Manage avocado tree growth cycles for productivity gains

A. W. Whiley, J. B. Saranah, B. W. Cull, Horticulture Branch and **K. G. Pegg**, Plant Pathology Branch

Avocado orchard yields are low when compared with those of apples, peaches and citrus. While this is partly due to the high energy cost associated with the production of oil-storing fruit with a large seed, it is also a reflection of the tree's rainforest origin, recent domestication and complex flowering and pollination behaviour.

The avocado is an evergreen tree which flowers in the spring from the tips of the previous summer's growth. Although in excess of a million flowers may be produced, the tree is predisposed towards vegetative growth rather than fruit production. Reasons for this are the high turnover of leaves, which are relatively short-lived when compared with those of other evergreen trees, and the evolution of the avocado under competitive light conditions in the rainforest.

Root systems are shallow, relatively inefficient for water uptake and susceptible to *Phytophthora* root rot. Internal tree water balance is easily upset and nutrient deficiencies are common in the highly leached coastal soils of Queensland where the avocado is grown. Heavy fruit set often occurs and is usually followed by excessive drop, which significantly reduces final yield. In addition the commercial practice of extended 'on-tree storage' of fruit after maturity is reached invariably leads to the development of pronounced biennial bearing patterns.

Avocado tree growth is very responsive to nitrogenous fertilisers when soil water and air temperatures are non-limiting. On free draining soils, in the absence of *Phytophthora* root rot, nitrogen is the catalyst for vigorous vegetative shoot growth. While a robust healthy orchard is a source of satisfaction, the aim of the serious orchardist is to produce economicaly regular crops of fruit. Understanding the growth cycle of the tree and the 'tools of the trade' that can be used to manipulate growth towards fruitfulness is a step to achieving this goal.

This article discusses avocado orchard management and its relationship to the growth (or phenology) cycle of the tree. However, it must be realised from the start that the environment exerts the most powerful effect on tree performance and any management strategies applied only reduce the impact of those factors that limit fruit yield. The concept has wider applications extending to other subtropical and tropical fruit tree crops which have a vegetative growth bias, for example lychee and mango.

How does the avocado tree grow?

Seasonal changes in the appearance of deciduous trees are obvious. From their nakedness in winter they erupt into a mass of bloom in the spring to be followed by a leafy canopy which provides the energy for developing fruit through to maturity in late summer. In autumn, the leaves drop and the annual cycle is completed.

While less spectacular, evergreen trees such as avocados also have distinct seasonal growth patterns which are interrelated and interdependent.

Growth activity occurs basically as the response by the cultivar to the environment. The pattern of growth of different cultivars in the same environment is similar, but on a different time scale. For instance, cv Fuerte starts to grow about 3 to 4 weeks ahead of cv Hass. Similarly, growth response patterns of the same cultivar in different districts also change in relation to the time of the year. Generally speaking, the further north the more advanced growth cycles of a cultivar become in relation to time.And finally, in any one district there may be seasonal differences from year to year between growth responses of a cultivar.

To use growth cycles as a management tool, orchardists must learn to recognise critical growth changes that occur during the year. Once these are identified and understood, they are better equipped to apply management decisions most likely to increase tree productivity.

Easily recognised are three types of growth in avocado trees: root, shoot and reproductive.

Roots account for all growth beneath the soil surface. This growth is difficult to study and our information to date is based on relatively superficial measurements. The functions of roots are obvious: they anchor the tree and are the major organs responsible for the uptake of water and mineral nutrients. They also produce growth regulators, which maintain a balance between shoots and roots.

Shoots include the trunk, limbs and new flush growth. Apart from the structural support and storage of tree reserves provided by the trunk and limbs, the leaves have a critical role in utilising sunlight to produce carbohydrates, which are the energy source for tree growth. It is the dependence of roots and shoots on each other that produces the cyclic pattern of vegetative flushing characteristic of avocado trees. As the shoot:root ratio increases in favour of shoots, vegetative growth declines and root growth increases, restoring the balance. The cycle is then repeated. Skillful control of the vegetative flush growth has the greatest impact on tree productivity.

