepal, with the inter-rows planted with vegetables or other crops. These are removed after about eight years. Planting distances in the Philippines are 7 or 8 m, equivalent to 150 to 200 trees per ha.

Plantings in Australia range from 100 to 300 trees per ha. Recommended spacings are 8 m x 6 m for spreading cultivars such as “Fay Zee Siu” and “Souey Tung” (equivalent to 140 trees per ha). Suggestions for upright or low vigour cultivars such as “Kwai May Pink”, “Salathiel” and “Wai Chee” are 6 m x 6 m or 6 m x 4 m, equivalent to 280 to 460 trees per ha. Many of the close plantings are grown as hedges, and pruned every year after harvest (Plate 6). There are some closer plantings that potentially can provide greater returns, but they are only experimental at this stage.

6.2.3 Relationship between yield and tree size

Horticulturists studied the relationship between yield and tree size for a group of ten small trees growing in an orchard in southern Queensland. This was to test whether larger trees were more productive per unit leaf area. There has been no previous study on allometric growth in lychee.

There was no apparent trend in relative yield over a 3.4-fold range of canopy surface areas (Table 7). This is consistent with the trees being small and widely-spaced, such that there were only minor differences in the degree of self-shading and shading from other trees. There was also similar relative partitioning of resources within the plants. It would appear, therefore, that from early in an orchard's life, fruit production is simply a function of the effective canopy surface area.

There was also no apparent trend in relative yield with relative leaf area index. These results suggest that a higher leaf area index conferred little additional productive benefit. It might be that mature trees have a considerable number of shaded leaves that contribute little to overall productivity.

Table 7. Range in number of leaves per tree, total leaf area per tree, canopy surface area, relative leaf area index (RLAI), specific leaf weight (SLW) and yield for the ten lychee trees at Bundaberg in southern Queensland.

Tree No.	leaves per tree	Total area (m ² per tree)	leaf Canopy area (m ² per tree)	surface RLAI	SLW (g m ⁻²)	No. fruit per tree
One	2730	11.8	23.6	0.50	120	474
Two	3135	15.3	31.7	0.48	134	558
Three	3453	15.4	32.0	0.48	125	563
Four	4021	20.5	31.3	0.66	113	252
Five	4603	18.7	33.3	0.56	121	518
Six	4753	20.9	28.9	0.72	135	635
Seven	6168	25.6	33.1	0.77	135	712
Eight	6784	38.6	51.1	0.76	123	956
Nine	8227	40.4	48.4	0.83	110	1321
Ten	9138	33.6	53.2	0.63	134	1274

(Data from Menzel et al. 2000).

For “Kwai May Pink”, there were about seven leaves per harvested fruit. This compares with two to three for “Tai So” and one to two for “Souey Tung” in South Africa. However, these two experiments are not directly comparable. The work in Australia used whole trees, whereas the previous estimates were based on girdled branches, where assimilates are stored in the branch and do not contribute to the rest of the tree. The leaves of “Kwai May Pink” are also smaller than those of “Tai So”.

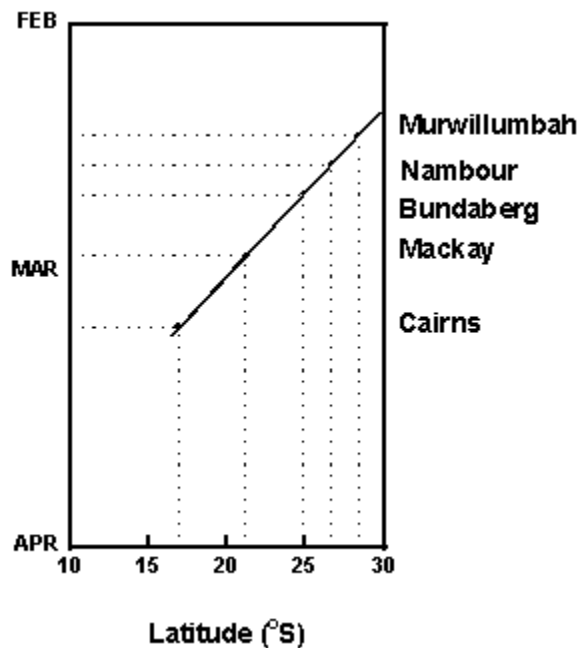
6.2.4 Development of pruning strategies

Left unchecked, lychees grow into large trees that are difficult to spray, harvest and net. Exclusion nets are an effective way to control the important bird, bat and piercing moth pests in Australia, but is most practical with small trees. Small trees can be closely planted and provide greater returns in the early life of an orchard.

