Canopy Management of Sweet Orange, Grapefruit, Lemon, Lime and Mandarin Trees in the Tropics: Principles, Practices and Commercial Experiences

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Abstract

Over the past 18 years, citrus canopy management strategies (CMS) were developed improving tree health, productivity, fruit quality and management efficiency of orchards in tropical Southern Africa and Australia. These CMS are based on understanding of knowledge of tree phenology and natural growth habit, recognition of fruiting habits of "strong" and "weak" bearing branch units (SBBU and WBBU respectively), tree physiology, floral biology, environmental physiology, effects of canopy illumination, branch sap flow patterns, and of effects on these of climate, weather, topography, altitude and local pest and disease cycles. Secondly, CMS were derived with an understanding of effects on tree physiology of specific pruning and regrowth management practices. Thirdly, cost-effective methods were developed of optimising growth, form and function of non-bearing trees, trees in full production, and old trees declining due to age and/or shading. The strategy is to create, after planting, strong, balanced tree frameworks, and to maintain these through the orchard's life by selectively pruning multiple light- and spray "channels" into the trees' canopies. As new "internal" growth arises and develops, fruiting is displaced to sheltered, well-lit and ventilated canopy interiors. Pruning specifically removes WBBU, and stimulates production of SBBU, directly subtended by scaffold branches in which sap flow is strong. These SBBU bear large, unblemished fruit of uniform high quality. Rejuvenation pruning of old trees is discussed, as is protection of leaf flush from the pests citrus leaf miner, thrips, leafhoppers and pathogens Citrus black spot (CBS), Asiatic citrus canker (ACC) and *Huanglongbing* (HLB). Also discussed are improvements observed to soil following additions of coarse, organic wood chip mulches derived from triturated prunings, and necessary adjustments in support of CMS to fertiliser practices, irrigation, pest-, disease- and orchard floor management.

INTRODUCTION

Citrus growers in the tropics have good reasons to consider pruning trees growing too tall, broad and dense. The resulting crowding and shading reduces yield and fruit quality, and makes difficult grove access, maintenance of irrigation, fertilizer delivery, spraying, and harvest. However, adopting an appropriate and effective canopy management strategy (CMS) solves these problems, and prevents trees investing energy in misdirected- or poor quality growth (Krajewski, 1996; Krajewski and Pittaway, 2000).

Fruit quality originates in the groves. It is strongly affected by cultural practices, and pruning exerts powerful effects on both yield and fruit quality (Krajewski, 1996; Krajewski and Pittaway, 2000). Over the past 18 years, principles and practices of selective pruning were developed and disseminated to commercial citrus growers in the following areas, situated between 23.5° latitude north and south and at altitudes from <50 m to >1200 m a.s.l.

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- Zimbabwe: ‘Miho Wase’ satsuma mandarin; ‘Nules’ clementine mandarin, lime, lemon, navel and Valencia oranges and grapefruit;
- South Africa: ‘Eureka’ lemons, ‘Texas Star Ruby’ grapefruit, ‘Olinda’, ‘Shamouti’, ‘Delta, ‘Juvalle’ and ‘MidKnight’ sweet oranges and ‘Minneola’ tangelo;
- Australia: the Kimberly area of northern Western Australia, and the Katherine and Darwin areas of the Northern Territory: growing pigmented grapefruit, ‘Eureka’ lemons and limes;
- Florida: ‘Texas Star Ruby’ and ‘Hamlin’ sweet orange;
- Pakistan: various grapefruits, sweet oranges (e.g. ‘Musambi’) ‘Kinnow’ mandarin; lime;
- Swaziland: (low lying zones of elevation <200 m a.s.l., with cumulative heat units* >3250 CHU [* for calculation, use temperature thresholds of 13°C for minimum temperature and 35°C for maximum]: ‘Texas Star Ruby’ and ‘Marsh Seedless’ grapefruit; ‘Delta’, ‘MidKnight’ and ‘Olinda’ valencias, ‘Ortanique’ tangor (in South Africa and Swaziland called ‘Tambor’: Saunt, 2000) and ‘Eureka’ lemon.