Reproductive growth begins with flowering and is followed by fruit set, development and maturity. All stages of reproductive growth have a high demand for tree resources, that is water, mineral nutrients and carbohydrates, contributing little to their own development and returning nothing to tree reserves. Fruit development is strongly competitive with root and shoot growth and exerts the most powerful attraction on available resources. However, at

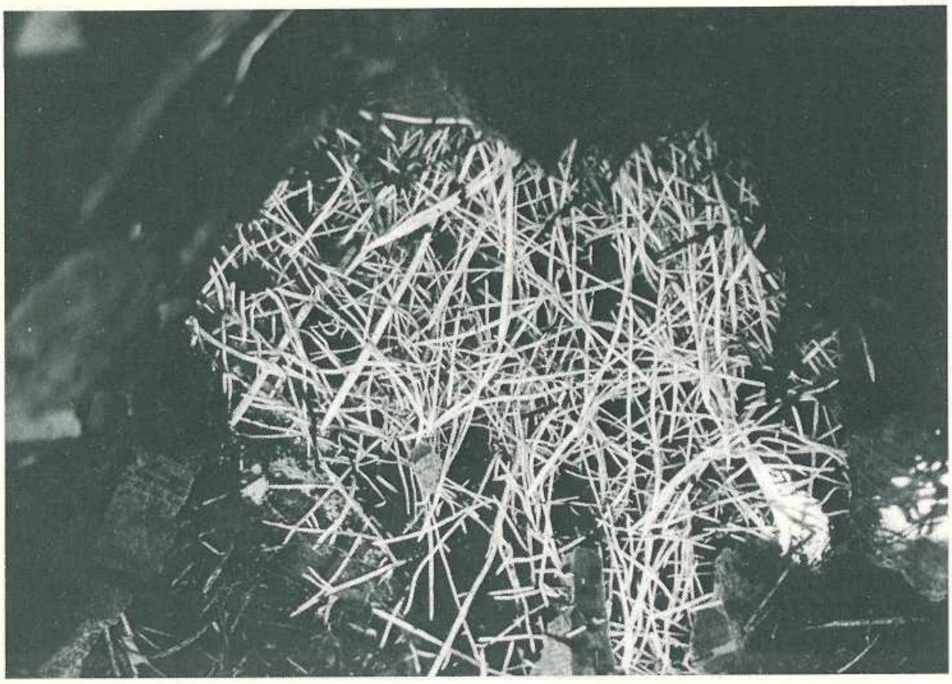

Plate 1. Feeder roots off avocado trees which are responsible for most of the water and nutrient uptake.

Plate 2. A vegetative flush characteristic of shoot growth of avocado trees.

critical stages of the growth cycle the resource requirement for fruit growth and vegetative flushing leads to depleted tree reserves. Stimulation of vigorous vegetative growth during these critical periods usually results in excessive fruit shedding.

To varying degrees, all three forms of growth draw on the 'pool of available energy' within the tree. This energy, in the form of carbohydrate, is generated by leaves and is either used for current growth or stored in the trunk and major limbs for future use.

Carbohydrate reserves are highest during winter when growth is minimal and are lowest during summer when use exceeds current supply from leaves. The management of tree growth cycles to increase productivity is essentially the management of reserve carbohydrate, the difference being the former can be seen while the latter is invisible though it nevertheless changes during the year.

Constructing the growth model

The development and interaction of root, shoot and reproductive growth are more easily understood if diagrammatic models are drawn showing major growth events. Except for root growth, this is a simple task and can be carried out by any orchardist willing to make regular observations over a full season. It is easier to begin recording during early winter when trees are relatively inactive. To construct a representative model, a minimum of 10 trees of each cultivar should be observed in the orchard. For flower bud development and vegetative flushing, an estimate of the percentage of terminals showing growth activity is made monthly for each tree and an average value derived.

Flower bud development refers to the growth of the flower panicle from the bud to the stage of the first flower opening. This point designates flowering, and estimates of the number of flowers open are made at weekly intervals until all buds are spent. Weekly observations are required during peak periods to record accurately fruit drop intensity. Fruit drop immediately after flowering is difficult to quantify but can be recorded by placing a small container under each tree and regularly counting the contents. When fruit is larger in early summer, whole tree counts are easily obtained and fruit drop intensity accurately assessed.

Root growth of avocado trees is primarily determined by soil temperature with significant root growth occurring when soil temperatures exceed 18°C. In most production centres, root zone temperatures would fall below this critical limit for most of the winter period.

An assessment of root activity can be gained by placing newspaper, about 6 sheets thick, under the mulch layer and inside the dripline.Root growth can be estimated by lifting the paper at regular intervals and rating the

