Sustainable Horticulture in Fruit Production

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INTRODUCTION

Human societies around the globe today rely on agricultural systems to provide most of their food needs, as they have for thousands of years. Farming is the primary means of converting solar energy into food, and no other approach is likely to replace it in the near future. Maintaining the integrity of the agricultural resource base (e.g. land, water, biodiversity) is necessary for continued production. However, history is replete with examples of countries and cultures that allowed their resource base to degrade over time, undermining their ability to provide for their needs (Lowdermilk, 1953). The desire to avoid this fate is a prime motivation for the emergence of the idea of "sustainable agriculture."

WHAT IS SUSTAINABLE AGRICULTURE?

The term "sustainable" first became widely known during the 1990s as a result of the Brundtland report (1987) from the World Commission on Environment and Development of the United Nations. Sustainability was defined as "meeting the needs of today without compromising the ability of future generations to meet their needs." We now hear about sustainable forestry, sustainable buildings, and sustainable development along with sustainable agriculture, an indication that the negative impacts of human activity on the global systems we rely upon are being recognized and addressed.

Some of the earliest sustainability discussions for agriculture in the 20th century revolved around soil erosion and conservation. The Dust Bowl period in the U.S. put soil sustainability on the national political agenda. In fruit production, pesticide issues have been more central to the development of sustainability concerns.

While ecological issues such as soil erosion, water scarcity, and air pollution are well-publicized, many barriers to sustainability are social, economic, and political – overpopulation, global competition, low commodity prices, shrinking numbers of farms. These are all "people" problems rather than agronomic or horticultural problems. Continued technological advancement can and must play a role in moving towards sustainability, but it will not be successful by itself in isolation from ecological issues, social concerns or long-term thinking.

Sustainability is commonly defined as being economically viable, environmentally sound, and socially acceptable (or just). Put another way, sustainability depends on the 3 E's – ecology, economics, and equity. It is sometimes described as a "three legged stool," with economic, ecological, and social legs. When all three legs are strong and equal, the stool is stable. If a leg is weak or short, the stool wants to tip over.

These ideas easily transfer to sustainable agriculture, where the farmer works to optimize and balance all three legs.

Sustainable agriculture should be considered a goal, a direction, or a concept, rather than a specific set of farming practices. Organic farming proscribes a set of practices in hopes of achieving sustainability, but does not address all three legs. Some see sustainable agriculture as a question, rather than an answer. How far can we go in optimizing the economic, ecological, and social benefits from our farms? Often farmers express their idea for sustainability when they say, “I want to pass the farm on to my children” or “I want to leave the land better than I found it.”

Discussions of sustainable agriculture are also relative. What is the time frame? What are the system assumptions (e.g. indefinite supply of oil)? What is the cost? What is the context of place? Sustainable agriculture will look different in Chile than in China, yet the principles must be applied in each place. Another aspect of the definition refers to the biophysical resilience of a system to stress or disturbance. How well does a farm resist soil erosion (for example, from severe rains), and how well does it recover from a disturbance? Does it bounce back to its former productivity, or has this been permanently degraded by farming practices?

Sustainable agriculture can be thought of as an array of options that emphasize management rather than purchased inputs, where production takes advantage of biological relationships that occur naturally on the farm. The objective is to support and enhance rather than reduce and simplify the biological interactions on which crop and livestock production depend. The extent to which this can be achieved is of course influenced by economic factors (profitability) and social factors (e.g. demand for blemish-free fruit).

Principles of sustainable agriculture

No widely accepted standards exist for sustainable agriculture, in contrast to organic or integrated fruit production. However, attempts have been made to articulate universal principles by which systems can be monitored and evaluated. For example, the Natural Step program, developed in Sweden, identifies four system conditions for sustainability that are used to evaluate current operating procedures and system design, and changes are made to help the system better comply with all four conditions:

“In a sustainable society, nature is not systematically subject to increasing:

1) concentrations of substances extracted from the Earth’s crust;
2) concentrations of substances produced by society;
3) degradation by physical means; and in that society
4) people are not subject to conditions that systematically undermine their capacity to meet their needs.” (The Natural Step, 2003)

The Natural Step parallels a number of key principles associated with sustainable agriculture. These include: enhancing biological diversity; cycling/recycling of nutrients and wastes; increasing reliance on renewable and internal production inputs; information intensive and site specific management; and recognition of both the long- and short-term costs and benefits of farm practices (Granatstein, 1991).

