Sustainability and Tree Fruit Production

David Granatstein
Sustainable Agriculture Specialist, Center for Sustaining Agriculture and Natural Resources, Washington State University, Wenatchee, WA, 98801 USA

'Sustain' is a simple enough word. According to Merriam-Webster, it means "to provide support or maintenance; to cause to continue; to endure; and, to last indefinitely." The term 'sustainability' becomes more complex to define and understand when we apply it to our agricultural systems as well as other aspects of human culture. Sustainability implies a balance between human resource demands and the ability of the biosphere to provide them on a long-term basis. Past civilizations, such as the Mayan Empire and Mesopotamia, lost this balance and faded out due to resource depletion and the ensuing social disintegration. Some of the earliest sustainability discussions relative to agriculture in the 20th century revolved around soil erosion and conservation. The Dust Bowl of the 1930s put soil sustainability on the national agenda, with farming practices as a major factor. More recently, pesticide use has been a prominent sustainability issue for fruit production. Genetic engineering and energy are likely to be key sustainability issues in the future.

Sustainability is now discussed in many venues beyond agriculture. Increasingly, businesses, government, religious organizations, and social and environmental change groups have incorporated sustainability language as part of their mission, values, and/or work plans. These interests are now influencing agriculture as buyers and policymakers begin to inquire about sustainability aspects of the food production system.

Sustainable agriculture is commonly described as trying to balance economic viability, environmental stewardship, and social responsibility within individual farming operations as well as across the entire food system (Granatstein and Kupferman, 2008). It can be thought of as a three-legged stool. If all legs (economic, environmental, social) are of similar length, the stool is stable. If one leg breaks off, the stool falls over. More realistically, sustainable agriculture represents a long-term goal that we move our farming systems towards, rather than a threshold that is crossed. This is an important distinction since there is considerable pressure to develop sustainable agriculture standards. Setting standards for a goal is probably not appropriate. We are able to say with some certainty what is "not" sustainable. But to declare something "sustainable" generally requires hindsight, with enough experience with a practice or system to have learned some of the unforeseen consequences. However, for many aspects of contemporary agriculture, we do know enough to tell whether we are moving in the right direction – towards or away from sustainability – and sustainable agriculture standards can be successfully built around this concept.

Sustainability is a relative term, as it depends on the system assumptions and conditions. Our concept of sustainability fundamentally changes with assumptions about the availability and cost of petroleum as an energy source. In Washington State, current irrigation withdrawls from rivers generally allow for adequate in-stream flows to support fish populations. The water is renewed each year from snowfall, and can be considered sustainable (as compared to overdrafts of groundwater aquifers). However, with a changing climate, summer snowpack is already declining and will lead to lower summer flows that will eventually be insufficient for fish, even though our irrigation withdrawls are the same.

Another example of the relative nature of sustainability is the evolution of codling moth (*Cydia pomonella*) control in apples. In the early 1900s, lead arsenate was the most common control. It did not degrade in the environment and the codling moth developed resistance to it. When DDT became available in the 1940s, it represented a major sustainability step forward. Problems with DDT and wildlife, an unintended consequence, led to the shift to organophosphate insecticides in the 1960s, pesticides that were highly toxic but more quickly degraded in the environment. Concerns about human exposure to these neurotoxins led to the adoption of pheromone mating disruption. This non-toxic technique only affects codling moth. It alone may not offer satisfactory control, and is now combined with other products such as codling moth granulosis virus, again a control specific to codling moth. We assume that these new tools represent major gains in sustainability, but need to monitor them carefully to know.