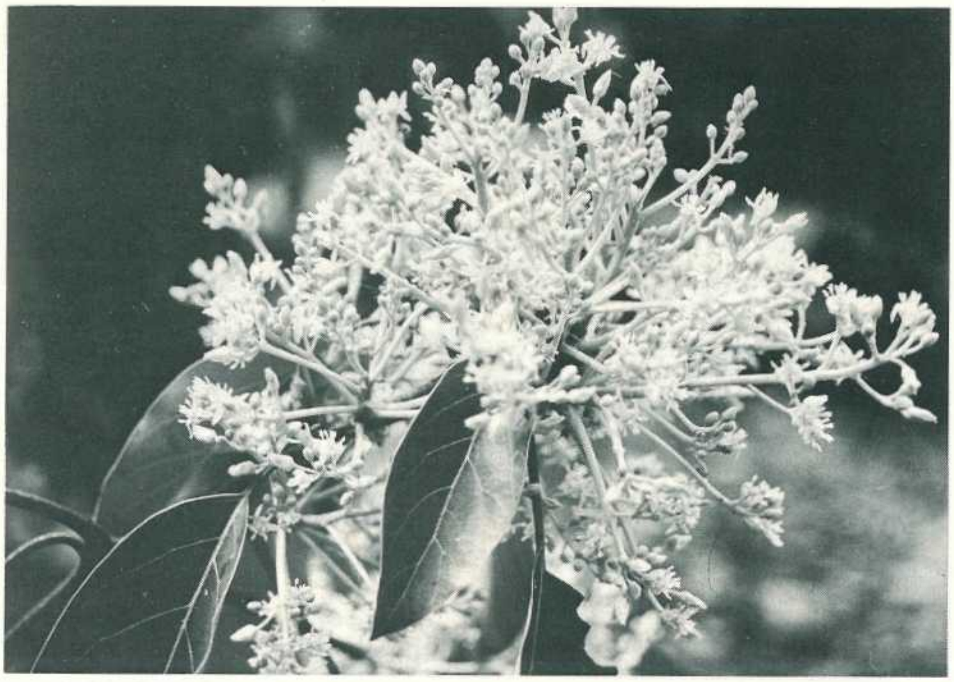

Plate 3. Prolific flowering in avocado results in few fruit set.

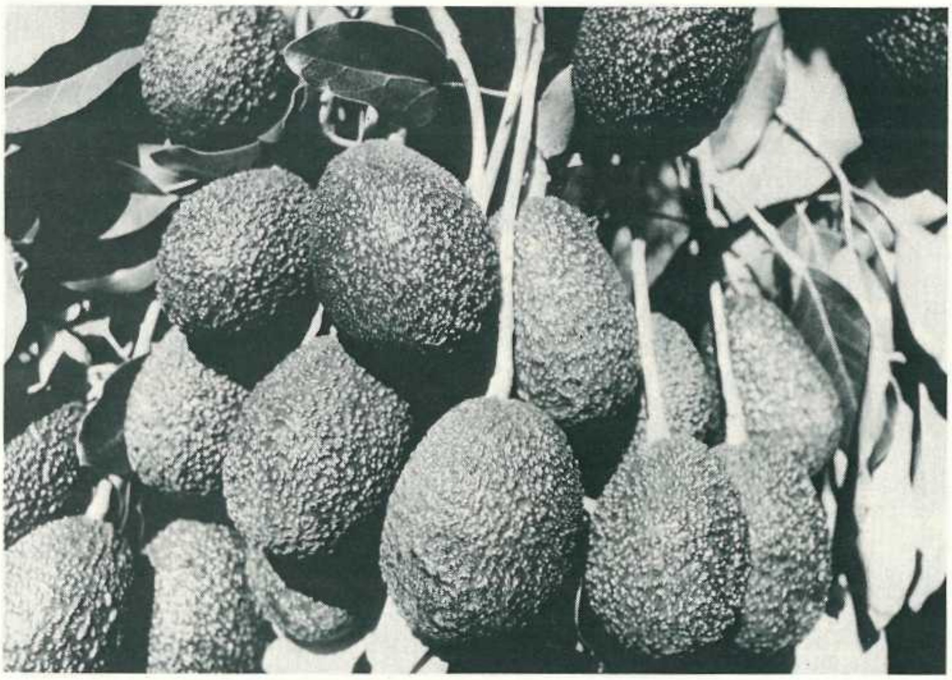

Plate 4. The avocado is an oil producing fruit with a high demand on tree resources.

activity on a 0 to 10 scale where 0 is no new growth and 10 is new growth over the total observation area. This information can then be drawn on the growth diagram.

Data collected from all these observations can be plotted on a graph and the extent of each type of growth quantified (see Figures 1, 2 and 3) and their relationship to each other clearly seen.

Interpreting the growth model

Once the growth model has been drawn (Figure 3), the interactions between root, shoot and reproductive growth can be seen more clearly.

Bearing avocado trees have two major vegetative flushes in a full growth season (Figure 1). Each flush is followed by a period of enhanced root growth. The first vegetative flush begins in spring towards the end of flowering, while the second flush occurs over the summer months.

Reproductive growth begins after a short period of semi-dormancy in the tree with flower bud development followed by flowering and fruit set (Figure 2). Flowering is a major event in the avocado tree's growth cycle, contributing 8% to total tree dry matter production in a full growth cycle. The floral organs increase the potential water loss surface of the tree by around 90% and are demanding on carbohydrate and nutrient reserves within a tree.