Other principles include systems thinking (don’t deploy solutions that create more problems than they solve), ‘Nature as model’ (e.g. the perennial polyculture work of Wes Jackson [1985]), and moving from external to internal inputs (Table 1, Francis et al., 1990). Identifying such principles makes it easier to monitor agricultural systems to evaluate their sustainability.

Sustainable agriculture should be considered a direction rather than a threshold. We can determine if a farm is becoming more sustainable relatively easily, for example, if it reduces soil erosion, increases reliance on biocontrol, or obtains a greater amount of N nutrition from legumes instead of purchased fertilizer. However, it is more difficult to validate that a farm is "sustainable", implying it has crossed a threshold much like a certified organic farm has done.

Moving towards sustainable agriculture

MacRae et al. (1990) proposed three strategies for moving agriculture in a more sustainable direction – efficiency, substitution, and redesign. Efficiency is relatively easy to achieve, for example, with better soil testing to reduce nutrient losses, but yields the least increment of sustainability per unit of change. An example of substitution would be replacing an organophosphate insecticide with a microbial insecticide – little has changed other than the product, but significant sustainability gains can be made in terms of reduced toxicity and enhanced biocontrol. The most desirable strategy is agroecosystem redesign, where problems are designed out of the system through utilizing natural processes and checks and balances. This is the hardest to achieve, has been researched the least, but would yield the greatest sustainability benefit. A good example is from a farm in Minnesota that grows maize (*Zea mays*) and alfalfa (*Medicago sativa*) on sloping ground prone to soil erosion. Normally maize is grown in one field, where it requires fertilizer inputs and herbicides, and is subject to severe soil erosion. A separate field has alfalfa, which is subject to none of these needs or problems. By combining the two crops in time and space (one strip of maize 12 m wide, followed by 3 strips of alfalfa each 12 m wide representing the third, second, and first year of the crop), a maize strip always follows three years of alfalfa and needs no fertilizer or herbicide. Since 75% of the surface of the field is in alfalfa (a perennial ground cover) at any one time, soil erosion is curbed. And since the maize strips are narrow, they can be planted at twice the normal plant population without being light limited, and yields per m^2 are nearly double a typical maize field.

Agriculture has become dramatically more dependent on non-renewable inputs and inputs external to the farm, and these inputs have been crucial in attaining the increased productivity per area of land. The use of fossil fuel inputs has masked the degradation of the resource base, and allowed for the separation of profit and stewardship. Poor stewardship used to result in rapid negative feedback to the farmer or society in terms of declining productivity. But we have been able to avoid these consequences by substituting petroleum-based products and other inputs. The discussion of "low input agriculture" originated from this concern, and implies a shift to internal and renewable inputs where possible (Table 1). Information, management skill, and biological resources will become more important inputs in the future.

Measuring sustainable agriculture

There are no widely accepted protocols for judging the sustainability of a farm or agricultural system. Tools exist to assess specific parts of a system, using direct measures such as soil organic matter, soil erosion, water quality, profitability, energy use, and wildlife numbers, as well as indirect measures or models such as the soil loss equation, pesticide toxicity indices, trends in farm size and ownership, and carbon sequestration models. Many practices exist that are well documented for their sustainability benefits, including direct seeding, drip irrigation, integrated pest management and biological control, cover crops, and crop rotations.

Often comparison studies are done between contrasting systems to determine how they affect the sustainability of different parts. For example, a study of the long-term differences in soil condition between a low-input sustainably oriented farm and a conventional neighbor in Washington State found that the low-input farm had better soil quality and 15 cm more topsoil than the neighbor, resulting from less soil erosion over 40 years (Reganold et al., 1987).

Such long-term comparison studies are very useful in understanding what sustainability parameters are likely to be substantially impacted by management choices. But farms can vary greatly in their performance even when growing the same crops in the same environment. So surveys of farm practices and impact can be as important as controlled long-term studies on one site if we are to have a real-world understanding of farm management choices and sustainability outcomes.

SUSTAINABLE FRUIT PRODUCTION

The impetus for thinking about sustainable fruit production came from challenges with pest management, particularly the use of insecticides that left a persistent legacy (e.g. lead arsenate), induced new pest outbreaks, or resulted in pesticide resistance. The emergence of integrated control and integrated pest management during the mid 20th century focused on minimizing the unanticipated problems with pesticides and maximizing natural control forces, much like sustainable agriculture’s emphasis on internal biological resources (Glass, 1975). These terms were described as concepts, not fixed techniques.

