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Requirements for Improved Fruiting Efficiency in the Avocado Tree

B. Nigel Wolstenholme
Department of Horticultural Science, University of Natal, Pietermaritzburg, Republic of South Africa
Anthony W. Whiley
Maroochy Horticultural Research Station, Nambour, Queensland, Australia

Abstract. **The reason for relatively low average yields of avocado orchards include evolutionary history, stage of domestication, the energy-expensive fruit, vegetative/reproductive competition at critical stages, and *Phytophthora* root rot. The main philosophy for improving yields centers on initial high density planting, precocity inducement, management based on knowledge of the critical yield-determining phenological events (including phosphonate fungicides), and timely orchard thinning. The merits and possible problems of an alternative philosophy based on selecting dwarfing rootstocks are outlined, with reference to ecophysiological research. Breeding objectives for greater fruiting efficiency are discussed.**

It is generally agreed that increased crop productivity has resulted mainly from improved partitioning of photoassimilate to economic end product, rather than from improved photosynthetic efficiency per unit leaf area (Gifford *et al.,* 1984). In fruit tree crops, the partitioning efficiency or "harvest index" can be surprisingly high. More than 70% of the total seasonal dry matter increment of 'Laxton's Superb' apple on dwarfing M9 rootstock was in the fruit, as compared with 40 to 50% on the more invigorating M16 (Barlow, 1971). Evergreen tree crops however, present very different problems in comparison with deciduous fruit, as they are usually less domesticated and differ fundamentally in tree architecture, phenology and potential for manipulation. In this sense, the avocado is no exception.

For various reasons, avocado orchards are relatively low-yielding in comparison with other fleshy fruit. This is in spite of considerable progress (Bergh, 1987) in selection and breeding of improved cultivars. At the same time, the potential for further genetic gain from dedicated breeding programs, utilizing the vast available gene pool, is huge. While we are not breeders, we feel that a horticultural viewpoint on the ideal, composite (scion and rootstock) avocado tree of the future may be useful. This paper discusses the main issues, and outlines the pros and cons of the two main approaches being followed today. Subtropical rather than tropical avocado growing conditions are emphasized, mainly from a southern hemisphere perspective.

Background to the Yield Problem

Low average yields of avocado orchards, calculated on a per ha basis over a number of years, are a worldwide cause for concern. National or state averages can be as low as 5 t/ha (Kotze, 1986). Alternate or irregular bearing may aggravate the situation, especially for certain cultivars (e.g. 'Fuerte') and in particular climatic areas. More realistic "good grower" averages may be anywhere between 10 and 15 and best growers 20 to 25 t/ha. Target yields with current germplasm are in excess of 30 t/ha. We stress that this is for reasonably large orchards over a period of at least 4 or 5 years.

The reasons for low average yields are complex. In the first instance the evolutionary history of the avocado tree is still relevant, if we accept that selection for horticulturally important characters is still at an early stage (Wolstenholme, 1985, 1987, 1988). Attributes ensuring competitive success in a highland tropical rainforest tend to be counterproductive in the orchard situation.

The avocado tree conforms architecturally with Rauh's model (Halle *et al.,* 1978). Although there is partial temporal and spatial separation of vegetative and reproductive growth, the pseudoterminal inflorescences (the terminal bud of an inflorescence is vegetative) characteristic of this model may result in unwanted vigorous vegetative growth at the critical fruit set period. This can drastically reduce fruit set in vigorous cultivars under invigorating warm and humid subtropical conditions.

Avocado floral biology, recently reviewed by Davenport (1986) after extensive studies by many workers, in particular Sedgley (1987), can also account for below potential yields in some situations. Whiley and Winston (1987) have explained relatively low yields of "B-type flower" cultivars in parts of Australia on the basis of below-optimum temperatures during flowering and fruit set. The history of 'Fuerte' in California is another example.

The total carbon cost of growing an avocado fruit to maturity has not been directly determined. Nevertheless, on theoretical grounds and based on fruit composition, it must be comparatively high, especially in relation to predominantly sugar-storing fruit (Wolstenholme, 1985, 1987). The high oil content of flesh (±10-30% of fresh mass) in subtropical, Guatemalan/Mexican type avocado fruit), and the low-moisture, carbohydrate-rich seed, make for an "energy-expensive" fruit. In spite of the much lower oil content of West Indian type avocados however, there is no evidence that they significantly outyield other avocados.

There are many other reasons why so few orchards approach the target yield average of some 30 t/ha. *Phytophthora cinnamomi* root rot has been a major constraint in the past.