Immediately following fruit set, there is a drop of poorly pollinated fruit along with a high proportion of fruit which appear quite normal. This fruit drop coincides with the beginning of the spring flush, when fruit and shoot growth are competing for limited tree resources already depleted by flowering (Figure 3). The next major event of reproductive growth is the second fruit drop during early summer. Similarly, this is associated with a major vegetative flush resulting in competition between the two growth forms for tree resources. These remarks identify the two periods of competition in the growth cycle that directly affect productivity.

While the spring and summer vegetative flushes are competitive with fruit retention and growth, they are essential for the long term productivity of the tree. However, managing the vigour of these flushes improves the opportunity to increase fruit yield and assists in containing tree size. The management of flush growth and fruit retention is achieved by careful fertilising and irrigation practices, and the maintenance of a healthy root system.

Irrigating by the growth cycle

The water requirement of the avocado tree related to the growth cycle is illustrated in Figure 4. The water requirement is lowest during the cool semi-dormant winter period when growth functions are minimal. However, in mid and later season varieties, fruit growth is still occurring and some water demand by the tree will be present.

As the tree begins flowering the water requirement rises substantially. This is a reflection of both the increased surface area on the tree available for water loss and the greater environmental stress imposed during spring. Management of water in the orchard during flowering can be critical for fruit set, particularly if trees are growing on sandy loams with low natural moisture retention. When water is limiting, the flower panicles are the first to stress and may suffer permanent damage. Similarly, young fruitlets with a tenuous hold on the tree may prematurely abort under stressful conditions.

During the latter part of the spring, when fruit has established sink strength, that is, made a claim on tree resources, water management is not so critical. Nonetheless, trees should not be allowed to become too stressed as final fruit quality may be affected. Such an effect at this stage is irreversible. Tensiometer readings should not be allowed to exceed 30 centibars (sandy loam) or 40 centibars (clay loam) at a depth of 300 mm within the dripline of the tree.

The second fruit drop stage of the growth cycle is the most critical period for water management. This is a period of crop adjustment and a fruit set at this stage promising a bumper crop may rapidly change to one of mediocre or less. As highly stressful days (high temperatures with low relative humidity) occur during this phase, it is important to ensure that the tree suffers as little water stress as possible. Tensiometer readings in the 300 mm root zone should not exceed 25 centibars (sandy loam) or 30 centibars (clay loam). While good irrigation practices during this period do not prevent fruit drop, sound water management lessens the impact of crop load adjustment on final yield.

During the final period of rapid fruit growth and maturity, effective irrigation management reduces fruit drop ('ring-neck', a water stress associated fruit stalk disorder, can cause significant fruit loss during late summer) and increases final fruit size. This latter effect is particularly important with heavy cropping cultivars, for instance Hass, to achieve a high percentage of fruit in the size range most preferred by markets.

Fertilising by the growth cycle

Most avocado producing areas in Queensland are located on highly leached soils with a low nutritional base. During orchard establishment it is important to assess the fertility of the site using soil analyses. Many nutritional problems are more easily corrected before planting and the benefits will be reflected by better growth of trees during their juvenile years.

The avocado is a shallow-rooted litter feeder with its most active root zone in the top 300 mm of soil between the trunk and drip-line. Covering this area is the most efficient way of fertilising the orchard. Fertilising can be carried out by using traditional solid forms through directional throw equipment, by fertigation using an under-tree irrigation system and in some instances by foliar sprays. It is not the intention of this discussion to go into the rates of application of the different nutrients but rather their timing in relation to the growth cycle (see Figure 5) and how this may affect productivity.

With the exception of nitrogen, the essential nutrients for growth can be applied to the soil at any time of the year without the fear of forcing competitive, non-productive vegetative flushing. This does not mean that some rationalisation of fertiliser application is not needed. Indeed, looking at tree requirements in relation to nutrients, application timing can be programmed in relation to the growth cycles.

On the other hand, nitrogen is one of the most powerful management tools currently available and learning to use it effectively in the orchard is essential. When all other mineral nutrients and soil water are adequately supplied and temperatures are conducive to growth (that is, during spring and summer), applying nitrogen stimulates vegetative flushing. Withholding nitrogen temporarily favours fruitfulness, but overall productivity declines if trees become nitrogen deficient. For these reasons, the timing of nitrogen fertilising in the orchard becomes critical in balancing the tree between reproductive and vegetative growth.

The growth curves in Figure 3 show that fruit drop coincides with vegetative flushing. From this, it is logical not to apply nitrogen fertilisers, which would stimulate flushing, leading into these periods when reproductive and vegetative growth are strongly competing for tree reserves. Thus the summer/autumn months, after fruit drop has subsided, is the appropriate time for nitrogen fertilising of the orchard.