Fruit production faces a whole range of sustainability issues today, spanning all the economic, environmental, and social dimensions mentioned above. For growers of all crops, economic sustainability must be addressed in the short-term or their operation will fail in an unsubsidized system. The economic issues include rising production costs (e.g. labor) with static or declining prices; retail consolidation leading to more sellers than buyers and less economic power for producers; declining demand for some fruits; global competition and counterseasonal production in opposing hemispheres.

Environmental issues around pesticides, water use and quality, energy, biodiversity, and air (e.g. methyl bromide) all relate to sustainability, but often on a longer time frame than economics. And social sustainability encompasses worker safety and other labor issues, the health-imparting benefits of fruit in the diet, urbanization and land use changes, and food security.

The sustainability issues influencing fruit production will depend on the scale, the marketing channels, and the geographic context of location. A small scale, direct market berry grower will face different challenges than a large scale export oriented apple producer. Apple producers in China face different challenges than their counterparts in Washington State. Therefore, any discussion of sustainability must take context into account.

The fruit production system

Commercial fruit production can be described as a system with the following elements:

Production – Post Harvest – Marketing – Distribution – Retail – Consumer Demand

While the "industrial" view of agriculture might see this as a linear process, with production inputs on one end, and products and consumption on the other, this chain is more like a circle, with multiple feedback loops along the way that influence sustainability. The history of 'Red Delicious' apple (*Malus* x *domestica*) in the USA is a good example. For years, orchardists produced bountiful crops of attractive fruit that were sold at profitable prices. Over time, market forces induced growers to plant more highly red color strains, as these fetched better prices and were supposedly preferred by consumers. However, these strains often had poorer flavor and eating quality than their predecessors, and over time consumer demand waned, and prices dropped. Thousands of hectares of 'Red Delicious' apples were removed during the late 1990s and early 2000s in Washington State (Fig. 1).

Thus, demand can be considered as a key system condition for sustainable fruit production. Without sustained demand, production of a given fruit will not continue. What influences demand? We typically think of cultural preferences, dietary diversity, taste, health attributes (real or perceived), price, and convenience (e.g. pre-sliced fruit) as important influences. But for long-term sustainability, unique characteristics of fruit need to be identified, validated, and communicated, as is being done in dietary campaigns such as the "Five A Day" effort in the USA (Heimendinger et al., 1996) to encourage more consumption of fruits and vegetables to combat obesity, diabetes, and other diet-related illnesses. New influences on demand include embedded values such as fair trade, food miles, and organic, as well as pesticide residues. Fruits that address these sustainability concerns are enjoying steady growth in demand (Oberholtzer et al., 2005). The same can be said for new varieties (e.g. 'Pink Lady'™ apple) and new presentation to the consumer (e.g. pre-ripened pears, pre-sliced apples).

Another major influence on sustainability relates to the biophysical capability of a site. Not all farms are created equal in their ability to produce quality fruit. A temperate tree fruit such as apple is produced around the world in a variety of climates, soils, and landscapes. In all locations, the fruit trees need light, heat, water, air, and nutrients. Production is inherently more sustainable where the environment can supply more of these in ideal amounts and times. Modern technology allows many environmental barriers such as hail, sunburn, and frost to be surmounted, but at a cost. Fruit production in all locations needs protection against economically important pests, for which many tools and techniques exist.

Fruit growers are increasing the biophysical sustainability through various practices and strategies, including information-intensive management (e.g. precision farming), enhanced biodiversity, water conservation, biological control, and increasing soil organic matter. A new challenge is climate change that may undermine the suitability of an existing premier production area for the current fruit product, such as shifting zones for wine grape production (Jones, 2005), or lead to new pests.

Over the past several decades, Integrated Fruit Production and organic fruit production have emerged as possible two approaches to sustainable fruit production. Their goals are very similar, but their strategies are somewhat different. Both have had a widespread impact on production of tree fruits and vines in many parts of the world.

Integrated Fruit Production

Integrated production is an umbrella concept intended to address sustainability issues in agriculture, emphasizing economic and environmental aspects. In the 1970s, an Integrated Production (IP) framework was developed by the International Organization for Biological and Integrated Control of Noxious Animals and Plants (IOBC) as an outgrowth of its pioneering work on biological control and integrated pest management (IPM). The IOBC members recognized that adoption of IPM would be more successful when considered in the context of the entire farming system, and thus the Integrated Production concept was launched.