The CMS discussed in this paper were designed to operate as a biologically rational production system in which soil and tree health are of primary importance. Practices are implemented such that a robust partnership results of trees, soils and beneficial organisms” doing the work” of growing high quality fruit. This frees managers to concentrate on addressing other issues, such as production of fruit for discerning markets with least impact to natural capital and at lowest fixed cost. All practices incorporate knowledge of tree phenology, pest and disease life cycles and of effects of practices such as pruning and fertilisation on tree growth patterns.

The CMS have proven to be cost effective, and well suited as management systems for use in countries without access to expensive or “technologically advanced” equipment. These systems contribute towards trees (and soils) better buffered against increasingly erratic, extreme and changeable climate and weather. This is made easier by the recognition of abiotic and biotic stresses affecting production, including little-known agrogenic (i.e. caused by farming practices) stresses, and the design of systems that place lower reliance on these stressors, which include pesticides, several high-analysis fertilizers, fungicides, herbicides and plant growth regulators.

Finally, these CMS are directly applicable to areas in which CBS, ACC and HLB are present, as well as insect pests Asian citrus leaf miner (CLM: *Phyllocnistis citrella* Stainton), the HLB vector psyllid *Diaphorina citri*, and African HLB (also known as “greening disease) psyllid vector *Trioza erytreae* (Del Guercio). With reduced inputs of many chemicals, these systems produce fruit perceived as safe to eat even by sophisticated and well-informed consumers.

UNDERLYING PRINCIPLES OF CMS

Physiological considerations were discussed by Krajewski (1996), Krajewski and Pittaway (2000) and Bevington, Falivene, Moulds and Krajewski (2002). There are two main effects when trees are pruned: reduction of bud number leading to changes in dominance relationships, and changes in canopy lighting. With respect to the former, it stands to reason that pruners should only remove dead, diseased, out of place wood or “weak wood”. The latter bears buds that usually only produce few- or low value fruit and retain old and inefficient leaves. Branches of this latter type are called weak bearing branch units (WBBU: Krajewski and Pittaway, 2000; Khurshid and Krajewski, 2010).

Light is critically important. One of the factors most limiting productivity of trees is the shade they cast upon themselves and their neighbours. In unpruned mature grapefruit trees, light intensity within the canopy may be 2% that of full sunlight (Fischler et al., 1983). Light drives photosynthesis and the amount of light intercepted by citrus trees and its distribution through their canopies strongly affects bud sprouting, flowering, fruit set, fruit size, fruit internal and rind quality and tree growth. Growers farm with light: solar energy that is one of the few free inputs into horticultural production systems (Krajewski, 1996; Krajewski and Pittaway, 2000).

Sap flow is also vital since sap is the transport system for water, minerals, plant growth substances, food reserves, and all essential factors required for growth and development. Fruit developing in positions within the tree canopy where light is optimal and sap flow streams are strong are of high quality, being both larger and sweet (Krajewski, 1996; Krajewski and Pittaway, 2000; Bevington et al., 2002). Even in grapefruit trees where developing fruits can draw assimilate required for growth and maturation from a distance of two metres away in the canopy (Fischler et al., 1983), fruit size and quality improves with judicious pruning and canopy management. In layman's terms, growers are advised to "simplify the plumbing" of their mature and old trees (Krajewski, 1996). Of all cultural practices, only pruning and training can optimise light distribution and sap flow to fruits (Krajewski and Pittaway, 2000) and in otherwise well managed trees, pruning is the management practice most likely to optimise production levels and fruit size (Bevington et al., 2002).

However, pruning citrus trees results in production of vegetative re-growth that must be carefully protected from all diseases and pests. Of especial importance in this respect are citrus black spot (CBS: *Guignardia citricarpa* Keily); Asiatic or bacterial Citrus canker (ACC: *Xanthomonas campestris* pv. *citri* (Hasse) Dye) and the pest CLM, and Asian greening disease or *huanglongbing* (HLB) caused by the protobacteria *Candidatus* Liberibacteria asiaticus (Asian organism) and *Ca.* L americanus (Brazilian form) plus its leafhopper vector *Diaphorina citri* Kuwayama. The epidemiology and economic impact on citrus of these diseases and pests or vectors are extensively documented (for example, CBS: Loest, 1960; Kotze, 1981, 2003; ACC: Stall, 1993; Gottwald et al., 2002; Schubert and Sun, 2003; HLB: Catling, 1969; Zhao, 1981; Gottwald et al., 2007).

