Organic Systems of Apple Production Bring New Horizons to Traditional Crop Physiology

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Abstract

Traditional apple crop physiology has majored on the effects of environmental factors on tree and fruit growth and development, in orchards or controlled environments, with adequate nutrition, water and good control of pests and diseases. This has undoubtedly led to greater understanding in the traditional scientific reductionist pattern. The advent of organic systems of production, however, raises new challenges for crop physiology, not the least of which is to attract funding for systems of production that are still seen by some as on the outer fringes of scientific endeavour. The real scientific challenges relate to the effects on tree growth and fruit development of less than complete insect and disease control, spray materials such as sulphur that are more phytotoxic to some cultivars than conventional fungicides and less than adequate nutrition. Fortunately, progress has already been made in computer modelling of crop growth of apples and peaches but this will need to be considerably expanded to include pest, disease and nutritional modules, including root growth, to adequately encompass the organic growing system - to do this we will need multi-disciplinary teams.

The wider issues raised by the organic farming community regarding sustainability are important for all of us to face with reasoned discussion based on sound experimental data if we are to be all-round environmental physiologists. The challenge for the physiologists of the future is to make all systems of production more sustainable. This can only be achieved by a detailed understanding of the total orchard environment and how we can then manipulate our system of fruit production to move more rapidly towards the ideal of a sustainable system.

INTRODUCTION

As we move into the opening years of the 21st century, the issue of sustainability will become increasingly important. Sustainability considerations will influence us all, whether we are producing fruit under an Integrated Fruit Production (IFP) or under an organic system. There are two main pressures upon us to take the issue of sustainability seriously 1) there continues to be a strong signal from the market that consumers are concerned about how fruit is grown and whether the environment is being degraded or enhanced by our growing system and 2) as responsible human beings we should be concerned for the environmental impacts of our growing system and the welfare of those involved in fruit production. As scientists we are in a privileged position to be able in some small measure to appreciate the whole system and to predict some of the changes that will occur due to our management decisions. Sustainability causes us to look at our whole system of growing, marketing and purchasing; it forces us to have a more holistic approach to our science rather than retreating into the details of our own discipline. Within fruit growing, there has been a tendency for the issue of sustainability to be linked primarily to plant protection. This has been unfortunate because pests and diseases are only part of the total orchard environment. Furthermore the primary reason we have orchards is to produce fruit, not to control pests and diseases. Although sustainability is a wide issue involving global and community issues, comments in this paper will largely be restricted to the local orchard environment.

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Organic production systems for apples were, until the 1990s, largely ignored by mainstream science. There has been a perception of ‘muck and magic’ and ‘questionable science’ directed at the organic fraternity from the conventional scientific community. Consequently it has been difficult to attract funding for work on organic systems from funding authorities, which are dominated by the thinking of conventional science and priorities set by the current size of the industries. Nevertheless, if we as physiologists are to remain true to our discipline then the imposition of an organic system is only another aspect of the environment our trees are exposed to. Due to the great advances that have been made in conventional horticulture over the last 50 years, we have become used to trees that are adequately watered, fertilised and with excellent control of pests and diseases. This undoubtedly has made physiological work much easier and has helped us to tease out details of plant response to environmental factors such as temperature and light and internal factors such as crop load. The imposition of a system that may result in lower levels of disease and pest control and inadequate nutrition and water opens up new challenges and horizons for the physiologist. Nevertheless the role of the physiologist remains the same - to understand the response of the tree to its total environment and manipulate tree and environment towards a more desirable outcome for the grower. It is important, however, to remember that there is a feedback effect of the apple growing system on its environment, the orchard environment is altered by our trees and how those trees are managed e.g. carbon and nutrient fluxes into the soil are influenced by our soil management system. Consequently our orchard management system entails a managing of the total orchard environment soil, plant and atmosphere.

CHALLENGES

Challenges fall into four areas - 1) can we adequately supply nutrition and pest and disease control to annually produce a crop from the orchard 2) what is the effect on the tree of increased pest and disease damage and less than adequate nutrition 3) can we maintain an economically viable orcharding system and 4) as an aid to interpreting the tree response and the future development of the orchard as a whole, can we enlist the help of computer modelling to adequately represent the orchard system?