Eleven principles of IP were identified, with guidelines for crops, nutrient management, soils, biological diversity and landscape, pest control, product quality, and animal production (IOBC, 1993). The initial systems of interest were perennial fruit. IOBC then produced technical guidelines under the IP umbrella for pome fruits, stone fruits (*Prunus* spp.), and vines (*Vitis vinifera*), specific to Europe (IOBC, 1994). This was one of the first attempts to delineate the specifics of sustainable fruit production. The guidelines for pome fruit detail the following elements for integrated fruit production:

- Definition
- Professionally trained, environmentally and safety conscious growers
- Conserving the orchard environment
- Site, rootstocks, cultivar and planting system for new orchards
- Soil management and tree nutrition
- Alleyways and weed-free strip
- Irrigation
- Tree training and management
- Fruit management
- Integrated plant protection
- Efficient and safe spray application methods
- Harvesting, storage and fruit quality
- Post-harvest chemical treatments
- Mode of application, controls, certification, and labeling

The level of detail provided in the guidelines varies among these elements, with plant protection receiving the most attention. The guidelines specify a system of classification of pesticides with three groups (permitted, permitted with restrictions, and not permitted), and the factors taken into account in making this determination. This emphasis on pest control illustrates that IPM is considered the key aspect of sustainable fruit production.

With the publication of the IFP guidelines, many tree fruit producing regions in Europe responded by developing their own technical standards and certification systems, based on the IOBC documents and tailored to the region. These efforts set the stage for the interest in integrated fruit production around the world, where environmental concerns and market forces have encouraged all fruit producing regions to look harder at the performance of their orchard systems. In Europe, government policy often provided direct financial incentives to growers who adopted IFP, and some markets requested IFP labeled fruit and promoted it to their customers. An estimated 40% of the pome fruit hectares in Western Europe were under an IFP program in 1994 (Reed, 1995). In the 1990s, IFP programs were also developing in New Zealand, USA, Canada, Argentina, and South Africa. Most of these used specific evaluation protocols for the orchards and vineyards, and some involved a certification program and label. IFP programs tended to push orchardists beyond the basic IPM they were doing and often resulted in measurable benefits across a region (e.g. decline in pesticide use or toxicity; less worker exposure and injury).

During the same period, consumer interest in organic foods was growing. In the USA, organic was the first food 'ecolabel' to achieve widespread consumer recognition, and IFP programs have not received the same prominence. In Europe, both IFP and organic were present in the market, but organic was much more difficult to achieve under most European growing conditions. Thus, IFP participation by growers dominated initially, but organic has been growing as market demand and price premiums have grown.

Integrated fruit production addresses sustainability in many regards. A good example is the shift to high-density plantings of dwarf rootstock trees. This change in orchard canopy and architecture has ramifications for many aspects of the orchard system. Earlier bearing of fruit helps economic sustainability. Low canopy height improves worker safety by eliminating much of the ladder work, benefiting social sustainability. A more open canopy helps reduce some diseases and improves pesticide coverage and efficacy, addressing environmental sustainability. However, as with most examinations of sustainability, there are trade-offs. For example, high-density orchards with thin leaf canopies may suffer from increased sunscald of fruit from the reduced protection against the intense solar radiation in the summer (Yuri et al., 2004), increasing fruit cullage and sometimes requiring evaporative cooling of the orchard with irrigation water. This is particularly true in semi-arid regions, which are much less prone to key diseases and require considerably lower pesticide inputs to produce quality fruit than in more humid regions.

Many practices employed in modern high-density orchards enhance sustainability. Microjet sprinklers and drip irrigation can greatly conserve water. Legumes and organic amendments can provide a significant portion of the fertility needs, offsetting fossil fuel based fertilizers. Mulches in the tree row can control weeds, conserve moisture, and build soil organic matter, while increasing tree growth and fruit yield (Table 2). IPM tools such as monitoring, mating disruption and granulosis virus can reduce traditional pesticide inputs (Table 3) for codling moth (*Cydia pomonella*) control, especially those organophosphate materials with a high level of environmental and human health concern.

