HIGH DENSITY APPLE PLANTINGS: PRINCIPLES AND PITFALLS

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1. Introduction

There has been a proliferation of new apple production systems throughout the world in the last forty years, as growers and scientists have sought new solutions to economic pressures by capitalizing on new options presented by dwarfing rootstocks and a greater understanding of tree growth and behaviour. With the ease of international travel and free dissemination of information, there has not only been considerable cross fertilisation of ideas between different geographical regions but current practices in the South Tyrol or Washington State are now rapidly applied in other fruit growing areas of the world.

It is important to bear in mind some of the general trends that have been impinging on apple growing over the last few years and influencing the development of new production systems. World annual apple production has been rising rapidly, from 34 million tonnes in 1979-81 to an estimated 63 million tonnes in 2006 (Anon, 2006), consequently fruit growers are facing strong international competition, with attendant pressure on prices, particularly for established cultivars. At the same time there has been an unprecedented introduction of new cultivars e.g. 'Jonagold', 'Royal Gala', 'Fuji', 'Granny Smith', 'Braeburn', 'Pink Lady®' and 'Jazz™', new rootstocks e.g. the P series from Poland, the CG series from Cornell-Geneva and new clones of M.9 e.g. Pajam 1 and Pajam 2.

The green movement is now part of the landscape, so there has been and will continue to be increasing pressure to reduce both the input of chemicals to the orchard environment and the residue levels on the fruit. The development and adoption of Integrated Fruit Production (IFP) worldwide is part of this trend, with its emphasis on spraying according to need rather than calendar date, the use of "softer", more targeted chemistry and the use of Integrated pest Management (IPM). Despite this trend for reduced chemical input, there has been some recent resurgence in the use of plant growth regulators in apple production e.g. Prohexodione Ca (Regalis®) for vigour control and benzyladenine e.g. CyLex® for fruitlet thinning.

2. Constraints on apple production

Apart from the global trends already referred to, production constraints can be physical, biological, economic and environmental. With all perennial fruit crops there is a continual need to maintain physical access for spraying, picking, pruning and other cultural operations. Despite the attraction of the meadow orchard concept (Hudson, 1971), it has not proved to be successful for apples because, among other limitations, it was a biennial system relying heavily on plant growth regulators. It was very much a system looking for a cultivar.

Biological Constraints

Plant productivity depends upon the absorption of light energy by green plant tissues and the conversion of that energy into biomass. A number of studies have shown a linear relationship between light interception and total dry matter production of several crops, including apples e.g. Monteith (1977). Dry matter production is the total biological yield, however orchardists are interested not so much in the total biological yield but the yield of fruit. Fruit yield has also been shown to be linearly related to light interception in a range of light environments including NW Europe (Palmer, 1989; Wagenmakers, 1991), Washington State (Barritt, 1991) and New Zealand (Palmer *et al*, 2002). Because of the deleterious effect of shade, this latter relationship would be expected to be curvilinear as light interception approaches 80-85%. High light interception by the canopy is therefore essential as **the prerequisite for potential high yield per hectare**. This principle lies behind the increases in tree density and the rapid development of a tree canopy inherent in high density planting systems.

Although high light interception is needed for high biological yield, shade within the canopy can have a deleterious effect on fruit yield, fruit quality, fruit set and flower initiation (Table 1). Shading can arise from within-tree or between-tree sources, including windbreaks. Fruit size, red skin colour, soluble solids concentration are all reduced by shading (Jackson, 1970; Barritt *et al.*, 1987). These effects of light on apple fruit quality have been shown by Warrington *et al.*, (1989) to be independent of orchard system. The response of fruiting to shade is a general phenomenon among perennial tree fruits and has been reported for apples, citrus, red raspberry, kiwifruit, cherries, peaches and grapes (Palmer, 1989). Although the response of fruit colour to shade can be reduced by using red sports, the other effects of shade on fruit quality still remain. Shading can also result in a reduction of flower initiation and fruit set. In some environments excessive light falling on the fruit can result in downgrading of the fruit caused by sunburn. In its mildest forms this shows as suntinting of the skin but in more serious cases results in brown burnt patches.

Table 1: Generalised effects of shade on apple fruit quality, storage disorders, flowering and fruit set.

Increase	Decrease
shrivel	fruit weight
Fruit firmness	fruit red colour
	soluble solids concentration (Brix)
	bitter pit incidence and severity
	sunburn
	flower bud numbers
	fruit set

Therefore, for high yield and, in particular, high fruit quality, the orchard system needs to combine both high light interception and good light distribution within the tree canopy (Wünsche *et al.*, 1996). The control of tree vigour is therefore an essential key component of any successful production system. Vigour is needed in the early years of the orchard to ensure rapid filling of the allotted space and increase light interception and early yields. In later years vigour can be counterproductive as it results in excessive shade with its associated negative effects of fruit quality.