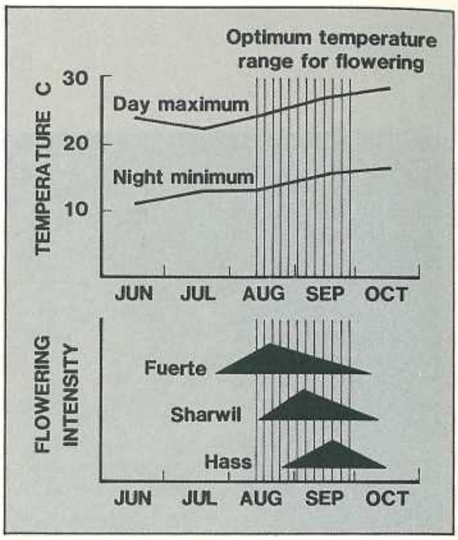

Figure 7a. Mean temperature and flowering patterns of cvFuerte, Sharwil and Hass at Walkamin, north Queensland. Peak flowering of all three cultivars falls during the defined optimum temperature range for fruit set, which is not a limiting factor in this district.

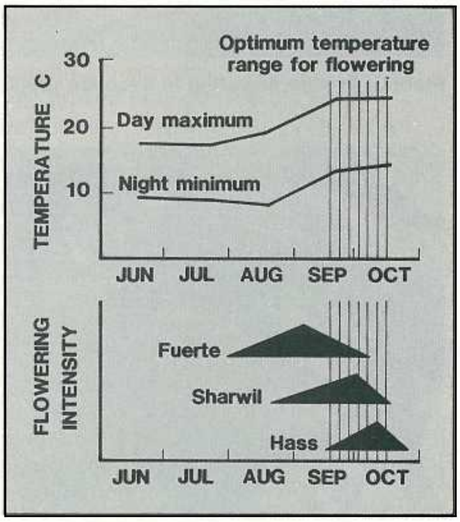

Figure 7b. Mean temperature and flowering patterns of cvFuerte, Sharwil and Hass at Maleny, south east Queensland. Peak flowering of Fuerte falls outside the defined optimum temperature range. Both Sharwil and Hass flower during temperature conditions favouring fruit set. Fuerte does not reach its genetic yield potential in this district.

The summer flush has a positive impact on both current and continued productivity of the tree. It is responsible for providing carbohydrate for growing and maturing the existing crop as well as producing flowers and setting fruit the following spring. Considering the strategic importance of this flush, it is critical that its management is nutritionally sound. Research has shown that provided the optimum nitrogen leaf levels are achieved in the matured summer flush, there are adequate reserves of this nutrient in the tree to take it through to the following summer.

Many of the remaining essential nutrients are required for root growth and, if soil and/or leaf analyses show deficiencies, they should be applied before periods of major root activity. These nutrients include phosphorus, calcium, boron and zinc. Boron is also important during flowering, when it affects pollen germination and growth. As boron has limited mobility in plant tissues, it is important that the summer flush matures with optimum levels of this nutrient, which moves from the leaves to the developing flowers as root uptake of nutrients is slow during winter.

Magnesium should not be overlooked in the orchard. If necessary, levels can be adjusted by using dolomite in the spring and autumn if the soil pH is low. Where pH is not a consideration, other proprietary forms of magnesium fertilisers are recommended. Potassium is another essential nutrient which readily leaches from the soil. It is needed for most growth processes in the tree and is particularly important in regulating water loss from leaves. In high rainfall districts, potassium is best applied in split dressings during the year (Figure 5) to counteract leaching.

With many crops, foliar spraying is a useful option for correcting trace element deficiencies. Avocado leaves grow quickly and soon develop heavily waxed cuticles which are impervious to foliar applied nutrients. To achieve any effective uptake, foliar sprays of nutrients should be applied when trees have a high proportion of actively growing leaves. As only low concentrations of product can be used several sprays during a growth flush are required to increase leaf levels significantly.

In most cases, there is no need to apply sulphur, iron, manganese or copper as they are available as impurities in many fertilisers or are in fungicidal sprays.

Phytophthora root rot control

Root rot caused by *Phytophthora cinnamomi* remains the greatest production threat in most areas where the avocado is grown. Understanding the interactions between the tree, the pathogen and the environment leads to a more