While efficiency and input substitution have been widely exploited in fruit production, agroecosystem design is now getting more attention as a strategy to improve sustainability. For example, border plantings of wild rose (*Rosa woodsii*) hedges in Washington State apple orchards augment the biocontrol of leafroller by providing alternate habitat for a key parasitoid, and add to biodiversity in the system (Pfannenstiel and Unruh, 2003). Establishment of the naturally occurring 'weed' *Ageratum conyzoides* in citrus orchards in China led to near total biocontrol of citrus red mite by natural enemies (*Amblyseius* spp.) encouraged on the weed. This practice was adopted on over 135,000 ha of citrus (Liang and Huang, 1994). In one experiment in West Virginia, USA, peach trees were interplanted in an apple orchard to enhance aphid control (M. Brown, pers. comm.). Many ideas remain to be identified and tested that can consciously 'design' specific problems out of the orchard system to improve sustainability.

Rise of organic fruit production

As mentioned above, organic farming is one approach to increasing sustainability in agriculture that is market-driven and growing rapidly. The origins of organic farming come from a focus on improving organic matter in the soil in order to grow healthy plants that can resist pests and diseases, and that provide maximum health to the people and animals that eat them. One guiding principle is the use of natural materials for crop production and the avoidance of synthetic materials (e.g. fertilizers, pesticides). Another principle is to work with the natural systems and processes as much as possible, concurring with the 'Nature as model' idea of Wes Jackson and others. Thus, organic farming shares virtually all the goals articulated by sustainable agriculture proponents.

As organic farming expanded in the 1980s, certification programs became necessary to guarantee to the consumer that the product they were buying, and generally paying a higher price for, was indeed produced as they expected. The 'no chemicals' or 'no synthetics' principles were often the strongest impressions in the consumer mind. Organic certification programs can more easily determine if a grower has or has not used a particular material than they can verify that a farm is 'working with natural systems.' As a result, much of the focus of organic certification has been on determining what materials are allowed for use on organic farms. Sustainable agriculture generally does not share this focus, although IFP programs often do exclude or restrict the use of certain more toxic or disruptive pesticides.

Organic matter, a key consideration in organic agriculture, is arguably the most important aspect of sustainable soil management. Tillage is a practice that can quickly degrade organic matter. Since tree fruit and vine systems are perennial and typically involve little tillage after planting, they can be very conducive to increasing soil organic matter. On the other hand, tree fruit and vine crops typically require a high level of pest management to produce marketable crops. Organic growers are greatly restricted in the pest control products they can use. The allowed products are generally less effective and of shorter duration than products that growers following other production approaches, including IFP, can use.

Key challenges for organic fruit production include nutrient management, weed control, and control of replant diseases. Organic pear growers in Washington State, USA, report a decline in fruit yield and size over time, due to the inability to control perennial weeds and control their competition for slowly available nitrogen (J. Dunley, pers. commun.). Organic tree fruit growers in the USA will commonly fumigate the soil prior to replanting an orchard (and restart their certification process) rather than risk the economic devastation from replant disease, for which there are no proven organic controls. Resistance management is another challenge, given the fewer effective tools for pest control. When a new tool comes along, such as spinosad, there is a tendency to overuse it and thus increase the likelihood of inducing pest resistance.

In many regions, organic fruit producers must spray more frequently, and use more kilograms of pesticide product, often achieving a lower marketable yield (Merwin et al., 2005; Weibel et al., 2004). This conflict between the potential for improved environmental sustainability of organic systems and their challenge in maintaining economic sustainability has limited expansion of organic fruit production in certain regions. Use of scab-resistant (*Venturia inaequalis*) apple varieties has expanded the potential for organic apple production in humid regions where this disease is difficult to control. However, lack of consumer acceptance of the varieties due to quality issues, and resistance breakdown that is already occurring, both challenge the sustainability of this strategy. The continuing expansion of organic fruit production in semi-arid regions reiterates the importance of the biophysical conditions and how well they support sustainability.

Comparing system sustainability

Various studies have compared the performance and impacts of fruit production systems to understand how well they achieve sustainability goals. Reganold et al. (2001) compared conventional, integrated, and organic apple production in side by side plots near Yakima, Washington, USA from establishment through six years of growth and production (Table 4). The integrated and organic had the best soil quality, while the organic had the lowest environmental impact based on a pesticide rating system. Tree growth and fruit yields were similar across all systems, as were production costs. However, the authors estimated that the organic system would need a 12% price premium to match the financial break even point in the conventional system (Glover et al., 2002).

Similar economic results were found in a 12-year study of tomato cropping systems in California, USA (Huyck et al, 2003). The organic system was the most profitable with price premiums, but the least profitable (and actually a net loss) without premiums. Both organic and low-input reduced nitrate leaching, but low-input had half the loss of organic.