Nutrition

Undoubtedly organic systems fit in well to a closed loop situation where nutrients are recycled within the farm. For the commercial orchard, however, there is a major loss of nutrients to the orchard system in the harvested crop. The amount of nutrients removed depends upon yield and nutrient composition of the particular cultivar. Table 1 gives a compilation of nutrient removal rates for apples from around the world. Potassium and nitrogen are the two major nutrients removed in the fruit. Within the orchard itself, nutrients in prunings and leaves can be recycled in situ if prunings are mulched and if leaves decompose under the trees and are not blown by the wind to areas around windbreaks. On a much longer time scale nutrients within the woody frame can be recycled if mulched when the orchard is removed. Table 1 gives only the nutrient removal in the fruit; nutrient **demand** by the tree is given by gross uptake. Undoubtedly some soils are capable of supplying adequate quantities of nutrients to balance that lost in the fruit but one must question whether we are dealing with a renewable system or merely mining nutrients, albeit slowly. In the UK, Greenham (1980) was unable to measure a response of apple trees to nitrogen at East Malling in the absence of grass competition. He went further and said, "the reduction or elimination of competition, by the use of herbicides, has removed the need for nitrogenous fertilisers in many orchards." In other parts of the world, where yields may be higher and/or soils may have lower ability to release nutrients, additions of nutrients will be required to balance the loss in the fruit. Nevertheless David Greenham's comments on herbicides make interesting reading twenty years on and illustrate the changes in our understanding of the need to enhance or at least maintain the soil environment.

Sources of potassium are rather limited to organic growers and this must be of concern for the long-term sustainability of organic systems in areas where rates of potassium mineralisation in the soil are low. Nitrogen can be supplied with potassium in compost but compost by its very nature is somewhat bulky and incurs a high transport cost if brought from any distance. Diesel used in transport of compost, however, is probably small in comparison to the total amount of diesel used in tractor operations on an orchard. Additionally, an organic mulch may be a means of disposing of waste organic matter from, for example, municipal authorities trying to reduce landfill. Mulches can also be “grown in situ” by utilising the alleyway space e.g. casting the grass clippings under the trees or specifically growing a crop in the alleyway e.g. lucerne which is cut and spread under the trees.

Nitrogen can be renewably supplied in situ if legumes are encouraged in the understorey vegetation. Nitrogen supplied from white clover is a key component of pastoral agriculture in New Zealand and Ledgard (2001) has estimated that the average annual total N_2 fixation in grazed permanent clover/grass pastures in temperate regions of the world is approximately 80-100 kg N ha^{-1}. In other environments, with more severe winters, clover may not be able to supply such high amounts of nitrogen. The orchard situation will not be directly comparable to the grazed pasture in terms of available light but the magnitude of the ability of white clover to fix nitrogen in a pasture situation suggests that its use within the understorey could be a major source of nitrogen to the tree (Goh et al., 1994). Success in using legumes depends not only on the total amount of N released but also whether the pattern of release matches the demand of N by the tree and whether the legume within the understorey can be maintained in the long-term. By using legumes in the understorey, the understorey itself becomes an integral part of the orchard system not just a convenient surface for foot and tractor operations. Consequently the management of the understorey in terms of the encouragement of some species and the discouragement of others, which may for example be alternative hosts of pests, becomes another component of the total orchard management.

Although the use of herbicides has completely transformed soil management in conventional orchards over the last forty years, this has resulted in deleterious effects on the soil environment e.g. decreased organic matter and earthworm activity in the soil of herbicide strips beneath apple trees (White and Atkinson, 1984; Hipps and Samuelson, 1991). There have been a number of trials looking at alternative management systems for the soil directly around the tree to mitigate the negative aspects of herbicides and these basically fall into two types a) the use of a mulch and b) the use of controlled vegetation. Mulches suppress annual weeds, decrease water loss from the soil surface and if, of organic material, can supply a range of nutrients, while a controlled vegetation of legumes can supply nitrogen and organic matter. Mulches have great potential, particularly for the newly planted tree, but can be rapidly overrun by perennial weeds like couch (*Agropyron repens*). Controlled vegetation can compete with the tree for water and nutrients resulting in decreased growth and early cropping (Stott, 1976; Miller and Glenn, 1985; Merwin and Stiles, 1994). This is a major drawback, particularly with the move to more intensive systems of production with small trees planted closely together on dwarfing rootstocks. Such systems require early cropping to offset the high establishment costs. Hipps et al. (1990) have shown that competition from grass can be reduced by supplying irrigation, so it would be instructive to see how much the competition from, for example, a sown clover understorey could be offset by more frequent irrigation. Certainly the presence of an understorey sprinkler irrigation system, common among growers in New Zealand, would ensure rapid establishment of understorey vegetation from seed. In other regions, however, with limited water supplies, water conservation with mulches might be a more sustainable option. This illustrates the important point that options for sustainability will differ in different environments. It is interesting to note that the development of overall herbicide systems of apple production by David Atkinson at East Malling in the 1970-80s was done at a time when few apple orchards in the UK were irrigated, so competition for water between the trees and the understorey reduced yield - the removal of the understorey competition by herbicides resulted in increased yields. In terms of the whole orchard system, however, such overall herbicide systems resulted in negative effects upon the soil environment.