Sustainable Agriculture Trends

Profitability in agriculture, a key indicator of economic sustainability, is anything but guaranteed. The most basic ingredient for profitability is demand for the product being grown. For decades, the Washington State apple industry enjoyed steady demand for 'Red Delicious' apples, which accounted for nearly 70% of the planted apple acres in the state. Prices went up and down over the years, and profits with them, but demand was relatively reliable. Then in the early 1990s, demand for this product started a precipitous decline (Figure 1). Fruit producers who had not diversified faced severe economic losses. One response was to plant new varieties such as 'Gala' and 'Fuji'. But this strategy was not a guarantee to economic sustainability. In a study of the economics of a high density 'Fuji' planting, the price paid exceeded the breakeven cost of production only in 4 of 8 years, resulting in losses as high at $7,000 per hectare (Table 1) (Schotzko and Granatstein, 2004). The emphasis on eating more fruit as part of a healthy diet provides a positive contribution to demand and economic sustainability, and per capita consumption of fresh fruit is expected to rise 5-7% between 2000 and 2020, along with increased demand from a growing population. Rising prices for energy, labor, and other inputs are hurdles for consistent profitability. Mechanization, for example, may help lower labor costs for production as well as the risk associated with an uncertain labor force (due to social sustainability issues around immigration). While profitability is a necessary condition for sustainability, it is not sufficient.

The 'environmental' leg of sustainability covers many concerns, such as soil erosion, water quality and quantity, air quality, toxin release, biodiversity and loss of habitat, desertification, and now greenhouse gases. Significant progress has been made in the past 20 years addressing many of these. Often these environmental impacts do have real costs associated with them (e.g., water treatment) that are not included in farm economic analysis. The degree to which these external costs (those not born directly by the farm but by society at large) are included into profitability calculations can influence conclusions drawn about economic viability and illustrate the close connection between economic and environmental aspects of sustainability. These costs can be internalized, commonly through regulation, but also through changes in technology and practice that not only reduce the environmental impact but improve farm performance and profits. For example, some grain farmers have been able to dramatically reduce soil erosion with direct seeding, and often experience increased yields due to better use of moisture that increases profits. This situation provides positive feedback to improved sustainability. A similar situation might be achieved in fruit production with adoption of biocontrol that provides economic control of a pest at less cost than pesticides, and also reduces pesticide release into the environment at the same time.

The ‘social’ leg of sustainability encompasses many topics, such as worker safety and other labor issues, the next generation of farmers, urbanization and land use changes, the health-imparting benefits of fruit in the diet, and food security. Social sustainability has generally received less attention than economic and environmental sustainability, and is more difficult to quantify. Programs such as Fair Trade and Certified Fair Labor Practices attempt to evaluate part of the social sustainability puzzle.

In discussing sustainability, it is critical to remember the context. A small direct-market grower with apples will face different challenges and responses than a large-scale export oriented apple producer. Orchardists in China face different challenges than their counterparts in Europe.

Globally, there are a number of trends that represent responses to sustainability in agriculture. These include Integrated Pest Management, reduced tillage, organic farming, nutrient management and water quality protection, energy conservation and renewable energy, biodiversity enhancement, and direct marketing and Community Supported Agriculture. Integrated Fruit Production has been put in places on tens of thousands of hectares of tree fruit land around the world, representing a more formal adoption of sustainability principles and practices.

Has Tree Fruit Production Become More Sustainable?

The development of Integrated Pest Management, and from that, Integrated Fruit Production, represents the most clear example of increased sustainability in tree fruit production. Results from pest management surveys such as one done in Washington State (Table 2) show quantitative change away from more toxic, broad spectrum insecticides to less toxic and often more targeted products (Brunner et al., 2002). Nearly 85% of all pome fruit acres in the state now use pheromone mating disruption for codling moth, indicating the willingness of growers to adopt more sustainable practices even when they may cost more. Increased use of biocontrol, including novel practices such as planting rose hedges on apple orchard borders (Pfannenstiel and Unruh, 2003) to provide an alternate host for the leafroller parasitoid *Colpoclypeus florus*, is a clear sustainability improvement. The rose garden idea illustrates the concept of ‘agroecosystem design’, where the orchard system is constructed with specific elements to reduce or eliminate problems, such as pests, rather than simply relying on treating a problem once it occurs. Tree fruit orchards have undergone significant ‘redesign’ in the conversion to the high density system of fruit growing. In large part, these changes were motivated by sustainability considerations, such as improved spray efficacy, improved fruit quality, less need for ladder work, and a shorter time to fruit production to enhance economics. Few other crops have experienced such a dramatic transformation.