A Swiss study comparing integrated fruit production and organic did not find consistent differences in pest and disease problems for apple (Bertschinger et al. 2004). Trees in IFP had better nutritional status but grew slightly less than organic, and organic fruit yields were slightly less than IFP. The authors concluded that the higher price for organic apples compensates for the lower yield, less premium fruit, and higher production costs (machinery +30%, pesticides +72%, labor +35%)

Kovach et al. (1992) developed the Environmental Impact Quotient (EIQ) to compare the relative impact of various pesticide programs. They calculated the EIQ for 'Red Delicious' apples grown under three pest management systems in New York State, USA, and estimated the following scores: conventional 938; IPM 167; organic 1799. Organic fared poorly due to the high use of sulfur and its negative effects on beneficial insects.

Stolze et al. (2000) reviewed the environmental performance of various farming systems in Europe. They made a qualitative rating, based on the scientific literature, for the ecosystem, soil, ground and surface water, climate and air, farm input and output, and quality of produced food. Organic was compared to conventional and rated as much better, better, same, worse, or much worse. All topics spanned more than one rating category, with all but soil scoring same to much better, and soil scoring much better to worse. This points out the need to look at similar systems across different environments, as the sustainability results are often greatly influenced biophysical conditions as well as farm management. Scialabba and Hattam (2002) also reviewed European studies on nitrate leaching and found large reductions (40-65%) with organic systems relative to conventional in all but one case. They also compared energy use in organic and conventional production, looking at both energy per hectare and energy per ton of product. While organic apple used 90% of conventional apple on a per hectare basis, it used 123% of conventional on a per ton of product basis due to the lower yields.

Virtually all fruit production systems today rely on significant inputs of fossil fuel energy. Organic systems reduce this by avoiding typical agrochemical inputs (especially nitrogen fertilizer) but have increased energy use from hauling in and spreading bulky organic amendments for fertility. Organic growers often spray more frequently and conduct more tractor operations for weed control. At the same time, consumers are becoming more aware of the distance that food travels from farm to store. Locally grown foods require the least fossil fuel for transport and are more sustainable from an energy point of view. Thus, consumers are asking challenging questions, wondering whether a recently harvested organic apple from Chile or an 8-month old conventional apple from Washington coming from Controlled Atmosphere storage represents a more sustainable food choice. In the U.S., locally-grown is often as important an attribute as organic for many consumers.

Finally, while all organic growers must comply with a specific set of standards, they can vary substantially in the sustainability of their system, as do growers in most any category. If a quantitative sustainability index existed, and the distribution of farms was plotted along this axis relative to their score, one could create a diagram such as Figure 2. This illustrates the blurring of lines regarding sustainability when we describe farms in categories such as conventional, integrated, and organic that are not discrete but overlapping. A 'conventional' grower using advanced IPM and many sustainable practices might be rated more sustainable than an organic grower who just meets the standards but has not embodied the "Nature as model' principle to a great extent. Thus the choice of farms for system comparison studies is critical, and can easily bias the outcome. To prove that organic is better than conventional, pick an organic farm on the high end of the organic curve and a conventional farm on the low end of the conventional curve. Do the opposite to prove that conventional is better than organic. However, if one were to calculate the average sustainability of all organic farms and compare it to the average of conventional farms (Fig. 2), it is likely the organic system would illustrate greater sustainability.

Ecolabels for sustainable fruit production

An ecolabel denotes an identity scheme for a product that has one or more special attributes (either in the product itself, or in the way it was produced) representing ecological and/or social values that are communicated to consumers. The most widely known and most successful food ecolabel today is 'organic.' In the U.S., many other food ecolabel programs have been developed, including the Lodi-Woodbridge sustainable winegrapes program in California, Food Alliance and Salmon Safe in Oregon, and fair trade and other social sustainability programs, which offer ecolabels that are somewhat broader than organic and more in line with the Integrated Production guidelines. European consumers are familiar with the various Integrated Fruit Production labels that emerged during the past two decades. The common goal is to achieve increased sustainability on farms through a feedback mechanism (the label) whereby consumers can support positive changes on farms through their purchase decisions. They also offer a voluntary approach to environmental stewardship as an alternative to regulation.

Food ecolabels share a number of common features. They all make a claim about the process or product, either relative to the typical product available (e.g. no genetically modified crops or livestock products), or relative to a particular environmental or social benchmark (e.g. no use of organophosphate insecticides, improved salmon habitat). They all have a protocol for validating that claim, some very rigorous and some not. And they all require an identity on or with the product at point of purchase to communicate the claim and why it might be important.