There have also been two interesting developments within water relations and nutrition, in both cases suggesting that although apple trees can **use** high levels of nutrients and water, fruit quality can be enhanced with some restriction to both. This suggests that our conventional production systems may have supplied unnecessary amounts of water and nutrients, resulting in groundwater leaching and enhanced denitrification. Kipp (1992) in his review on fertiliser use in Dutch apple orchards concluded that one of the reasons for the decline in fertiliser use over the late 60s and early 70s was the realisation that leaf nutrient levels for the best fruit quality were lower than the levels required for maximum yield. Mpelasoka et al. (2000) have recently shown that periods of restricted water supply can increase the dry matter content, flesh firmness and soluble solids of ‘Braeburn’ apple fruit, albeit with some reduction in mean fruit size. These differences persisted through storage even when fruit of comparable size were compared.

Pest and Disease Control

There are two key physiological considerations 1) direct effects of the plant protection sprays and 2) the effects of the pests and diseases on tree performance. The use of fungicides can result in direct effects upon tree physiology e.g. some triazoles can increase leaf chlorophyll content and dithiocarbamates can increase leaf zinc content (Creemers and Vanmechelen, 1993). Lime sulphur and sulphur have been reported to reduce leaf assimilation rate from the 1940s (Ferree, 1979). In later work, Ferree et al. (1999) found that a single spray of sulphur resulted in a significant decrease in leaf photosynthesis of greenhouse grown MM.106 trees after 11 days and a 50% reduction after 20 days, which persisted for the 45 days of the trial. The nature of the greenhouse environment and the "softer" growth of the leaves may have accentuated the adverse effects of sulphur. In New Zealand, ‘Braeburn’ is particularly sensitive to lime sulphur sprays. From a larger study of the effects of fungicides suitable for organic systems on productivity (Palmer et al., 2003), light saturated leaf CO_2 assimilation rate of ‘Braeburn’ was reduced by lime sulphur to 52-84% of that recorded on the trees receiving an IFP compatible programme (Table 2).

Although light saturated leaf photosynthesis rates of ‘Braeburn’ can be reduced by up to 50% by lime sulphur applications compared to IFP compatible spray programme, other apple cultivars, however, such as ‘Fuji’, ‘Pacific Rose’ and ‘Royal Gala’, show only a transient and minor leaf photosynthetic depression after lime sulphur treatment (unpublished results). Our preliminary results so far indicate that lime sulphur and its breakdown products lead to a collapse/flattening of the lower epidermal cell layer of ‘Braeburn’ leaves, followed by impacts on the carbohydrate transport mechanisms, leading to a buildup of starch in the chloroplast. Cultivar differences in response to lime sulphur may be due to several cultivar specific factors such as composition/thickness of the epicuticular wax formation, thickness of cuticle and epidermis.

Inherent within both IFP and organic systems of production is a strong reliance on integrated pest management (IPM). IPM, however, is not a zero tolerance system but depends upon a balance of pest and biocontrol agents and only resorting to spraying when necessary. Consequently, apple trees may have low levels of pest infestation or disease. (This raises particular quarantine issues for apples shipped across international boundaries.) Pests and diseases can reduce the carbon dioxide uptake by the trees by reducing the leaf area e.g. mildew or severe red spider mite damage and/or by reducing the leaf photosynthesis rate per unit leaf area e.g. red spider mite or leaf miners. Fortunately the combination of a pomologist (Dave Ferree) and an entomologist (Frank Hall) ensured that effects on leaf carbon dioxide assimilation of red spider mite populations and physical leaf damage, as might arise from insect feeding, were known as early as the 1970s. Even relatively low populations of mites reduced leaf assimilation before leaf colour changes were visible, for example 15 mites per leaf reduced leaf assimilation by 26% after three days (Ferree and Hall, 1976). This was an important finding as IPM often involves a visual assessment of damage by the grower. At the whole tree level, Francesconi et al. (1996) found that the effects on fruit size, return bloom and return crop load following red mite infestation were better explained by considering carbohydrate supply/demand balance rather than cumulative mite days. This was a significant conclusion as it confirmed the possibility of modelling tree response to pests in terms of existing carbon balance models.

Hall and Ferree (1976) found that the effect of removal of sections of leaf to simulate insect attack on leaf photosynthesis depended not only on the total area removed but also on the number of holes and whether the holes cut through main lateral veins. After seven days, leaf photosynthesis of ‘Golden Delicious’ was reduced by 28% by the removal of 15% of tissue where side veins were severed compared to a reduction of 15% where interveinal tissue was removed. Leafminers have been found to variously reduce fruit size, shoot growth and fruit set the following season, depending on cultivar, location and level of infestation (Reissig et al., 1982). Again damage of this type could also be included in carbon balance models.