Economic Constraints

The cultivated apple has shown itself to be very adaptable, and there is probably no end to the possible ways of arranging apple canopies in space. The key determinate, however, in all business, not least that of growing fruit, is whether the system is economic. Yield and fruit quality determine the income but the cost of establishment and maintenance determine expenditure. If expenditure exceeds income then, however elegant the system, it is not economic. Goedegebure (1989) clearly demonstrated the effect on profitability of price per kilo, interest rate and establishment costs in relation to trees per hectare. In situations of low interest rates and high price per kilo, very high density systems can be financially very attractive, but such systems become uneconomic as the price per kilo tumbles and/or the cost of capital (interest rates) rise. Similarly low establishment costs favour the higher density systems. High prices for new cultivars have often been the incentive for the introduction of high density planting systems.

Environmental Constraints

The last major constraint is the orchard environment - the soil, the climate and the grower. The soil can impose serious limitations to rootstock choice and similarly the climate can seriously limit the choice of rootstock and cultivar. The individual grower is not always seen as a constraint but it is important that he/she has the technical expertise and skill to manage profitably any new system; it may not, for example, be within the capability of the grower to successfully change from the current, familiar system to a new system. The grower may have this choice in a favourable economic situation, but as profits are squeezed, and the grower is unable or unwilling to adapt, he goes out of business. It has frequently been said that the real question is not “Can I afford to change?” but “Can I afford not to change?”

These therefore are the main constraints upon fruitgrowing. The successful grower, however, makes full use of the tools he has at his disposal to exploit the positive advantages of his crop and environment and to minimise the disadvantages.

3. Tools

Horticulturists are skilled manipulators of the plant kingdom. From Biblical times, if not earlier, fruit growers have been using rootstocks and tree training and pruning to control the vegetative and reproductive development of the apple tree.

Since the work of Hatton at East Malling in the early 1900s, apple growers have been fortunate to have a wide range of clonal rootstocks available to them with known, predictable characteristics. Clonal rootstocks have given the fruit grower advantages over seedling stocks of predictable tree size control, uniformity of tree size, improvements to fruit quality and resistance to soil borne pests and diseases. The array of available apple rootstocks is continually increasing due to breeding programmes in many parts of the world. Apple growers are very fortunate to have such a wide range of clonal rootstocks available to them; few fruit crops are so favoured.

The apple tree is very adaptable and can be trained into a wide range of canopy shapes, owing to its ability to form flowers on lateral buds, on young and old wood, and to produce new growth from terminal and lateral meristems. Gardeners in the large European houses, with ample labour, took canopy manipulation almost to an art form in the seventeenth and eighteenth centuries.

Tree manipulation begins in the nursery before the tree reaches the orchard. Precocity can be enhanced by using well-feathered trees in preference to unfeathered whips. Excellent work has been done with physical manipulation including tree spacing and leaf plucking and chemical techniques such as the use of Promalin® and repeat benzyladenine sprays, to improve the feathering of trees in the nursery. The advantages of a well-feathered tree are two-fold - earlier cropping and easier tree training in the first two years in the orchard. The planting of well-feathered trees, therefore, has a major influence on the economics of high density planting systems. Such systems would be expected to give their first crop in the second year in the orchard. This is almost impossible without the use of well-feathered trees. Systems which rely on severe pruning of young trees are at an obvious disadvantage in terms of precocity compared to systems which take full advantage of well-feathered trees. Although the advantages of well-feathered trees are often emphasised with high density plantings, even semi-intensive central leader systems on MM.106 can take advantage of the improved precocity and easier tree training of the feathered tree (Tustin, *et al.*, 1990).

The success of pruning and training is to be able to predict the consequences of the action but that in turn assumes an understanding, albeit empirical, of the vegetative and reproductive growth habits of the apple tree. The French have led the way in describing morphological development both at the tree (Lespinasse and Delort 1986, Lauri and Lespinasse, 1999) and the shoot level (Costes *et al.*, 1997). The French vertical axis relied on the natural development of the leader to eventually limit its height. In contrast, the Dutch, with their desire to limit tree height and tree vigour, brought regimented order to their slender spindle trees by extensive shoot bending and leader replacement. It is interesting to see how both approaches tended to come together, with much use of bending in the French solaxe. Nevertheless, both systems succeeded in controlling vegetative development by relying on the centre leader to suppress excessively strong lateral growth. Even the Dutch slender spindle could be too top dominant on fertile soils, leading to the use of more dwarfing rootstocks than M.9, such as P.22 or M.27. Systems such as the Lincoln canopy and the Ebro trellis, where strong growth was tied horizontally, were only able to control the inevitable upright lateral growth and dense shade, by the use of excessive summer pruning. It is difficult, however, not to see this massive reliance on summer pruning as an inherent weakness - the system should have been more in tune with the growth of the tree in which growth was **used** rather than **removed** in this wholesale way. The extent of this shading in these two systems was clearly demonstrated by Ferree *et al.* (1989) and Tustin *et al.* (1989), respectively. Again this discussion emphasizes the importance of the **control** of vegetative vigour, once the canopy has been established.