The effects of pruning on flowering and yield have been studied in Florida, Taiwan Province of China and Israel. Trees were pruned in summer, autumn or winter, but responses were mixed. Experimental work has also been carried out in Guangdong and Australia to address some of these issues. This research has shown that tree size and production can be regulated, and has opened up the prospects of high-density plantings. The same principles probably apply to the related longan and rambutan.

Scientists in Australia developed a model to assist growers choose the most appropriate time to prune their trees. The optimum time of pruning varies from northern Queensland to northern New South Wales (Figure 17). The model allows for one or two growth flushes before winter in warmer areas and one flush in cooler areas. In any one location, the optimum time of pruning does not appear to vary dramatically across different cultivars. The model is a significance advance as it takes into account the effect of weather on the flushing rate in different localities. Previous research did not provide recommendations for individual growing areas. If pruning leads to leaf flushes in winter, they can be controlled with selective ethephon applications or a light manual pruning.

Figure 17. Variation in the optimum date of pruning for lychee in different latitudes along eastern Australia.



6.2.5 Yield and assimilate supply

Experiments were conducted in Australia on “Tai So”, “Bengal”, “Brewster”, “Kwai May Pink” and “Wai Chee” to evaluate the role of assimilates on fruit retention. Girdling of trees or large branches increased fruit yield by an average of 15 to 20 percent compared with ungirdled plots. The best responses generally occurred when the girdles were applied between flowering and

early fruit growth (30 days from anthesis) compared with application later in the season. In contrast, girdling did not increase the yield of small branches.

Yields were reduced by 45 percent when all the leaves from the last flush or previous flush were removed from terminal shoots, and by 35 percent when all the old leaves were removed. These results indicate the importance of the leaves behind the fruiting clusters for cropping. Fruit retention was very low on girdled branches that had been defoliated, especially when the leaves were removed in the first 20 days after anthesis. This suggests that the yields of girdled branches were determined by the availability of assimilates soon after fruit set. In contrast, the number of fruit retained on ungirdled branches was unrelated to the number of leaves, with defoliation having no effect on yield. Fruit growth on these branches was supported by resources from elsewhere in the tree.

Removing 20, 50 or 80 percent of the flowering panicles had no significant effect on yield compared with unthinned plots (77, 75, 65 and 82 kg per tree). Thinning apparently increased fruit retention in the remaining clusters. Lychees set more fruit than the tree's resources can carry to harvest. The tree's assimilates may be diverted to areas with strong demand. Opportunities exist for increasing yields by defining the optimum tree shape and leaf area index.

6.3 Fertilizer management

Lychee requires soil nutrients and water for satisfactory growth and cropping. Nitrogen (N) is the major nutrient and occupies an important position in the fertilizer programme. The other major nutrients are phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). The micronutrients, iron (Fe), boron (B), copper (Cu), zinc (Zn) and manganese (Mn) are required in very small amounts. When the concentration of a nutrient reaches abnormally low or high levels in a plant, characteristic symptoms appear in the leaves, stems, flowers or fruit. Normally, growth and yield are reduced long before visible symptoms appear. The only way to avoid this is to monitor the concentrations of the nutrients in the plant and soil, and maintain these within the acceptable range established from healthy, high-yielding orchards.

Fertilizers generally have small impacts on production, unless trees have nutrient deficiencies or excesses. Yield and fruit quality are usually adequate over a wide range of leaf nutrient concentrations. Trees take a long time to respond to fertilizer applications, with new growth more dependent on reserves in the tree than on fertilizer applied just recently to the soil. On the other hand, when leaf concentrations have fallen below critical levels, it may take several years for the trees to recover.