Many approaches are available to validate the sustainability claim in fruit production systems. These include positive points for best practices, negative points for pesticide use and toxicity, lists of mandatory best practices, quantitative performance (e.g. Environmental Impact Quotient), continuing improvement, and uniform mandatory standards (as in organic). Most ecolabels other than organic avoid uniform mandatory standards and use a combination of the other approaches. For example, the Protected Harvest standards require growers to have a minimum number of points awarded for a variety of practices in nine management categories; to stay below an established level of toxicity units for pesticides used; and to pass a chain-of-custody audit from farm to market (Protected Harvest, 2002). The Food Alliance requires a score of 75% of available points for soil and water conservation, integrated pest management, fair and safe working conditions, and biodiversity, along with continuing improvement, while using no genetically-modified organisms or any of the prohibited pesticides (Food Alliance, 2006).

Understanding the target consumer is critical in developing an ecolabel. If the target consumer is most concerned about pesticide residues on the fruit, then an IFP program that does not address that issue specifically is unlikely to succeed. If the target consumer is most interested in wildlife habitat and biodiversity, a label focused on soil and water conservation is unlikely to succeed. The potential to layer attributes important to consumers through IFP or organic is illustrated in Table 5. IPM without some reference to pesticide reduction has little consumer appeal. IPM with pesticide reduction and other conservation improvements (water, soil, wildlife) received the strongest willingness to buy response.

Consumer research (e.g. Hartman, 1997) suggests that altruistic motivations (protecting the environment, worker safety) tend to rank lower than self-interest motivations (pesticide residue free, nutrition, taste) when consumers respond to ecolabels. Thus, there is a need for greater consumer awareness and understanding of how support for environmental protection does directly impact self-interest. The widening discussion about sustainability within many countries promises to help address this need.

CONCLUSION

Public interest in sustainability is growing in many countries today. As agriculture is critical to world food supply and is linked to numerous environmental and social issues, consumers are increasingly aware of and interested in the sustainability dimensions of the food they buy. They express this interest with fruit products through their purchase of foods with IFP, organic, and other ecolabels. Both IFP and organic have clear environmental sustainability objectives, while social sustainability objectives are present in IFP but currently less codified in organic. Neither can guarantee economic sustainability, but as one strategy for increasing demand for fruit products, they can make a positive contribution. Some countries have subsidized these production systems to benefit from their potential 'environmental services.' Both IFP and organic have been driven by markets in the more affluent nations. However, interest in more sustainable fruit systems is growing in developing countries as well, as governments and communities seek alternatives to the problems caused by some input-intensive production systems. Also, our reference point changes over time. What was considered IFP yesterday might be called conventional today. In some areas, the distinction is blurring between the progressive edge of conventional and the codified organic.

While many sustainability indicators are available for pieces of the agricultural system, widely accepted methods to quantify improvements in agricultural sustainability have not yet been deployed. Results from systems studies indicate that meaningful sustainability benefits can be achieved with organic and IFP. The ultimate impact from changes in fruit production will be the sustainability impact per unit area times the area influenced. Therefore we will need to understand how adoption of IFP on 50% of a production area might compare to adoption of organic production on 5% of the area in terms of overall sustainability gain.

Future challenges such as climate change and peak oil will test these systems in new ways, with local likely to become a more important sustainability attribute. Decreasing labor costs through mechanization, and increased emphasis on the nutritional and nutraceutical value of fruits are other trends to watch. Sustainability remains a goal, and the most accurate way to evaluate it is with hindsight, looking back from 20 years in the future and determining whether the actions taken today to increase sustainability actually did so.

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Table 1. Agricultural production resources derived from internal and external sources (adapted from Francis et al., 1990).

	Internal Resources	External Resources
Light	Solar energy	Artificial (greenhouses)
Nitrogen	Fixed from air, recycled in soil	Primarily from applied synthetic fertilizer
Seed	Varieties produced on farm	Hybrid or certified seed purchased annually
Machinery	Built, maintained on farm or local	Purchased and replaced frequently
Labor	Mostly from farm family	Mostly from hired workers
Capital	From family & local sources, reinvested locally	External debt, benefits leave community
Management	Information from farmers and local community	From input suppliers, crop consultants

Table 2. Effect of tree row mulch on apple tree (6th leaf Spartan / M.9) growth and fruit yield in British Columbia, Canada (adapted from Neilsen et al., 2003).