CANOPY MANAGEMENT PROCEDURES

Citrus trees have been "pruned" in many ways; some better than others. The closer the pruning method fits the natural growth habit of the trees, the more effective, efficient, sustainable and sensible it is. It is wise to work with trees, and not against them. The first cuts made to the tree are the most important. It is worth doing this correctly from the start, and not delaying pruning until large cuts have to be made. The rule is, as soon as a branch is seen to be out of place, train it or remove it. How one defines "out of place" is the key, since pruning must be selective, meaning one cuts away only dead, diseased, and dysfunctional branches, of whatever size is deemed appropriate. One aims to do so each year, in the right season, and to never prune more than is necessary. Finally, an ongoing programme is needed for maximum benefit, and some patience is required for the full range of benefits to become evident.

The rule is simple: do the right things at the right time to the right trees. The guiding principles apply to trees of all ages. One should try to see the link between how young trees are trained and how they will be pruned when mature. Pruners should from the outset view these as connected.

The aim is to induce trees to produce a balance of vegetative and fruiting wood, with uncrowded bearing wood situated conveniently within the relative shelter of the well-lit, adequately ventilated inner citrus canopy and low enough to harvest from the ground or from no more than a two-rung ladder. The CMS manage tree complexity through three phases of the groves' life:

1. Induction of complexity in young trees.
2. Maintenance of complexity in bearing trees.
3. Reduction of complexity of large, old trees declining due to the effects of age and/or shading.

The benefits of pruning are most often undermined or negated by over-irrigation and over-fertilisation with especially nitrogen and potassium. Growers pruning trees would be well advised to review and adjust these practices accordingly.

Training Young Trees

It is a mistake thinking non-bearing trees should not be pruned, since correctly pruning trees aged 1 to 3 years is the best use of the limited time that citrus pruners have. Early steps can be taken to form the tree's structure before it invests energy in out of place, too strong or too weak branches, and it is far easier to cut small branches than large ones.

Young trees are trained by removing immediately any broken, dead or diseased branch. The height above soil level of the tree's lowest limb is set at between 45 to 65 cm above soil level, and the young tree's trunk is kept clear of all growth below this point. Growers also must select the 3 to 6 well-spaced and oriented branches that will be left to form the limbs of the mature tree. Equal dominance of these is maintained by removing at point of origin any vigorous water-shoots, or by bending these. Finally, trees should be skirted at a convenient height to avoid damage by herbicide applications and to facilitate ant and/or snail control.

Commercial experience shows that this can be done spending no more than 2 min per tree per year. Young trees can be trained at any time of the year, and might require two to three passes over the same trees, several months apart. However, avoid if possible cutting trees and generating vegetative regrowth at any time when activity is high of such leaf pests as aphids, thrips, Lepidoptera larvae, and especially of CLM and leafhoppers. Citrus leaf miner feeding activity greatly aggravates severity of canker (Gottwald et al., 2002) and psyllid-feeding activity hastens spread of HLB (Catling, 1969; Gottwald et al., 2007).

Canopy Management of Bearing Trees

When pruning, one aims to improve- and make less variable, canopy lighting and sap flow to fruits and to renew the fruiting wood. Tree structure is modified so that an optimum number of fruits develop within a more uniformly lit, better-ventilated canopy, close to the strong sap flow of supporting branches, yet low-accessible enough to be conveniently harvested (Krajewski, 1996; Krajewski and Pittaway, 2000; Bevington et al., 2002).

1. Skirting and Light Hedging. As soon after harvest as possible, skirt trees at such height at which fruit at maturity is no less than 400 mm above the soil surface, and no lower than 300 mm for trees planted on berms or ridges. Commercial experience shows that correctly skirted trees appear to "reallocate" flowering and fruiting to remaining parts of parts of the canopy. Hence skirting results in little or no reduction in yield, and skirted trees are easier to fertilise, irrigate, spray and to keep free of ants, harvest, mulch and service by sanitation crews (Anonymous, 1995; Smith, 1995; Krajewski, 1996; Krajewski and Pittaway, 2000).