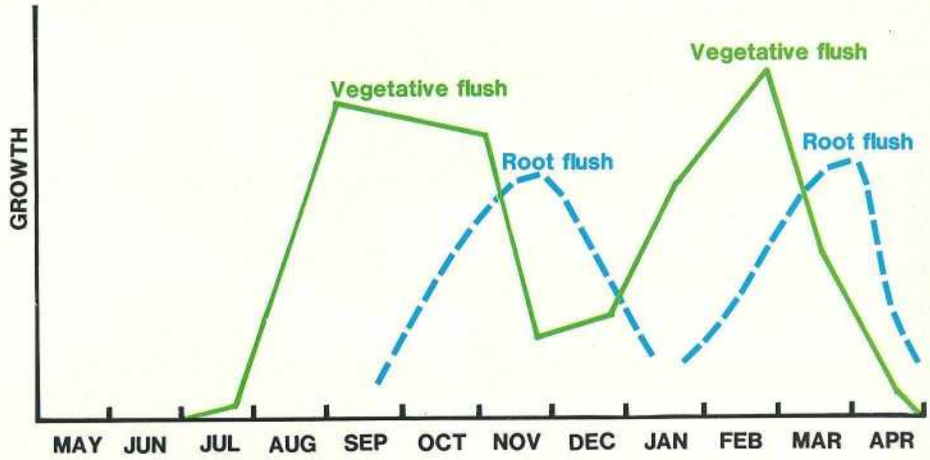

Figure 1. The vegetative and root cycle of growth in mature cv Fuerte avocado trees at Palmwoods, Queensland (latitude 27°S). Vegetative and root growth flushes alternate to maintain a balanced shoot:root ratio.

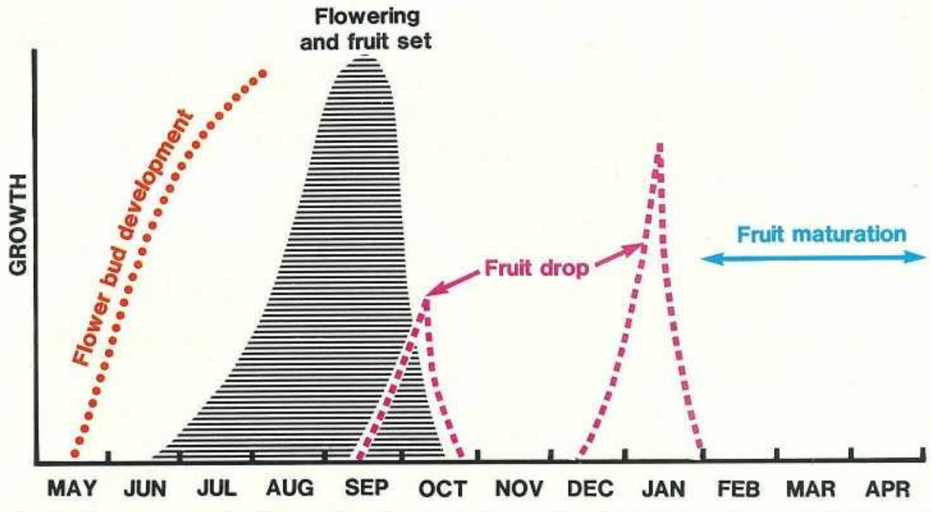

Figure 2. The reproductive cycle of growth in cv Fuerte avocado trees at Palmwoods. Reproductive growth consists of flowering, fruit set and drop, and fruit growth and maturity.

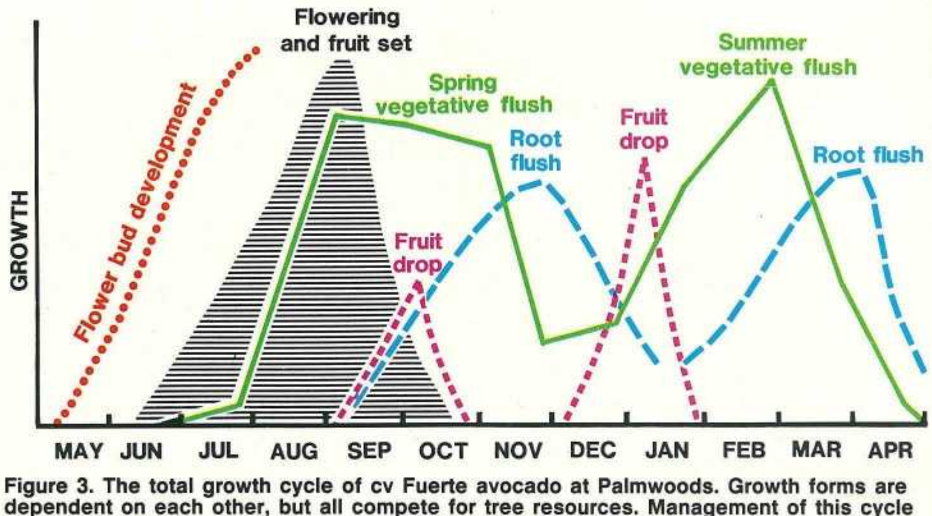

Figure 3. The total growth cycle of cv Fuerte avocado at Palmwoods. Growth forms are dependent on each other, but all compete for tree resources. Management of this cycle leads to improved fruit yields.