Manipulating Orchards for Improved Efficiency

Phenological cycle. As a first step to an overall understanding of tree physiology and management options, the avocado phenological growth cycle provides a tangible visual conceptualization (Whiley *et al.,* 1988) for researchers, advisers and growers. Current thinking, for example, is that the summer vegetative growth flush should be emphasized, rather than the spring flush. Nitrogen can be regarded as the main manipulator element for most tree crops (Cull, 1989), and is a major tool for controlling vigor. Similarly, the growth cycle is used as a basis for irrigation management. The most critical periods are undoubtedly flowering and fruit set (overlapping with the first period of fruit drop - a major sieve for adjusting crop load to tree resources and environmental constraints) and during the summer flush. The latter occurs at the time of highest evaporative demand and is accompanied in the early stages by the summer fruit drop. It is the final sieve for crop load adjustment. Good irrigation management can reduce stress at these critical times.

Vegetative-reproductive competition. Vegetative-reproductive growth competition, especially in early spring, has been recognized as a major limitation to avocado yield potential (Embleton *et al.,* 1959; Blumenfeld *et al.,* 1983; Köhne and Kremer-Köhne, 1987; Adato, 1990; Wolstenholme *et al.,* 1990; Whiley, 1990). This is in contrast with citrus, where spring shoot growth favours fruit set

(Monselise, 1985). In avocado, vegetative growth competition (in vigorous trees) may overlap with fruit set and early fruit growth, whereas in citrus it tends to precede it. Key factors are the timing of the sink-source transition in new leaves, relative to the critical fruit set period, and perhaps in particular the establishment of strong vascular connections in the pedicel and good water supply to the fruitlets via the xylem.

Whiley (1990) showed that 'Hass' avocado leaves become net exporters at ± 80% of full size, after some 40 days. Maximum photosynthetic efficiency was reached about 60 days after bud break, when fruit drop stabilized. There is therefore a strong correlation of peak spring fruit drop with the "sink" phase of spring shoot growth, suggesting that availability of photoassimilates may be limiting during initial fruit set, at least in the humid subtropics. Little is known about plant growth substance interactions at this time. The possibility of water stress limiting fruit set must be emphasized - Whiley *et al.* (1988) found that flowering can increase the transpiring surface by ca. 90%.

The ultimate cause(s) of spring fruit drop remain controversial, and there are dangers in generalizing across cultivars, growing areas and management practices. It cannot be disputed however that timely control of excessive vegetative vigor by managed N nutrition (Embleton *et al.,* 1959), spring flush removal or tipping (Blumenfeld *et al.,* 1983), or the use of growth retardants such as paclobutrazol (Köhne and Kremer-Köhne, 1987; Adato, 1990, Wolstenholme *et al.,* 1990; Whiley *et al.,* 1991), has benefited yield in avocado. The converse may apply - lack of or inadequate spring shoot growth will mean that fruit set and early growth is dependent on older, less efficient leaves and on stored photosynthate, the latter probably already severely depleted by heavy spring flowering. Wolstenholme *et al.* (1990) found that the magnitude of the second drop was directly correlated with initial (spring) fruit set.

It is evident that the spring shoot flush, while often initially competitive, is nevertheless important for overall tree performance. Similarly, the subsequent summer growth flush is vital for reinforcement and renewal of the efficiency of the photosynthetic canopy at a critical time of heavy demand for carbon and energy by rapidly developing fruit, followed by adequate root growth and buildup of carbohydrate reserves for the following season. This is particularly necessary in a tree which has relatively short leaf longevity (for an evergreen), and which is subject to insidious and debilitating fungal root attack. The key to management is therefore control of the timing of episodic growth events, more than their magnitude.

Phvtophthora control. The onset of an era of relatively cheap and effective chemical control of *Phytophthora cinnamomi* root rot using phosphonate-based, trunk-injected fungicides (Darvas and Bezuidenhout, 1987; Pegg *et al.,* 1985, 1987) ironically at first resulted in growers experiencing problems with excessive tree vigor in South Africa and Australia. There is little doubt that chronic *Phytophthora* infection is highly exhaustive of the tree's resources, and that the typical symptoms of tree decline reflect diminished reserves and ultimately resource starvation. The effect on yield potential can be catastrophic

Philosophies for Improving Fruiting Efficiency

With current germplasm and technology, and apparently sustainable average yields in the 20 to 30 t/ha range, a prime consideration is the achievement of the yield ceiling in the shortest possible time after planting. As Jackson (1985) points out, the logic of discounted cash flow analysis makes output early in the life of an orchard more valuable economically than later output especially with high real interest rates. Precocity of yield is therefore all-important., especially in the humid subtropics.

High density plantings. These represent the most effective way, in the absence of dwarfing rootstocks, of maximizing early yields. Toerien *et al.* (1984) have shown that "intensive" management philosophy implies a "package deal" of up-to-date technology with advantages both in precocity and in eventual yield. In South Africa, typical initial tree populations for 'Hass' would be 200 trees/ha (7x7 m spacing) for "intermediate" growers, and 400 trees/ha (5 x 5 m spacing) for "intensive" growers. Yields of 10 t/ha by year 5 and 20 t/ha by year 7 are then easily attainable with current technology. If very vigorous growth is encouraged for the first two to three years, the yield buildup can be more dramatic. Wolstenholme *et al.* (1990) record 10 t/ha by year 3 and 20 t/ha by year 6 for 'Mass' on Duke 7, spaced 200 trees/ha under invigorating soil and climate conditions, and intensive management. Köhne and Kremer-Köhne (1990) are even researching ultra-high density orchards of (initially) 800 trees/ha, with the use of paclobutrazol to control vigor and delay tree thinning. It is axiomatic that these philosophies are dependent on timely tree thinning programs when orchard crowding starts. With growth rates of ± 1 m per year in tree diameter in the humid subtropics, the first tree thinning may be necessary in year 5 in the absence of growth retardant sprays, although precocity of fruiting does help to reduce tree vigor.