6.3.1 Leaf analysis

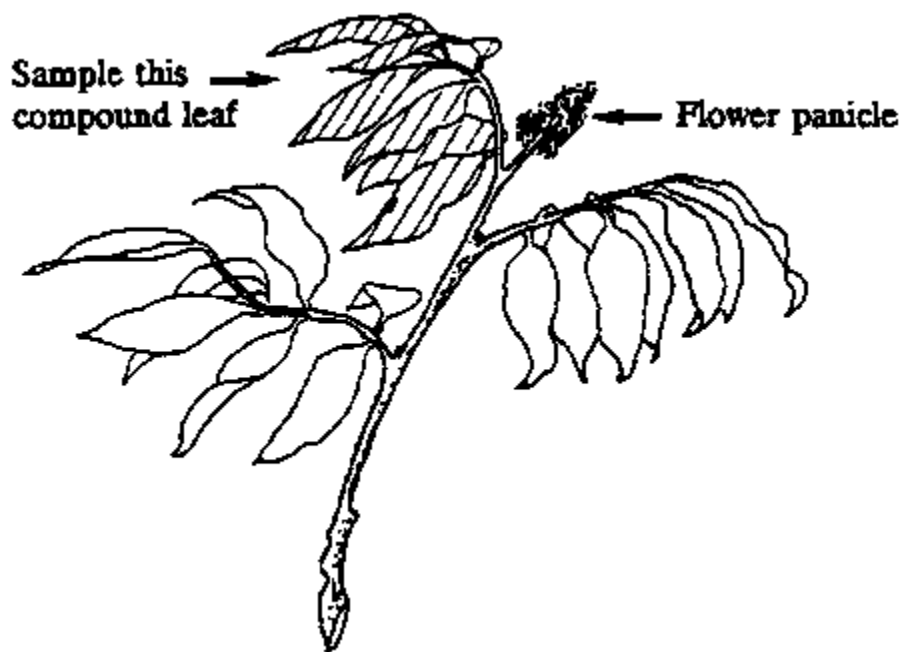
Horticulturists in Australia developed leaf nutrient standards in 1992. These were based on surveys of high-yielding orchards in southern Queensland, but have application in other environments. The recommended time for sampling is one to two weeks after panicle emergence

or about May to August in Australia, depending on cultivar and season. The equivalent period in Asia is from October to December.

Whole leaves are sampled from the first leaf under the panicle (Figure 18). Leaves from eight branches, uniformly distributed around the tree are selected. The leaf sample should be accompanied by a soil sample from 0 to 15 cm each year. A leaf and soil sample should represent a planting of no more than three hectares, with separate samples recommended for each soil, block and cultivar. Approximately 20 uniform trees that are well spread should be selected.

The results should be supported by a record of leaf colour, tree vigour and yield so that fertilizer management can be adjusted for the next crop. The ultimate fertilizer programme depends on tree size, crop load, cultivar and soil type, and will vary considerably between different districts, orchards and years.

Figure 18. Leaves for nutrient analysis are collected from just behind the flower panicle in winter.



Recommended leaf nutrient concentrations are as follows: N, 1.50 to 1.80 percent; P to 0.14 to 0.22 percent; K, 0.70 to 1.10 percent; Ca, 0.60 to 1.00 percent; Mg, 0.30 to 0.50 percent; Fe, 50 to 100 ppm; Mn, 100 to 20 ppm; Zn, 15 to 30 ppm; Cu, 10 to 25 ppm; B, 25 to 60 ppm; Na, <500 ppm; and Cl, <0.25 percent.

Leaf tests are widely used in Australia, but are less common in Asia. Many farmers cannot afford the cost of the analyses. However, samples can be collected by Government Extension Officers to provide a guide to nutrition management in different areas. For instance, this approach can be used to monitor for certain trouble nutrients such as boron or zinc. Symptoms of nutrient

deficiencies have been described in Australia and India, but are not a good basis for fertilizer management.

6.3.2 Soil analysis

Soil analysis can be used to assess the nutritional status of tree crops. It can ensure that a particular site does not fall outside the range of fertility considered adequate for that particular crop and soil. Soil tests have a role for correcting or avoiding problems such as acidity, salinity and nutrient interactions and toxicities, which are not directly related to plant composition. The analysis should preferably be taken with a leaf test.