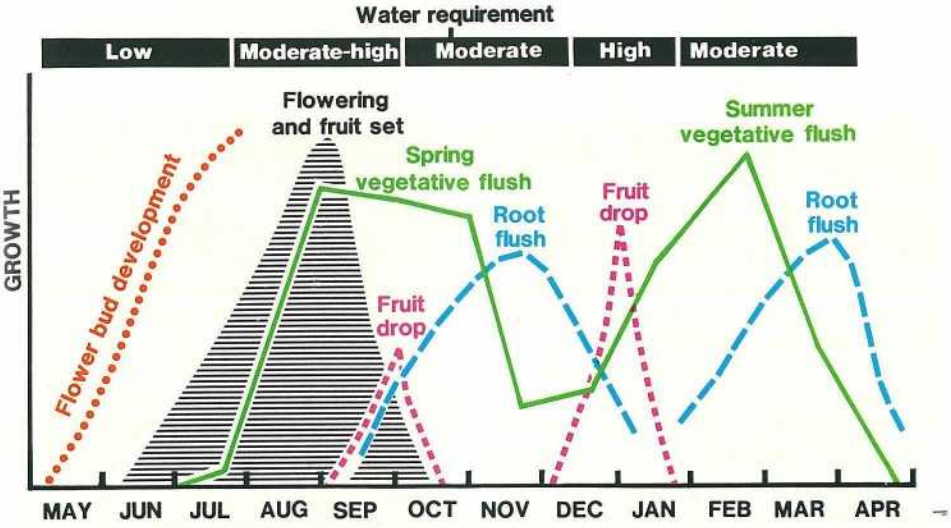

Figure 4. Irrigating by the growth cycle. Periods of low, moderate and high water demand by the tree for the various growth processes are identified. They should be monitored with tensiometers or other soil moisture sensing equipment as irrigation frequency depends on soil type and prevailing climatic conditions.

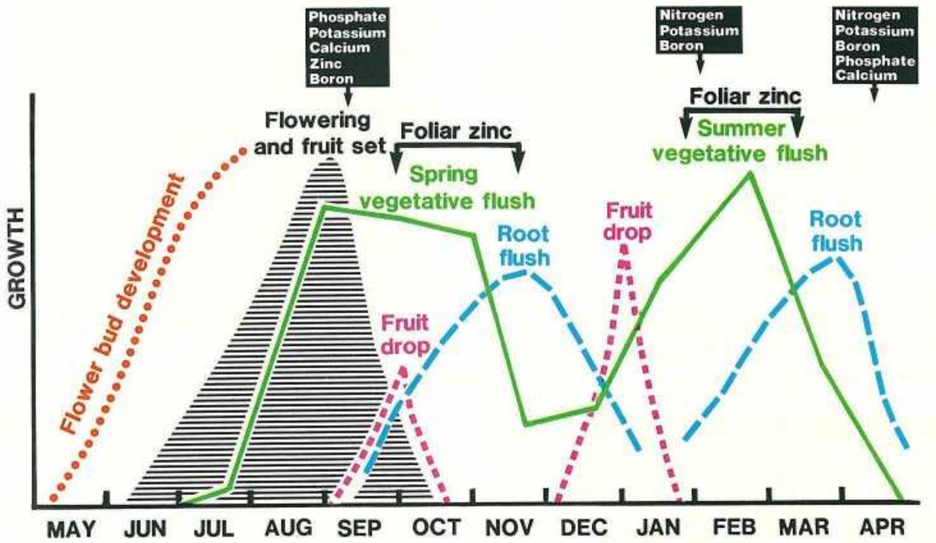

Figure 5. Fertilising by the growth cycle. Nutrient levels should be established by leaf and soil analysis prior to application. Fertilise when indicated to correct deficiencies or to maintain base levels.