As with many changes, some unintended trade-offs have occurred. The increased sun exposure through the canopy has elevated fruit sunburn as a major problem in some regions and with certain varieties. Responses to this have been the use of evaporative cooling and the development of sun protectants sprayed on the fruits. While high density orchards have generally reduced their water use through adoption of micro-sprinkler technology and soil moisture monitoring, evaporative cooling may be an unsustainable practice in an era of more constrained water supplies. Likewise, the inputs for the trellis system (posts and galvanized wire) have not been fully assessed in terms of their impacts.

Sustainability of demand for tree fruits has been mixed. Consumption of sweet cherries has gone up while apple consumption remains flat or slightly declining. New apple varieties are being developed with more focus on taste, and consumers do respond as shown by the success of Honeycrisp®. The launch of pre-sliced apples and their subsequent growth offers families a healthy product that competes with snack foods and increases fruit consumption by children.

Measuring Sustainability

Given that sustainability is difficult to precisely define, and hindsight is often the best indicator, there is no widely accepted method for measuring sustainability in agricultural systems. Various approaches are used, but none result in a comprehensive, unified measure. For example, systems comparison studies can be done, often over many years. These can be replicated plots on a single site or comparisons of pairs of adjacent farms with contrasting systems. A study in the Yakima Valley, USA, compared conventional, integrated, and organic apple production over seven years in side-by-side replicated plots and measured many parameters, including tree growth, fruit yield and quality, energy inputs, costs and returns, pesticide impacts, and soil quality (Reganold et al., 2001). The organic system was equal to or superior to the other systems on all of these parameters. But often in these studies, there are conflicting results and it is not possible to reach an objective conclusion on whether one is more sustainable than the other.

There are established standards that can be used to evaluate sustainability, including soil loss, water quality (e.g. nitrates at less than 10 mg/L), and pesticide residues. Several indices have been developed to assess system components, such as the soil quality index (Glover et al., 2000) and the Environmental Impact Quotient (Kovach et al., 1992) for apples. Economic indicators can be annual profitability, reinvestment and orchard renewal rate, debt to asset ratios, and more intangible indicators such as entry of new farmers. Social indicators might include a measure of family farm predominance, community impacts (e.g., the Arvin and Dinuba study by Goldschmidt, 1946), and food quality and human health results from the fruit produced.

The Keystone Center is developing a sustainability assessment tool for field crops in the U.S. with its Fieldprint calculator (Keystone Center, 2009). This uses existing industry-wide data from different years to track change on key indicators, in this case soil loss, water use, energy, greenhouse gas emissions, and land use, calculated on a per bushel basis for maize. Soil loss shows a dramatic decline from 1987 to 1997, probably due to the USDA conservation compliance provisions, and little change after that. Energy use was similar in 1987 and 1997, but declined some by 2007. The Fieldprint provides visual as well as numerical insight into sustainability changes.

The concept of a ‘footprint’ is now commonly used in sustainability discussions. A footprint is a measure of the impact of a system, practice, or product on one or more environmental factors. A reference point is needed to understand what any given number or score might mean. Quantitative footprints can be calculated for a range of indicators, such as energy, water, and greenhouse gas emissions. Assumptions and methods must be transparent and clear. For example, an energy footprint could include both fossil fuel based energy as well as renewable energy; these have different sustainability implications, but a single energy footprint number might not distinguish between them. Similar to the dilemma with a systems comparison study, it can be challenging to combine the results of various footprints for a system into a single indicator. One approach to do this is Life Cycle Assessment.

Life Cycle Assessment (LCA) was developed as an environmental analysis tool originally for industrial applications. It was meant to provide a method of evaluating a product or process from ‘cradle to grave.’ It has been used after the fact to compare the same product (e.g. a coffee cup) from differing sources (e.g. in a coffee shop, a single use paper cup versus a ceramic cup that is washed and re-used). It can also be used in the development of a product to minimize the environmental impacts of production, use, and disposal. And a specific product (e.g., an Apple® iPhone) can be evaluated to calculate its environmental burden for use as a formal environmental product declaration in promotional materials or to meet sourcing standards. LCA is a data-driven method that has been codified under the ISO 14400 standards such that a given LCA study can be judged regarding the quality of the analysis.