Scientists in Australia developed a sampling technique for soil analysis and proposed tentative nutrient standards. Several high-yielding orchards were sampled over four years, with the data then used to create an optimum range.

Soil samples should preferably be taken at the same time as leaves collected for tissue analysis. This is normally just after panicle emergence in winter, prior to the application of fertilizer. Collection of soil samples just after fertilizing is best avoided, due to sampling errors associated with the uneven distribution of fertilizer in the topsoil. Research has shown that the feeder roots and nutrients under the trees are concentrated in the topsoil. Consequently, sampling the 0 to 15 cm layer provides the most reliable estimate of soil nutrient reserves.

A soil sample should be taken every year to a depth of 15 cm. Each sample should be accompanied by a leaf sample collected from the same trees. Take a sample from half way between the trunk and the drip-line or edge of the canopy. The leaf mulch should be removed first. Separate samples should be taken for each block, soil and cultivar.

Recommended soil nutrient concentrations in Australia are as follows: pH, 5.5 to 6.0; organic carbon, 1.0 to 3.0 percent; electrical conductivity, <0.20 dS per m; Cl, <250 mg per kg; Na, <1.0 meq per 100 g; NO₃-N, 10 mg per kg; P, 100 to 300 mg per kg; K, 0.5 to 1.0 meq per 100 g; Ca, 3.0 to 5.0 meq per 100 g; Mg, 2.0 to 4.0 meq per 100 g; Cu, 1.0 to 3.0 mg per kg; Zn, 2 to 15 mg per kg; Mn, 10 to 50 mg per kg; and B, 1.0 to 2.0 mg per kg. It is not known if these data apply to soils in Asia. Local values can be collected for other areas.

6.3.3 Role of different nutrients

Nitrogen is the most important nutrient affecting growth and productivity. Deficiency symptoms have been reported when leaf concentrations fall below 1.3 percent. Because nitrogen moves from old to young leaves when concentrations are low in plants, the first signs of deficiency (yellowing) are noted in the older leaves. In cases of severe deficiency, the margins of the leaves may curl, leaves may be small or fail to develop or be shed prematurely. Growth is stunted and flowering and fruit set prevented. Fruit are small, with low flesh recovery and eating quality.

Increases in fruit set, retention and yield with nitrogen have been reported in India, China and Australia. In contrast, this nutrient does not have a direct effect on floral initiation. In any case, it is difficult to shift tree nitrogen concentrations and flushing patterns with nitrogen fertilizers. There was no consistent relationship between flowering, and time of nitrogen application and soil nitrogen concentrations in several studies in Florida in the 1950s and 1960s. Temperature exerted a greater influence of floral initiation.

Low phosphorus concentrations are rare where mixed fertilizers have been applied regularly. This is because phosphorus is not readily leached from the topsoil. Once soil concentrations are high, they should be sufficient for several years. The first symptoms of deficiency show as dead patches on the tip and margins (coppery brown colour) of mature leaves that progress towards the midrib. Eventually, the leaves curl, desiccate and are shed. These severe symptoms have only been recorded in sand culture in India and Florida.

Many orchards in the Region have potassium concentrations below 0.80 percent. This can occur late in the season when potassium is translocated to developing fruit, after heavy nitrogen applications, or after heavy rain. These problems are more likely to occur on sandy soils. The leaves start to yellow, the leaf tips die and later the bases of the leaves. The old leaves are eventually shed. Consequently, the canopy consists of small terminal cluster of leaves. Severe deficiency in sand culture can restrict shoot and root development. Plants flower, but do not set. Trees may die.

Symptoms of calcium deficiency have been achieved by growing plants in sand culture, but are rare in the field. Typically, the plants in the sand had smaller leaves than those fertilized with calcium. Eventually, the new leaves, stems and roots stopped growing. Plants flowered, but did not set. No general responses to calcium have been reported in the field, although research in China implicates a role for this nutrient in fruit development. Foliar applications have been suggested for the control of skin browning and cracking.

The concentrations of magnesium are often low, especially when trees are grown on sandy soils that are readily leached. Deficiencies can also be induced by heavy applications of nitrogen and potassium. Magnesium is not readily transported from old to young leaves, hence, symptoms occur first on young tissues. Plants grown in sand culture without magnesium had small leaves that died between the veins, and eventually dropped. Flowering was suppressed when leaf concentrations fell below 0.25 percent.