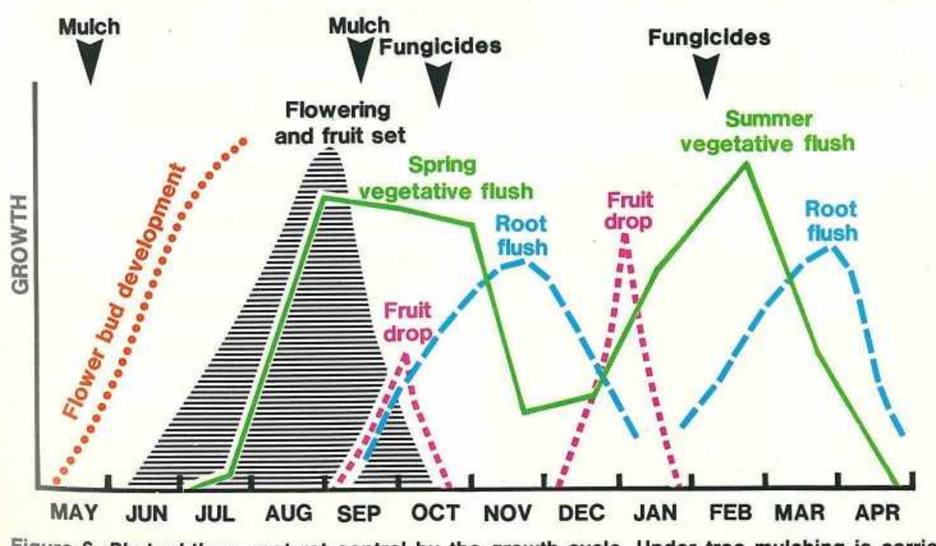

Figure 6. *Phytophthora* root rot control by the growth cycle. Under tree mulching is carried out during the winter/early spring months when *Phytophthora* activity is minimum. Fungicides are applied, either by trunk injection or soil application, prior to major root flushes. Injections are delayed in the spring until air temperatures are consistently exceeding 23°C.

effective management programme, using the medium of the growth cycle.

Phytophthora cinnamomi grows actively at temperatures between 15°C and 28°C, and optimum infection of roots occurs when the soil is saturated with water. Low soil temperatures in winter are not conducive to *Phytophthora* activity. The pathogen causes the most damage during the summer months when its growth conditions are met and there is an abundance of white feeder roots available for invasion (Figure 1). Therefore, all root rot control strategies should be aimed at protecting the roots during the summer when disease pressure is greatest.

The benefits of the organic cycle in assisting *Phytophthora* control are well known and the management aspects of tree mulching can be interpreted with the help of the growth curve (Figure 6). Mulching adds to the surface litter, generating root zone conditions similar to those of the rainforest where the avocado originated. Mulching stabilises the root environment and stimulates a microflora population which suppresses *Phytophthora* activity. It is particularly beneficial to young trees up to the time they are able to generate their own ground litter through leaf fall, and to trees with *Phytophthora* activity in the root zone.

Leaf fall in avocado trees is continuous, but there are times through the year when it accelerates. Spring grown leaves may begin falling in early winter, while the main leaf drop is during flowering and as the spring flush grows away. By summer the leaf trash is shallow, partially decayed and biologically active. The management of tree mulching should follow the same time scale with an application in the early winter, a top-up if the mulch is sparse in spring and finishing with a biologically active shallow open litter during summer allowing good aeration of the soil.

Likewise, timing of chemical protection against *Phytophthora* root rot can be related to the growth cycle. Trunk injections or soil applications of fungicides should be applied in time to protect major root growth activity during late spring and summer. Where there is high disease pressure, injections or soil applications are given to protect both growth flushes (Figure 6). Where root rot is is not a serious problem one treatment each season should be adequate.

Time of flowering

Although the avocado flowers profusely, it has a complex floral cycle which results in comparatively few fruit setting. Nevertheless, if 0.1% of flowers result in mature fruit then the tree produces a heavy crop.

To complete its cycle the avocado flower opens on two consecutive days. On the first day of opening, the flower is functionally female and the second day functionally male. Cultivars fall into one of two groups, 'A' or 'B', depending on the time of day they open. Some of the more important cultivars are categorised in Table 1.

Table 1. The flower type of some avocado cultivars

'A'	'B'
Hass	Fuerte
Reed	Sharwil
Wurtz	Shepard

The floral cycle is sensitive to temperature, with 'B' type cultivars being more sensitive than those with 'A' cycles. When day maxima fall below 20°C and night minima below 15°C, then floral cycles of 'B' type cultivars are disrupted and many flowers may only open as functionally male. This has disastrous consequences on fruit set and, in localities with low temperatures during flowering, cultivars may never reach their potential.

The optimum temperatures for 'B' type cultivars during flowering are 25°C day maximum and greater than 10°C night minimum. Type 'A' cultivars tolerate day maxima of 20°C and night minima of 10°C without disruption to their floral cycle.

By recording the flowering span of a cultivar in a district and relating it to mean maximum and minimum temperatures during this period, the commercial viability of the cultivar in any area studied can be predicted (Figure 7a and 7b).

Conclusions

The growth of an avocado tree follows a cyclic season pattern which is repeated each year, though not necessarily on the same time scale or with the same intensity of growth for each stage. Three separate growth forms can be easily distinguished : root, shoot and reproductive. While they are dependent on each other, they do compete for limited tree resources and, if a balance is not maintained, fruit yield is ultimately reduced. By recognising the stages of growth and understanding their requirements and the interactions within the tree, management practices can be modified and programmed to develop strategies which lead to productivity gains.

The principles of tree growth and management discussed in relation to the avocado apply similarly to other subtropical and tropical tree fruit. In particular, the phenology approach to management can be easily related to the lychee and the mango. Both species are similar to avocado in being evergreen and in producing large panicles with many flowers from terminal growth. Likewise, the status of tree reserves at critical stages of the growth cycle determines their final productivity in any one year.