In order to keep trees within their allocated space and tree rows open to orchard traffic, light hedging may be considered. For best results, cut wood no thicker than 10 to 12 mm diameter. This usually achieves adequate control of tree spread, renewal of strong bearing wood and production of vegetative re-growth not excessively vigorous. Hedging at an angle of 20° to the vertical allows light to reach tree skirts (Bevington and Bacon, 1978; Bevington and Bacon, 1980; Anonymous, 1995; Krajewski, 1996; Krajewski and Pittaway, 2000; Bevington et al., 2002; Khurshid and Krajewski, 2010).

Commercial experiences with hedging show trees should be hedged as lightly as possible: harder is not better. However, heavy topping of trees is not recommended, due to rapid ensuing shading of internal growth and subsequent loss of bearing potential low down in well lit and ventilated portions of the tree canopy. Moreover, mechanical hedging of citrus trees in areas in which ACC is endemic is "an excellent way to cause tremendous wounds and spread citrus canker" (Gottwald et al., 2002). In addition, this non-selective method induces extensive leaf flushing, especially in trees abundantly supplied with nitrogenous fertiliser, which often attracts the attention of such foliar pests as CLM and psyllids, with implications for management of ACC and HLB. For this reason, we advise citrus producers in such areas to consider implementation of alternative canopy management methods.

2. Canopy Structure Improvement. After skirting, prune multiple light and spray channels (Krajewski, 2010) into tree canopies and thin out tree “tops and shoulders” by removing, at their points of origin, wood of the following types: dead, diseased or broken branches; crossover branches; rubbing branches, water-shoots growing up the centre of the tree and sharp branch stubs left from previous cutting. Spend about two to three minutes per tree on this step: typically, one would each year make four to 6 saw-cuts of wood of 25 to 50 mm diameter.

3. “Window Pruning” to Remove Weak Bearing Branch Units (WBBU). With high value varieties, or where crop regulation (reduction of flower number) is required (e.g. mandarins), pruners may make “window cuts” by removing inferior bearing wood. Pruners are taught to recognise this type of inferior fruiting wood, (as defined in Krajewski and Pittaway, 2000) and to remove such wood. This includes WBBU called “hangers” (old, unproductive, long, thin, spindly, much-branched, growth with smallish, yellow leaves, arising from the underside of their supporting branches); branches bearing leafless, “white” bloom. In addition, pruners thin out branches in congested (dark) areas of canopy and shorten “long” flushes to one-third of their length, spending a total of two to three minutes per tree on this, during which time 12 to 15 secateur cuts are made, intersecting wood of 8-15 mm diameter.

4. Rejuvenation Pruning of Old Trees. As trees age, their canopies become too tall and broad to conveniently manage. Their productivity also declines through the effects of age and/or shading. In old trees both canopy physical dimensions (height, spread, length) and complexity may be reduced through rejuvenation pruning. In general, the same sorts of cuts are made as those used on mature trees, although heavier pruning of older, thicker branches will be needed to rejuvenate them. Try not to over-prune in any one year: it is a work in progress, and trees may be pruned every year.

Growers are advised to take two to three years to reduce canopy size and complexity. When done in this manner, excellent results may be expected with regard to increased yields and improved fruit size. As a rule only healthy trees respond positively to pruning.

5. Re-Growth Management. Pruned, healthy trees produce both localized and general re-growth, which MUST be managed some three to five months after pruning (i.e. in late summer to mid autumn) in order to maintain good canopy light distribution, optimize bearing potential of re-growth, improve fruit quality and maintain effective spray coverage.

Re-growth should at least be spaced-out by hand-thinning (to 15 to 20 cm apart) surplus shoots resulting from large cuts. Remaining shoots can be left alone, or topped or bent to make them branch, depending on local canopy structure. Bending highly vigorous shoots induces lateral shoot growth. It is a useful technique to help manage high vigour situations. Growers usually allocate one to two minutes per tree per year on this step, and protect re-growth from foliar insect pests and pathogens.

COMMERCIAL EXPERIENCES WITH CMS

Correct pruning and canopy management of trees results in many benefits, including increased production and fruit size, improved fruit rind- and internal quality, generation of high quality bearing wood, improved blossom quality, improved ease and efficiency of orchard access, and spray applications, reduction of post-harvest decay potential, and easier grove sanitation of both fallen and out-of-season fruit, infested with such pests as red scale *Aonidiella aurantii* (Maskell) and such diseases as ACC and citrus black spot (Krajewski and Rabe, 1995a, b; Krajewski, 1996, 2010; Krajewski and Pittaway, 2000).