Orchards established on sandy soils often have low iron levels, especially after excessive superphosphate applications that interfere with iron uptake by the roots. There can also be problems in alkaline soils with a pH above 7.0, or after excessive lime applications. There is a general yellowing of the young leaves, spreading to older leaves. When the deficiency is severe, the branches may die. Concentrations below 40 ppm are considered a problem.

Zinc deficiency occurs on acid leached soils where native zinc is low, or on alkaline soils where zinc is not readily available to plants. These problems are often exacerbated after heavy nitrogen applications. There may be general bronzing or mottling of the leaves, smaller shoots and smaller fruit. The branches may die when leaf concentrations fall below 10 ppm.

Copper deficiency is most likely in sandy soils with an inherently low copper content, but is not common. Often the young leaves roll and die. Shoots may also die when leaf concentrations fall below 6 ppm. In some soils in Australia, copper and zinc deficiencies occur together.

Leaf boron concentrations are often below 30 ppm in China, Thailand and Australia. Low boron concentrations are associated with the death of new shoots and roots, poor fruit set and misshapen fruit at harvest. The range between deficiency and toxicity is small, so care should be taken when applying boron fertilizers.

There have been many attempts to increase fruit set and fruit size with foliar applications of zinc, copper and boron. However, most of these sprays did not result in consistent increases in yield. Few authors presented data on leaf or soil nutrient concentrations. Responses to foliar applications would only be expected if leaf nutrient concentrations were below critical values.

6.3.4 Nutrient reserves

Destructive harvests in Australia showed that the greatest reserves of nutrients occurred in the leaves, twigs and small branches, which accounted for about 75 percent of the total reserves of the tree. The amount of nutrients in the other plant parts was usually less than 5 percent. The high reserves in the leaves, twigs and small branches were mainly because these tissues accounted for a large proportion of the plant's weight, although the concentration of nutrients was also higher. The concentrations of nutrients in the leaves reflected the reserves in the rest of the plant indicating that they are a reliable index of the tree's nutrient status. These reserves are used for new leaf, flower and fruit growth, but can last a long time. For instance, nitrogen concentrations were maintained for four years in Australia after fertilizer was withdrawn. This explains why it can take several years to respond to changes in nutrition management.

6.3.5 Crop removal

Indian and Australian scientists have determined the concentrations of nutrients in fruit. These data can be used to estimate the removal of the different nutrients by the crop. Average concentrations in the fruit were as follows: N, 0.85 percent; P, 0.19 percent; K, 1.04 percent; Ca, 0.10 percent; Mg, 0.18 percent; Mn, 29 ppm; Zn, 34 ppm; Cu, 36 ppm; B, 15 ppm; and Cl, 0.01 percent. It was calculated that a 50 kg crop would remove the following nutrients in the fruit (g per tree): N, 98; P, 22; K, 120; Ca, 12; Mg, 21; Mn, 0.3; Zn, 0.4; Cu, 0.4; B, 0.2; and Cl, 28. Thus, the fruit use more potassium than nitrogen. The amounts of nutrients needed for new leaves, stems, roots and flowers were not included in these calculations. Some of the nutrients from the tree would be recycled as leaf litter and fallen twigs, flowers and fruit. These data can

be used as a guide for fertilizer applications to avoid over fertilization and leaching of nutrients off-farm.

6.3.6 Time of fertilizer applications

The time of fertilizer application during the crop cycle generally has no impact on yield or fruit quality. An example is given for nitrogen applied at different times in Australia.

Nitrogen was applied over four years to six year old “Bengal” trees growing in southern Queensland. The soil was a sandy loam with low reserves of soil N (2.8 mg NO₃-N per kg). Applications equivalent to 750 kg N per ha in year 4 were made after panicle emergence in July, after harvest in January, or split between the two periods. Control trees received no nitrogen.

Leaf N concentrations in April to June were on average 0.1 percent lower after a single application in winter than application in summer or split applications. Leaf N concentrations in November to February were about 0.1 percent higher after winter application or split applications than after summer. In other words, the time of nitrogen application had little impact on leaf nitrogen concentrations.