Clearly, high density plantings have been shown to be economically feasible in avocado, even in the humid subtropics with their fast growth rates. They will be more appropriate where nursery trees are relatively cheap, as in South Africa, and where clonal rootstocks such as Duke 7 improve orchard uniformity and permit precocity of bearing. It could be argued however that high cost of trees, stakes, labor, etc. can preclude further intensification, as in Australia.

Dwarfing rootstocks. The avocado industry does not yet have proven dwarfing rootstocks or inter-stocks in general use, although there have been interesting developments in Mexico (Sanchez and Barrientos, 1987). The belief that dwarfing rootstocks will dominate the future is widespread. The writers urge some caution in applying this concept to avocados. The advantages of

dwarfing rootstocks for apple growers result mainly from the special advantages of the very dwarfing M9 rootstock. They also make possible the planting of large numbers of potentially small trees with high light interception. However, this has meant a switch of resources from labor for tree management to capital investment at planting time, which may be economically dubious with high real interest rates (Jackson, 1985).

Furthermore, for other fruits such as pears, truly dwarfing root-stocks do not have the specific advantages of M9 for apple, or do not exist. In the main deciduous fruit-growing regions in South Africa, truly dwarfing rootstocks have been unsuccessful in high density plantings, partly because soil and climatic conditions do not promote sufficient tree vigor. The philosophy here is to use vigorous rootstocks, and then to control vigor by pruning, training, girdling, and chemical methods.

Will truly dwarfing rootstocks work for avocados? Obviously we must find them and test them, and above all incorporate resistance to *Phytophthora* into them. This alone will be a daunting task, even with genetic engineering techniques. Freedom from sunblotch viroid will also be necessary. Our interpretation of the literature leads us to conclude that the avocado tree, with its short-lived leaves, peripheral-bearing habit and energy-expensive fruit, requires at least moderate vigor from both major growth flushes (especially the second) to maintain high average yields. Semi-dwarfing rootstocks may represent a compromise.

Some thoughts on breeding objectives. In the first instance, the avocado orchard of the future should permit sustainable yields of quality fruit in excess of 30 t/ha. Table 1 summarizes a likely scenario. Undoubtedly trees will be smaller, but we believe initially not truly dwarfed. Ideally we will have a range of semi-dwarfing rootstocks (say ± 2/3 of standard size) incorporating *Phytophthora* resistance. Scion cultivars will also be semi-dwarfed, with some of the attributes of 'Pinkerton' and 'Gwen'. They will also exhibit regularity of bearing, with sufficient leaf canopy to cope with a heavy crop without exhaustion of carbohydrate and other resources.

Perhaps one of the key selection criteria will be greater complexity of branching from an early age, giving more fruiting sites (inflorescences), and reduced overall vigor but with sufficient partitioning to fruits, leaves and roots at the expense of unwanted stem growth. Delayed vegetative bud break in spring may reduce competitiveness of this flush with fruit set, as in 'Reed' and 'Nabal' (Adato, 1990). Unfortunately, due to tree architecture, much earlier vegetative growth relative to flowering (as in citrus) is not an option. Alternatively, selection for determinate rather than indeterminate inflorescences is suggested, provided that sufficient vegetative buds remain to augment the aging leaf canopy with efficient new spring flush leaves.

Both these latter options reduce the critical spring vegetative-reproductive competition; the first by greater temporal, and the second by increased spatial separation of vegetative and reproductive growth sites. Excessively heavy flowering will also be seen to be wasteful of scarce resources at a critical time and should be selected against.

Table 1. Past, present and future characteristics of avocado trees

Parameter	Development stage		
	Evolutionary	Present	Future
Tree size	Very large, climax rainforest	Large to medium	Medium to semi-dwarfed
Branching complexity	Simple, delayed	Intermediate	Complex, precocious
Spring vegetative bud break	Partial overlap with flowering	Variable, some overlap	Delayed relative to fruit set?
Bearing precocity	Non-precocious	Variable	Highly precocious
Flowering	Profuse, irregular, prolonged	Profuse, prolonged	Moderate, regular, highly synchronized
Fruiting	Irregular, low	Variable	Regular, high
Yield potential (avg t/ha)	Low	20+	30+
Fruit quality	Generally poor	Good	Outstanding
Relative seed size	Large	Medium	Small

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