Production Economics

Fruit growing is a business and for the continued sustainability of production the fruit grower has to maintain a profit. Production costs are higher for organic apples in New Zealand compared to conventional IFP production. Currently this is offset by higher prices per kilo for organic apples. Indeed this improved price per kilo has encouraged the further development of organic apple production in New Zealand for perceived economic returns rather than an acceptance of organic production philosophy. If this price differential is reduced, this may well alter the number of organic growers. Currently, however, no apple growers are charged for the costs of using the environment, the externality costs, e.g. damage to soil, groundwater or biodiversity arising from the orchard (Pretty et al., 2000). If this situation changes, then the relative costs of fruit growing between IFP and organic may change considerably. In a comparison, however, of conventional (broad spectrum insecticides), IFP and organic apple orchards, Suckling et al. (1998) found reduced natural enemy biodiversity in the conventional system but comparable if not higher biodiversity in the IFP system compared to the organic system, suggesting that organic systems may not necessarily have lower externality costs. Even the costs of production in different regions may also change if the externality costs are allocated differently in different countries.

Modelling

Traditional crop physiology has followed a scientific reductionist pattern of examining the effect of one factor while endeavouring to keep all other factors constant or comparing the effect of one factor in the presence of another and examining interactions. As we move to more sustainable systems of production, reductionism must be supplemented by synthesis and single disciplines supplemented by a multi-disciplinary approach, if we are to examine the orchard more as a complete system rather than as isolated parts. This of course is where computer modelling comes into its own and allows us to examine the complexities of the system in a way that our traditional scientific experiments have not been able to. Fortunately progress has already been made in computer modelling of crop growth of apples (Lakso et al., 2001) and peaches (DeJong et al., 1996) but both of these models are carbon based models which assume that nutrients are not limiting. To adequately encompass the whole growing system, such models will need to be considerably expanded to include pest, disease and nutritional modules, including root growth. Already Habib et al. (1989) have made considerable progress in understanding the dynamics of nitrogen supply and partitioning within young peach trees. Although as Girardin et al. (1999) point out we are a long way from computer models of whole agro-ecosystems, nevertheless we believe that computer modelling will form a key element in any sustainability analysis of our apple orchards. Already we are seeing composite models which include both crop growth and soil biogeochemistry e.g. Zhang et al. (2002). We may also need to look outside our normal boundaries of pomology and take some of the developments in ecology into our thinking, remembering that we are not dealing with a natural ecosystem but a managed ecosystem.

CONCLUSIONS

Sustainability is an issue that influences us all today and will become even more important in the future, whatever kind of orchard management system we follow. The organic grower has taken the high ground and proclaimed that the organic system is synonymous with sustainability. The challenge for the physiologists of the future is to make all systems of apple production more sustainable. This can only be achieved by a detailed understanding of the total orchard environment and how we can manipulate our system of fruit production to move more rapidly towards the ideal of a sustainable system. We believe this is an exciting area of research, as it involves a more holistic approach to our science but it also brings with it particular challenges to insert scientific objectivity into areas where it has been somewhat lacking in the past. To achieve this aim, however, the physiologist must work in a multi-disciplinary scientific environment where all branches of science can contribute to the understanding of the complex dynamics of the orchard environment, both in the short-term and in the long-term.

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Tables

Table 1. Nutrient removals from apple orchards in harvested fruit.

Cultivar	Country	Fresh weight yield (t/ha)	Nutrient removal (kg/ha)			Reference
			N	P	K	
Cox	UK	23	17	3	34	Greenham (1980)
Delicious	USA	45	21	6	57	Greenham (1980)
Golden Delicious	NZ	44*	21	4	120	Goh & Haynes (1983)
Braeburn	NZ	83	34	8	90	Dryden pers. com.

* estimated from dry matter yield assuming 14% dry matter.

Table 2. Effects of lime sulphur sprays on light saturated leaf CO_2 assimilation rate (μmol m^{-2} s^{-1}) of basal extension shoot leaves of 'Braeburn' during the season in Nelson, New Zealand. Control trees received standard IFP compatible fungicide sprays compared to the lime sulphur treatment which received 1% lime sulphur.

Date	Control	Lime sulphur	5% LSD	Lime sulphur as % of control
Nov 24	12.7	10.7	2.39	84
Jan 5	14.7	7.7	3.33	52
Jan 12	16.5	9.2	2.87	56
Jan 26	12.7	7.4	3.30	58
Feb 8	14.5	9.8	2.93	68
Mar 15	11.7	7.4	2.74	63