The time of fertilizer application had no effect on yield, and in fact, it took four years without fertilizer to show significant reductions in yield compared with fertilized trees. In year 4, yield increased as leaf N in August increased from 0.95 to 1.56 percent. Lower yields in control trees were associated with poor leaf growth in the previous two years, and lower CO₂ assimilation after fruit set compared with trees receiving nitrogen.

6.3.7 The effects of phosphorus and potassium on production

The fertilizer requirements of field trees have not been well studied. South African workers examined the response in “Mauritius” over eight years. There was a 50 percent increase in leaf P from 0.12 to 0.18 percent, but only a 10 percent increase in leaf K from 0.91 to 1.06 percent. Yield increased with phosphorus fertilization from 38 to 46 kg per tree, but not with potassium (41 to 44 kg per tree).

The effects of phosphorus and potassium applications were studied in sub-tropical Queensland. The Scientists were interested to see if deficiencies would appear after three years without fertilizer, and if excessive rates of application had any detrimental effect on production. The trees were growing on a sandy loam, red clay loam and a heavy clay soil, and thus differed in their ability to buffer against sudden changes in external nutrient supply. The sites were selected on the basis that they had soil nutrient concentrations common to many orchards in Australia.

Fertilizer applications were equivalent to 0 to 2.4 tonnes per ha for phosphorus, and 0 to 3.2 tonnes per ha for potassium. In the first two years, there was no effect of fertilizer on leaf phosphorus and potassium, while in year three, leaf phosphorus was related to phosphorus application at two out of two sites and leaf potassium to fertilizer potassium at one out of three

sites. Thus, phosphorus and potassium accumulated at some sites at high rates of fertilization. In contrast, concentrations in unfertilized control trees fell only slightly over time.

Fruit production was similar over the range in leaf phosphorus of 0.18 to 0.44 percent, and leaf potassium of 0.75 to 1.10 percent, compared with the Australian standards of 0.14 to 0.22 percent and 0.70 to 1.10 percent, respectively. The buffering capacities of the soil and tree were thus indicated. These results suggest that annual applications of phosphorus and potassium may not be required, indicating savings for growers. This would provide a saving in operating costs of US\$70 per ha for 15 year old trees for phosphorus, and a saving of US\$80 per ha for potassium. These results also suggest that the leaf standards for phosphorus and potassium need to be reviewed.

6.3.8 Fertilizer guide

Tables 8 and 9 outline the suggested applications for well-grown, high-yielding trees in Australia. These rates are a guide only and should be supported by the results of leaf and soil analyses. Depending on cropping patterns and soil, they can easily be modified to suit other environments. In many parts of Asia, most of the nutrients are supplied from organic fertilizers. The suggested applications of the different nutrients can be amended as necessary. The major nutrients are best applied to the soil. Responses to foliar applications have been reported in some countries, but tend to be short-lived. Leaf nutrient concentrations are increased only temporarily.

For nitrogen, don't apply fertilizer if leaf concentrations are above 1.8 percent and the trees are vigorous and have not set a crop. If the range is 1.5 to 1.8 percent, apply the rate recommended. If the range is 1.2 to 1.5 percent, apply 25 percent more, if it is 1.1 to 1.2 percent, apply 50 percent more, and if it is less than 1.0 percent, apply 100 percent more.

For phosphorus, interpret the results in conjunction with soil analysis, and don't apply if the leaf test is more than 0.22 percent or if the soil test is above 300 ppm. Annual applications are not likely.

For potassium, trees carrying a heavy crop, with less than 0.50 percent K in the leaf test, will require twice the amount of fertilizer listed for their size or age. If the leaf test is 0.5 to 0.6 percent, use another 50 percent than the recommendation. If the leaf potassium is 0.70 to 1.10 percent, use the recommendation, but if it is above 1.10 percent, add nothing.

Table 8. Annual fertilizer requirements (kg per tree).