Commercial experience has shown that for the results above to be achieved, canopy management practices need to be augmented with adjustments to nutrition and irrigation practices and by mulching. In this respect, one strives, through this combination of practices for the implementation of a production system resulting in amenable, calm, productive and resilient trees growing on fertile, resilient, biologically-active soils naturally suppressive to soil pests and diseases. Such trees produce sustained volumes of high quality, safe-to-grow- and eat fruit with prolonged shelf life. Furthermore, such fruit is produced with lowest impact on natural capital in tropical areas in which diseases including CBS, ACC and HLB are present. One needs to look for- and make use of synergies in management practices (Krajewski, 2010).

Irrigation and Fertilization

Any significant reduction (i.e. >15%) of the mature tree canopy by pruning requires concomitant changes to the applied amount of especially nitrogenous and potassic fertilisers, and usually also to irrigation. In this way, excessive vigour of regrowth is reduced. Improved fruit set may reduce the number and intensity of subsequent leaf flushes, and facilitate pest and disease management. The aim is to balance vigour. Flushes need to be vigorous enough to form strong BBU and to withstand CBS infections (see Loest, 1960; Kotze, 2003), yet not so vigorous as to increase risk of attack by CLM, psyllids nor by ACC. Lowering leaf nitrate levels reportedly reduces pest and disease infections (Chaboussou, 1986, 2004; Dordas, 2009). One would also expect reduction of CLM feeding activity. Finally, growers might also consider silicon applications, which reportedly increase plant resistance to biotic and abiotic stresses, decrease susceptibility to pest and disease outbreaks, and perhaps also exhibit anti-feedant properties (Matichenkov et al., 2001; Epstein, 2005; Fauteux et al., 2005; Laing and Adandonon, 2005; Ma, 2005).

Mulching

Pruning large trees results in literally piles of pruning debris: a rich source of carbon many other elements (Calabrese and Panno, 1992), which are recyclable if soils are correctly managed. Wood chip mulch, applied to the soil surface (and NOT worked into the soil) under the trees' drip zones in a layer three to five cm thick, results in favourable changes to soil physical, chemical and biological properties. Outlined by Brady and Weil (2002), Primavesi (2006) and Thies and Grossman (2006), these effects include reduced water requirements of citrus trees; reduced soil erosion, compaction, crusting and cracking; reduced weed growth; darkening of soils and increased soil aggregation; reduced soil splash onto low-hanging fruits; increased activity of soil macrofauna (e.g. earthworms and collembola) and microflora (saprophytic fungi) and the rapid breakdown of pruning debris and fallen leaf litter, through feeding activity of the soil food web. This breakdown is most rapid in subhumid or arid climates where trees are irrigated with under-tree micro-sprinklers. Finally, differences were observed in citrus root density, gross morphology, and distribution within the soil.

These are significant factors affecting production. Trees with such root systems are more buffered against various environmental stresses caused by nutritional or drought factors, and others (Neumann and Laing, 2006). Finally, to optimise production and management efficiency, changes need to be made to such practices as irrigation, fertiliser applications and weed management where mulches are applied.

Growers who mulch trees may have a powerful tool at their disposal for reduction of inoculum levels. The ACC bacteria survive only for a few days in soil and only a few months in plant material incorporated into soil (Gottwald et al., 2002). We have observed very rapid breakdown of triturated citrus material under trees irrigated by micro-sprinklers with soils exhibiting high activity of cellulolytic fungi and leaf shredders such as collembola, earthworms and snails. This rendition of material is theoretically rapid enough to reduce levels of infective material and so improve control of ACC and CBS. Further work is necessary to validate these observations, since the very real potential exists for reduction of inoculum levels by biologically-mediated rendition of infective plant material such as CBS-ascospore-riddled fallen citrus leaves by a very wide range of active soil organisms.

Management of Leaf Flushes

Young citrus stems and leaves are attacked by both CBS and ACC. New flush is also attacked by many insect pests of which CLM and psyllids are the most serious where ACC and HLB are endemic. However, healthy leaf flushes are essential for tree health and production and flushes must be protected from the pests and diseases mentioned. It is easier to monitor and protect fewer, better-synchronised flushes (even if these are heavy ones) than intermittent ones (Krajewski, 2010).