	Control	Mulches	Change
Trunk cross sectional area (mm^2)	1011	1406-1565	+ 39-55 %
Roots ($g/0.018\ m^3$)	11.3	28.7-41.8	+ 154-270 %
Fruit yield (kg/tree)	10.3	13.0-14.9	+ 26-45 %

Table 3. Pesticide reduction and IPM adoption in Washington State apples (Brunner et al. 2002).

	Total kg active ingredient/year	
Pesticide	1989	2000
Guthion	193,273	117,682
Dimethoate	5,409	64
Malathion	28,818	1,727
B.t.	373	11,091
Spinosad	n.a.	3,000

IPM Practice	% growers using practice	
Field monitor	91	99
Economic threshold	37	92
Use biocontrols	34	81

Table 4. Effect of apple orchard management system on sustainability indicators. (adapted from Reganold et al., 2001; Glover et al., 2002)

	Conventional	Integrated	Organic
Total energy input (MJ/ha)	516,489	488,661	445,328
Environmental impact rating	2,893	2,211	466
Soil quality rating	0.70	0.81	0.83
TCSA* 6th leaf (cm^2)	28.0	28.2	28.5
Fruit yield 1996-99 (MT/ha)	210	205	198
Total cost of production (1998-99) ($/ha/yr)	18,343	18,260	17,440

*TCSA=trunk cross sectional area

Table 5. Consumer response to sustainable agriculture system (adapted from Hartman, 1997). Data represent survey respondent agreement (in %) with "likely to buy" statement for the different agricultural systems described.

Farming system	% likely to buy
IPM + conservation + pesticide reduction	67
Integrated Fruit Production	63
IPM + pesticide reduction	51
Conservation without pesticide reduction	33
IPM without pesticide reduction	13

Figure 1. Decline in production of 'Red Delicious' apple in Washington State, USA. (Data source: Wenatchee Valley Traffic Association)

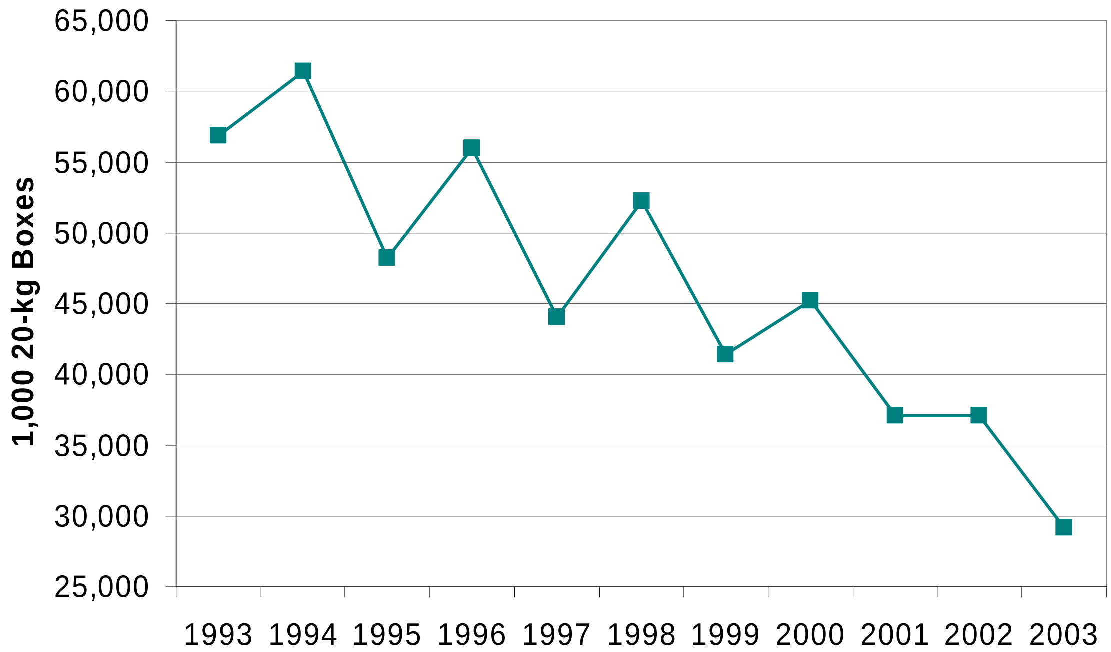

Figure 2. Hypothetical distribution of conventional and organic farms along an idealized sustainability index.