Where wind is a problem to commercial fruit production, the wind can be moderated by the use of windbreaks around the orchard. An alternative approach is to use a trellis system of posts and wires to restrict the movement of fruit bearing branches. Dutch orchards are frequently surrounded by windbreaks, while trees in Washington State are frequently grown on some form of posts and wires. Clayton-Greene (1993) found significant reductions in the proportion of fruit suffering from limb rub on Tatura, Ebro and Lincoln canopies compared to palmette and central leader systems.

Within the many thousands of apple cultivars, there is considerable variation in tree habit as well as the obvious differences in fruit characteristics. Spur types, which show short internodes and compact habit, have been widely used in the United States. The ultimate spur type is the 'Wijick' mutation of 'McIntosh' which produces a single stem with very short internodes with a spur in each axillary position. This level of genetic control has not yet been commercially exploited.

4. Drivers for change

As each country has adopted high density planting systems, it has been in response to economic pressures for improvements to fruit quality, the rapid introduction of new cultivars, reduced production costs (especially to increase labour efficiency as cost of labour spiralled) and/or reduced spray drift. These reasons for adoption have been universal, although the order of priority of those four factors may be different in different situations.

Before any widespread adoption of intensive planting systems occurs within an area, however, there are a number of key drivers that need to be in place.

A demonstrated advantage over existing methods. Growers in general tend to be somewhat sceptical of results from elsewhere in the world or from research plots in their own country being directly applicable to their own situation. It is, therefore, the innovators within each industry that lead the way, aided and abetted, one hopes by the scientists and extension services.

Availability of dwarfing rootstocks. The availability of newer rootstocks can be delayed by quarantine regulations or a nursery industry that lacks a vision of what rootstocks will be required in the future.

Availability of well-feathered trees. As the use of well-feathered trees can dramatically enhance early cropping and tree development, fruit tree nurseries can inhibit the rapid uptake of intensive systems by producing poor quality trees.

Economic pressures. There is undoubtedly a reluctance on the part of growers to make wholesale changes to their existing systems of production if there is little perceived economic incentive to do so. Unfortunately like the story of the frog in the pot of water the heat can gradually increase until it is too late. Pipfruit growing is both a long term and risky business so the grower must be studying current changes both in his/her own backyard and elsewhere, if the business is to remain viable.

New cultivars. Part of that wider study involves the selection of new cultivars that will give improved returns over his existing cultivar mix. Growers must consider not just the profitability of their existing orchards but whether that profitability could be enhanced by replanting with new cultivars. The high prices per kilo for new cultivars has certainly acted as a strong catalyst for change into intensive systems on dwarfing rootstocks in many parts of the world.

Skill base. Finally there must be a sufficient understanding of a new system before it can be taken up successfully. The ready availability of cheap air travel has undoubtedly helped the movement of growers and advisors and in turn hastened the uptake of new systems. It is much easier to understand a system by standing next to a good example of it with a disciple of the system explaining the details, rather than reading a third party's interpretation.

5. Common solutions

The interrelationships between the choices open to the grower have been likened to "an orchard system puzzle" (Barritt, 1992). This is a helpful illustration as it emphasises the linked nature of the management choices - rootstock, tree quality, tree arrangement, support system, tree density, tree training and pruning. It is appropriate to also add to this list machinery, particularly sprayers, as the equipment used must be appropriate for the system. Clayton-Greene (1993) found a higher incidence of pest and disease damage on fruit from Tatura, Ebro and Lincoln canopies compared to central leader trees reflecting the poorer spray coverage on the former systems because of the lack of the appropriate sprayer for each trellis system.

Although there have been many new training systems for apples described over the last forty years, each with their enthusiastic adherents and proselytizers, there are a number of common trends within these systems 1) a rapid achievement of high light interception and early cropping 2) the maintenance of good light penetration into the canopy at all times, and 3) efficient harvesting.