Timing and intensity of flushing may be at least partly controlled through use of suitable nutrition, irrigation and/or fertigation practices, resulting not in *maximum* growth but in calm, resilient and productive trees. Flushing can also be controlled through judicious canopy management practices, using carefully controlled time and intensity of selective pruning, as well as regrowth manipulation practices such as shoot bending in high vigour situations (e.g. lemons on vigorous rootstocks in areas with rich soils and high CHU). Leaf flushing also tends to be to be reduced when trees are carrying a heavy crop, and the improved fruit set observed with leafier inflorescences (Davenport, 1995) that result from pruning (Krajewski and Rabe, 1995b; Khurshid and Krajewski, 2010) may contribute to "calming" the flushing of trees.

Finally, protection from defoliation of trees by insect pests, diseases or herbicide applications, and the increased longevity of leaves developing in well -it canopy zones, close to strong sap flow may collectively reduce the risk of intermittent production of leaf flush.

Commercial experience suggests that heavy leaf flushes are not problematic: unprotected heavy- or intermittent flushes are. Finally, monitoring of flush by pest scouts is a key management practice, and must be done at all times of vulnerability (Krajewski, 2010).

PEST AND DISEASE CYCLES AND THE POSSIBLE DISRUPTIVE EFFECTS OF CMS

Several countries in S.E. Asia and S. America have lived with canker for many years, although reportedly with, in all cases, the necessity for a concomitant "alteration" of the industry and at higher cost of production. In some cases, these become so high as to make it "impossible to grow such (highly susceptible) cultivars profitably" (Gottwald et al., 2002).

However, is this necessarily so? Practical experiences have shown that a significant degree of overlap already exists between such production practices as optimal nutrition, pruning, efficient tree spraying, mulching, inter-row mowing and grove tree phenology surveys and tree inspections, already implemented for the sustained production of high yield and fruit quality and those required for effective management of CBS, ACC, CLM and HLB (Krajewski, 2010). In this regard, Gottwald et al. (2002) reported that, with citrus varieties resistant- or moderately resistant to ACC, adequate control could be achieved using copper fungicidal sprays alone, whereas with sensitive cultivars (e.g. grapefruit), adequate control requires implementation of several control measures (our emphasis). We fully agree and the CMS aim to achieve this "depth" of defence against these diseases and pests using a high degree of synergy between practices.

Asiatic Citrus Canker

Epidemiology and effects of the disease on citrus trees have been documented (Kotze, 1981, 2003) as have the effects of cultural practices on ACC control (Loest, 1960; Schutte and Kotze, 1997), specifically in the tropics (Krajewski, 2010).

In areas where ACC is endemic, growers pruning trees a dilemma with regard to copper fungicide sprays. Current advice is to maintain a copper barrier covering the periods of sensitivity (Gottwald et al., 2002). However, Belotti (1998) established 0.677 mg bioavailable Cu/kg of soil as the critical copper concentration for "soil impairment". Copper is therefore a significant soil pollutant (see Bünemann et al., 2006), and every attempt should be made to decrease the amount of metallic copper deposited on soils.

However, pruning reduces spray volumes required for complete coverage of trees (Krajewski, 1996), Canker spread is also favoured by feeding activity of CLM whose control is made easier through improved spray coverage of standard pesticide applications where trees are so pruned (Krajewski and Pittaway, 2000).

Trees should not be pruned at times when CLM activity coincides with emergence of susceptible new growth. In areas with ACC, pruning should be done in summer, or at a time when it is dry, in order to minimise spread of inoculum by airborne spores from pruned, infected trees to adjacent, non-infected trees, especially where pruning debris is being processed to mulch (Gottwald et al., 2002).

In seasons during which spring and summer rains combine with wind-speeds exceeding 30 km/hr (i.e. 8 m/s; 18 mph), ACC bacteria, carried in raindrops, are “blown” into natural openings as stomata. The bacteria are also blown into wounds caused by abrasion and punctures by dead wood and thorns, or by mechanical hedging or other pruning, and feeding galleries made by CLM. Reduction of wind-speed by effective windbreaks reduces this bacterial ingress (Gottwald et al., 2002). However, pruning trees such that new flush (BBU) and fruits are borne within the sheltered canopy interior also reduces wind-speed (Krajewski, 1996; Krajewski and Pittaway, 2000). As a result, entry of spores carried by wind blown rain may be further reduced (Krajewski, 2010).