Tree age (years)	Canopy diameter (m)	Urea	Super-phosphate	Sulphate of potash
4-5	1.0-1.5	0.4	0.8	0.7
6-7	2.0-2.5	0.7	1.0	1.1

8-9	3.0-3.5	0.9	1.3	1.3
10-11	4.0-4.5	1.1	1.7	1.7
12-13	5.0-5.5	1.3	2.0	2.0
14-15	6.0-6.5	1.8	2.5	2.9
>15	>6.5	2.2	3.0	3.4

Dolomite is recommended for the correction of soil pH below 5.5, when magnesium concentrations are low, but the response can be slow. Where leaf magnesium is low, magnesium sulphate (9.6 percent Mg) can be applied to the soil at the rate of 40 g per m². Magnesium oxide (54 percent Mg) can also be used, but is fairly insoluble. Another strategy is to apply the magnesium sulphate as a foliar spray (20 g per litre), although the results can be short-lived.

For low calcium concentrations, apply gypsum at 500 g per m² if the pH is above 6. If the soil pH is below 6, use lime or dolomite at the rate recommended by your chemical laboratory.

For micronutrients, if the range is within the optimum values, use the recommended rate (Table 9), but if it is below the optimum, apply a second application. If the leaf test is above the standard value, apply nothing.

Table 9. Micronutrient recommendations.

Nutrient Product		Soil application (g per m ²)	Foliar application (g per litre)
B	Solubor	2	2.0
Zn	Zinc sulphate	25	1.0
Cu	Copper sulphate	4	2.0
Fe	Ferrous sulphate	10	5.0
Mn	Manganese sulphate	5	2.5

Timing of fertilizer application is not likely to influence tree performance. Most nutrients can be applied between spring and summer. If using foliar applications, apply boron, copper and manganese to the mature summer and autumn leaves. Zinc should be applied to the expanding summer and autumn flushes.

Similar rates of fertilization are suggested in China, although there is emphasis on split applications during the year. For a ten year old tree with a 100 kg crop, it is suggested growers apply 600 g N, 40 g P and 250 g K prior to flowering; 200 g N, 50 g P and 700 g K at full bloom; and 600 g N, 40 g P and 250 g K prior to harvest. Foliar fertilizers can be used instead of the soil applications at flowering. The fertilizer is normally applied in a trench around the tree. The amount of phosphorus applied appears much higher than that recommended in Australia.

In India, the suggested approach for 12 to 15 year old trees is to broadcast 600 to 800 g N, 150 to 200 g P and 300 to 500 g K in two or three applications. There is generally an emphasis on organic fertilizers. Applications of foliar zinc, copper, manganese and boron are suggested.

6.4 Irrigation management

Lychees have a deep root system and can survive long dry periods, although leaf, flower and fruit production are usually reduced. The period from flowering to early fruit development is particularly sensitive to water supply. Most orchards in the Region are not irrigated because of costs or lack of infrastructure, but it is generally agreed that yield and fruit quality would be improved with supplementary watering. It is recommended that new orchards should be irrigated. In the absence of irrigation, an annual rainfall of 1,200 to 1,500 mm is required for satisfactory production.

There has been only limited research on the irrigation requirements of commercial orchards. Work in South Africa showed that drought from panicle emergence to harvest reduced yield and fruit size in “Tai So”. Gross returns dropped from US\$125 to US\$18 per tree. This work has relevance to many areas in Asia, which experience dry winters and springs. Different results were recorded in Australia, although the drought was less severe and applied later in the reproductive cycle. Plants dried out after flowering had higher yields than well-watered plants, although this was at the expense of fruit size. Fruit in droughted plants were 10 percent smaller than those from plants watered regularly. These two studies showed that trees are capable of extracting water at considerable depths in most soils, and can produce acceptable yields with fairly long intervals between waterings. Some orchards in Australia are watered two to three times per week, but this is excessive.

An acceptable cycle in a sandy loam would be two weeks, and considerably longer in a clay, with greater water-holding capacity. Irrigation in a sandy loam before 50 percent of the available soil water is used, would maintain tree water status in the acceptable range. The profile should be brought back to field capacity with every irrigation. This strategy is dependent on the trees being well grown with a deep root system and the soil having a good structure. Trees growing on compacted sites, with limited roots at depth will need more frequent watering.