Early cropping per hectare and the rapid establishment of the canopy has been achieved by high tree densities (1500-5000 trees/ha), planting well-feathered trees and an emphasis on tree training rather than pruning. In order to avoid later problems of excessive vegetative vigour resulting in poor fruit quality, size controlling rootstocks have been widely used, with more emphasis on the use of appropriate rootstocks to induce smaller tree size with closer planting. The push for improved precocity has come from two economic forces; when orchards are replaced, the fruit grower would like to see a positive cash flow from the replacement orchard as soon as possible, particularly if there has been high investment in that new orchard, and secondly, new cultivars often attract high prices in the market and the sooner a grower can exploit this situation the better. In the early years of the orchard, yields are frequently determined by tree density rather than system (e.g. Clayton-Greene, 1993, Robinson, 1997).

Traditionally, in many parts of the world apple fruit have been picked from large trees using ladders. In many new systems there has been a strong emphasis on reducing the size of the tree so that more, if not all, of the fruit can be picked from the ground. If tree size is reduced, this also means that the canopy is easier to spray, prune and thin. There have also been some attempts to mechanically harvest dessert apple fruit and this has led to drastic changes in the canopy form to accommodate the harvester. Although this would further reduce the cost of picking, there are at present no commercial orchards using mechanical picking for fresh market fruit. There are, however, a number of mechanical systems available that can enhance the hand picking of fruit within current systems of production. Rapid advances in robotics and in fast pattern recognition software are currently occurring, and even select picking of apples by robotics is by no means a pipe dream, and some of the 2D orchards being developed in Washington State would lend themselves to this type of technology.

As shade is known to be deleterious to fruit quality, all successful systems ensure that sunlight can penetrate into the canopy. This frequently relies on renewal pruning to replace branches that have become too large for that position in the tree. To allow penetration of light into the canopy, many modern orchard systems maintain a thin conical shape to the tree or develop a thin, almost planar canopy layer.

The Dutch slender spindle, the French vertical axis, the New Zealand slender pyramid and the Washington HYTEC all share a basic conical tree shape, although tree height varies from 2-5 m. The Dutch spearheaded the use of intensive systems, with tree densities of 2,000-5,000 trees/ha, based on a small conical shaped tree, the slender spindle, frequently grafted on the dwarfing rootstock M.9, with a tree height of 2-2.2 m. All tree management operations - pruning, thinning and picking - were done from the ground or with short step ladders. The high tree densities ensured a high light interception and the combination of a size controlling rootstock with the conical shape ensured that light could penetrate into the lower parts of the canopy. Although use was made of even higher tree densities, super spindles (10,000 - 20,000 trees/ha), and multi-row rather than single row systems, low fruit prices made many of these very high density systems economically questionable. The French vertical axis system had a similar conical tree shape, but trees were planted at lower densities than the Dutch slender spindle and were permitted to grow to 3-4 m tall. It is variants of this system, the soleaxe or tall spindle hedgerows which are now the most popular high density production systems, with an emphasis on letting the leader crop itself out and the production of a large number of relatively weak branches bent below the horizontal.

To improve light penetration into the tree, the canopy can be trained into a thin layer which, with a suitable wire trellis, can be inclined at different angles to the vertical. The Australian Tatura Trellis, originally designed for the mechanical harvesting of peaches, has been used for apples. There have been, however, numerous other forms of Y and V canopies. In some cases individual trees are trained into two halves (e.g. Robinson *et al.*, 1991), while in other cases alternate trees down the row are trained to each opposite plane as in the Vee-trellis used extensively in Washington State. The horizontal Lincoln canopy was also designed for mechanical picking but, as already mentioned, suffered from excessive annual, vertical shoot growth from the horizontal canopy, with attendant shading of the fruit below. A narrow depth of canopy does not necessarily ensure good light penetration if the leaf area density within the canopy is too high.

6. Conclusions

The apple canopy has proved to be extremely adaptable to manipulation and this coupled with the extensive range of size controlling rootstocks has ensured there is no shortage of innovative canopy designs. Within any industry, innovation is vital to its continued growth. Innovation of itself, however, does not necessarily bring success, as has been illustrated by some of the systems described, but innovation that brings new tools to our armoury or that seeks to exploit our knowledge of plant behaviour will bring successful advances. Factors such as world apple supply, changes to trade barriers and tariffs, currency movements and interest rates may be out of the control of the individual fruit grower, but establishment and production costs, as determined by the system, are all amenable to grower choice. The successful grower is one who not only understands the nature of the physical, biological and economic constraints but is able to correctly harness the tools of his trade.

"The discussions and controversies between orchard management specialists and between growers about planting distances and tree training systems for a given fruit species undoubtedly began with the first orchard; they will last as long as fruit trees are planted" (Hugard, 1980).

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