Citrus Black Spot

Epidemiology and effects of the disease on citrus trees have been documented (Kotze, 1981, 2003) as have the effects of cultural practices on CBS control (Loest, 1960; Schutte and Kotze, 1997), specifically in the tropics (Krajewski, 2010).

Growers who prune and mulch citrus groves can disrupt the life cycle of CBS. Citrus tissues with low vigour are most susceptible to infection, and pruning trees to increase leaf, twig and general tree vigour reduces the effects of CBS. Pruning also reduces levels of inoculum where debilitated and low-vigour wood is cut from trees. Since the greatest risk of CBS transmission comes from ascospores released from fallen, decomposing citrus leaves, the covering of fallen, infected leaves with organic mulches interferes with free liberation of ascospores. Furthermore, where such mulches are wetted by under tree micro-sprinklers, decomposition of organic material by the soil food web can skeletonise leaves within a short time, and so reduce effective levels of inoculum.

Huanglongbing

Epidemiology and effects of the disease on citrus trees have been documented (Catling, 1969; Zhao, 1981; Gottwald et al., 2007) as have the effects of cultural practices on HLB control, (e.g. the effect of time of pruning: Joubert and Stassen, 2000), specifically in the tropics (Krajewski, 2010).

In some areas, growers who prune citrus trees must know that psyllids that feed on new flush transmit the Asian form of HLB. Both quantity and timing of the flush is important, and in this regard, the severity and time of pruning can affect HLB. Wherever possible, one would avoid pruning trees at a time when psyllids are active and feeding. Finally, short-term, high-density production systems have been proposed as a management strategy for HLB, to maximise early production and economic return before the anticipated premature demise of a planting due to HLB. If one accepts this, these production systems will have to be managed from planting by pruning. Pruning will best succeed if tree nutrition practices do not emphasise maximum growth rate, using high quantities of especially nitrogenous fertilisers.

Tree and Soil Health: Trophobiosis and Agrogenic Stresses

Tropical soils considered poor in chemical terms are rich in biological activity in comparison with temperate soils. With low supply of nutrients per unit volume of soil, however, plant growth depends on intense soil biological activity; the development by plants of root systems that can explore large volumes of soil, especially helped by mycorrhyzal fungi that increase the root-soil interface, and rapid turnover of organic matter by cellulolytic, aerobic microbes (Primavesi, 2006). Soils high in organic matter (from wood chip or mown grass mulches) and with active soil biology generally exhibit good soil fertility.

Experiences with *Citrus* trees grown in such soils suggests that in general, there are lower levels of several insect pests, reductions that have been attributed to lower nitrogen content of their tissues (Altieri and Nicholls, 2003). However, a high level of soil organic matter is not itself enough for efficient soil function and fertility, especially given that the all-important processes of soil aggregation are tied to soil biological processes (Primavesi, 2006). A key practice that underpins successful canopy management is the addition of organic material to all soils except those affected by chronic waterlogging.

Furthermore, growers who accept that soil fertility is closely linked to the biological activity of the soil food web should consider very carefully the repeated use of fungicides, herbicides, and insecticides. These chemicals profoundly affect soil organisms (Bünemann et al., 2006). Many of these same chemicals have been shown to exert effects on aspects of plant physiology such as photosynthesis and protein synthesis (Chaboussou, 1986, 2004). These effects have been argued to predispose treated trees to outbreaks of other pests and diseases.

Tree Vigour

Management and maintenance of tree vigour implies finding the correct balance between growth vigorous enough to bear large fruit and to withstand infection of, for example, CBS, and so vigorous as to attract the attention of pests such as CLM and psyllids, and other leaf diseases such as ACC. Vigour is affected by fertilisation and irrigation practices, and excessive application of especially nitrogenous fertilisers following even moderate pruning often results in excessively vigorous re-growth responses, which complicate grove management. Most often, progressive, moderate reductions in amounts of fertilisers applied help to make trees calmer, more productive and amenable.