Suggested water applications for trees in southern Queensland are shown in Table 10. It may be much drier in some areas of Asia. The only efficient way to irrigate is to monitor changes in soil water under the trees. Various instruments are available, but they are too expensive for most

farmers. Experience is the best approach. Evaporation from a Class A pan can be used as a guide, although the relationship between actual water use and evaporation from the pan varies with the weather and crop cycle. Local horticulturists can give you advice on irrigation systems and application rates for your orchard.

Table 10. Suggested irrigation rates (litre per tree per week) in southern Queensland. (Some areas in Asia may be drier).

Time of year	Years 4-6	Years 7-15	Years 15+
May-June (pre-flowering)	120	200	400
July-September (flowering)	400	600	1,200
October-February (fruit growth)	500	800	1,500
March-April (leaf growth)	400	600	1,200

6.4.1 Irrigation in different countries

Most of the orchards in China are not irrigated, although some trees planted along the rivers and streams have access to water. Only a few of the new orchards planted away from the rivers at elevation on red clays are irrigated. Water resources are normally reserved for rice. It is usually dry from October to March (flowering and fruit set) in Guangzhou and wet during the rest of the year. Orchards in Viet Nam are also reliant on rainfall, since there is no water available in the elevated areas. It is felt that rainfall is normally sufficient for good production.

Most of the orchards in Thailand are found in the northern hills on steep slopes, and thus are not readily irrigated. Flood irrigation was sometimes used in the low areas, but has now been replaced by mini-sprinklers in the larger commercial plantings.

Experiments in India showed that irrigation every second day was required for good yields and fruit quality. This watering regime also helped to reduce the incidence of skin cracking which can be quite severe in some districts. Most orchards are watered by basin or flooded, even though drippers are more efficient. Irrigation is generally not available in Nepal or Bangladesh, with some trees suffering water deficits during fruit development. Orchards in the Philippines are also dependent on rainfall.

Irrigation is normally required to produce commercial crops in Australia, but care must be taken with the water to make sure it is not too saline. About two to four megalitres of stored water is required for each hectare of trees. Under-tree sprinklers are recommended. Drippers are rare. Some growers base their applications on experience, while others reply on estimates of water use calculated from evaporation from a Class A pan. The use of tensiometers and other soil water

sensors is less common. Irrigation is more important in northern Queensland at elevation in Mareeba, and in Rockhampton and Bundaberg in central Queensland, and less of an issue in southern areas with more uniform rain during the year such as Nambour and Ballina.

6.5 Use of growth regulators and cincturing to improve flowering and fruit set

Synthetic auxins were used in the 1950s and 1960s to control growth and flowering in Florida and Hawaii. Typically, the chemicals were applied before flowering to prevent late vegetative shoots developing. There were many instances where the treatments increased yield, however, often the responses were unpredictable. This was possibly because cool weather needed for flower initiation did not always follow the sprays.

More recently, Australian horticulturists showed that ethephon could be used to control early red leaf flushes when applied in May or June in sub-tropical areas. New buds emerge behind the damaged shoots within a few weeks, and flower if the weather remains cool enough. Mechanical pruning of the red flushes also induces the same response, but is difficult with large trees. If too much leaf is removed at this time, the crop will be very poor. This is because fruit are dependent on assimilates produced by leaves behind the fruiting clusters. Many similar strategies have been developed in Guangzhou and Chiang Mai.

Girdling or cincturing can be used in the same way as the auxins or ethephon to improve flowering as shown in China, Thailand and Australia. Girdling is normally carried out after the post-harvest flush has matured which would be in late March in sub-tropical Australia. This prevents new shoot growth for about three months, so that the next activity of bud growths occurs when conditions are favourable for flowering. In essence, it manipulates the growth cycle so that new buds develop during cool weather, and so is similar to the drought treatments used in Hawaii and Israel. However, it cannot substitute for cool weather at the time of flower initiation. Chemicals applied at this time are also not likely to increase flowering unless followed by cool weather.

Growth regulators and girdling have also been used to improve fruit retention. Chinese and Israeli workers showed that synthetic auxins reduced fruit drop and increased the yield of several cultivars when applied to trees soon after fruit set, when the fruit weighed about 1 or 2 g. Work in China, South Africa and Australia indicated that girdling soon after fruit set gave similar increases in yield. Girdling presumably redirected assimilates that normally supported stem and root growth. However, the long-term effects of these treatments on tree health are unknown.