The opening of light and spray channels into canopies by pruning also usually leads to a gradual reduction in amounts of dead wood in trees. Dead wood holds spores of many major post-harvest pathogens, and causes mechanical injures to fruit. However, it is seldom economically feasible to break out dead twigs. Pruners rather concentrate on removal of dead *branches*. After several seasons of pruning, with increased lighting and canopy ventilation two things happen. Firstly, new BBU show increased longevity. These BBU are in any case removed after several seasons of fruiting once they are declining. This is done by pruners to renew wood. Secondly, dead twigs become very brittle and break out with little force.

Finally, leafy BBU close to strong sap flow of the main tree scaffold branches remain on the trees longer, an indirect effect of which may be a reduction in the amount of CBS inoculum embodied in fallen leaf litter. Internal re-growth following pruning has also provided suitable habitat for the natural enemies of such pests as citrus thrips, which aids their control (Grafton-Cardwell and Ouyang, 1995).

SUMMARY AND RECOMMENDATIONS FOR CMS IN THE TROPICS

Based on commercial experiences over the past 18 years, citrus growers in the tropics might consider the following practices:

Pruning Procedures

Prune correctly: prune the right trees in the right way at the right time. Protect large pruning wounds with tree sealant. Consider treating large pruning cuts with NAA to reduce localised sprouting. Avoid pruning heat and water-stressed trees to reduce cavitation of the xylem elements of remaining branch parts close to the site of these cuts. Avoid opening tree canopies to excessive light, to reduce risk of photo-inhibition and sunburn of bark. Do not leave branch stubs after pruning: these are dangerous to pickers and grove maintenance crews. They also give rise to strong localised regrowth that leads to congestion and shading inside the canopy. Finally, time pruning whenever possible to reduce influence of foliar pests and diseases attacking new flush, and rigorously disinfect instruments between trees in areas where especially ACC is endemic.

Soil and Plant Health

Harmonizing soil and plant health and reducing stresses on trees induces resilient and productive trees. Growers should consider the stresses imposed by such farming practices such as imbalanced and/or excessive fertiliser application, and use of insecticides, fungicides and herbicides that are known to adversely affect plant physiological processes including photosynthesis and protein synthesis. Finally, the key to soil fertility and plant health is active turnover of organic matter by the local soil organisms: convert pruning debris into organic mulches wherever possible.

Nutrition Programmes and Irrigation of Pruned Trees

After pruning, adjust pro rata applications of N especially and K so as not to induce highly vigorous regrowth. Where mulches are applied in groves under drip irrigation systems, reposition the drippers on top of mulch layers. Finally, pruning trees suffering untreated lime-induced chlorosis makes this chlorosis worse. Treat affected trees with iron chelates first!

Pest and Disease Management

Protect regrowth after pruning from pests and diseases. In subhumid or arid tropical regions where CBS is endemic, the use of under- or between tree sprinklers to wet the fallen infective leaf litter accelerates the breakdown of this aerial and reduces levels of inoculum. Pruning makes trees easier and faster to spray, thus spray units should be recalibrated to reduce spray costs. It is advisable to revise pest management plans with respect to scouting and insect trapping to enable inside-canopy fruit and flush to be protected. At all times, avoid contamination of pruning wounds with soil, and use only pruning equipment regularly disinfected with QAC and or strong solutions of chlorine bleach. Wash bare skin of hands with QAC in areas where ACC is endemic.

Finally, one should learn about tree phenology, pest and disease cycles affecting local trees, keep records, and incorporate this knowledge into management systems.

CONCLUSION

In conclusion, strong evidence is accumulating that substantial increases in production are attainable with sound, biologically-mediated production practices. These systems are often cheaper to operate, and the lower costs of production may increase the profitability of the farmers (Uphoff, 2006).

However, Gottwald et al. (2002) stated “(the) Current USDA system for protecting agricultural industries (against ACC) has been overwhelmed”. If one accepts this view as a symptom of the dilemma faced by citrus growers, citrus growers might face one of two options: go out of the business of growing citrus or take the “defence” of their trees and their livelihoods to the level of their groves.

Our experiences are that simple, robust, biologically- oriented, and truly sustainable citrus canopy management systems have been derived. These technologies are consistent with the natural processes and dynamics of tropical regions. These allow growers to better manage their citrus trees in sustainable and sensible ways, in many regions where these serious pests and diseases are endemic.

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