LCA is now being applied to agriculture and food systems. These are quite different than linear manufacturing systems, and LCA use in agriculture is still in a learning phase. An LCA of apple production in New Zealand provides a good example of how this process can work (Milà i Canals et al., 2006). Several orchards from two different growing regions were assessed to provide a broader base than a single farm. Orchard machinery accounted for 64-71% of the energy use, compared to 5-11% for fertilizer (which is generally much higher in crops such as maize). Total energy use was 420-720 MJ/metric ton apples. This range provides a baseline for New Zealand growers to compare themselves to, as well as a comparison to energy use in apple production in other countries. The range also indicates an opportunity for reducing energy inputs, and can be used in setting sustainability goals for continuous improvement. The degree of uncertainty in LCA studies of agriculture is often high; it was +/-50% for the New Zealand apple study. However, when multiple studies of the same crop become available, the data can start to define the dimensions of production of that product (Table 3). The choice of functional unit, in this case kg CO_2e/MT apples versus kg CO_2e/ hectare, is critical to proper interpretation and conclusions.

Sustainable Agriculture Standards and Certification

The demand for measurements of sustainability in agriculture is growing as various players in the food system develop their sustainability strategies. Growers and fruit companies were some of the early pioneers of more formal sustainability assessments. This began with the development of Integrated Fruit Production in Europe in the 1970s, a protocol that is widely used there and has been adopted in other countries. Organic production represents another certification protocol that has a strong sustainability base. Corporate sustainability is being developed by many companies, including fruit buyers such as Sysco, Unilever, and Wal-Mart. These companies are now asking their suppliers, including fruit growers, to provide information on sustainability in their operations. Thus, access to meaningful, science-based, quantitative, and easy to use metrics is needed. Efforts such as the Keystone Alliance and the Stewardship Index for Specialty Crops are attempting to address this. Existing sustainable agriculture programs such as Food Alliance, Protected Harvest, and Salmon Safe have developed their own processes, standards, and tools for evaluating farms, processors and packers. Unilever has an on-line tool for growers to use in calculating their greenhouse gas footprint (http://www.growingforthefuture.com/content/Cool+Farm+Tool). Even food safety programs are beginning to add modules that address other aspects, such as environmental and social sustainability. Ultimately, there will need to be harmonization of these diverse efforts so growers can undergo one process and meet the needs or requirements of multiple buyers. In addition, growers have used sustainable agriculture certification to distinguish their products in the marketplace, often adding value and finding new customers. Shepherd's Grain, a company that markets grain products from no-till farmers in eastern Washington, has found markets supportive of their environmental efforts to conserve soil, water, and wildlife, and this has transformed their sales from a commodity to a value-added and relationship based product. Key end users such as bakeries get a more tailored and consistent ingredient that saves them money and also allows them to advertise their contribution to sustainable agriculture.

Future Sustainability

Tree fruit production has some inherent advantages for sustainability given the perennial and three dimensional nature of the orchard. Soil erosion and nutrient losses to water are generally not significant problems. Advances in biocontrol as well as development of lower risk and less disruptive pesticides continue to provide growers with more sustainable options for pest management. However, new pests such as spotted wing drosophila (*Drosophila suzukii*) and brown marmorated stink bug (*Halyomorpha halys*) can disrupt the years of work that have gone into implementing biologically-based IPM programs.

The innovation present among tree fruit growers and researchers is a huge and important asset for addressing sustainability issues. The extensive amount of research on orchard systems and mechanization will lead to big opportunities for labor efficiency and cost reduction in the future, along with improvements in fruit quality and yield. Research and development with genetics and genomics for tree fruits can help address key sustainability challenges such as water shortages, pest management, labor (through tree architecture), consumer demand (through taste), and climate change adaptation. Sustainable agriculture programs will likely focus on continuous improvement, and growers have many practices they can implement now to demonstrate this. These include soil moisture monitoring, use of biofuels and solar panels, decision support for pest management, reduced-risk pesticides and biocontrols, choosing fertilizer with a lower greenhouse gas footprint, and planting disease-resistant trees.

Energy is a critical sustainability issue to pay attention to. If petroleum energy becomes unavailable, most tree fruit production will come to a halt. Virtually every aspect of modern orchard management involves petroleum-based energy, save the photosynthesis driven by the sun. We need to find ways to reduce that reliance and potentially harvest and use more current solar energy on the farm. Electrification of orchard machinery is possible; electric platforms are already manufactured in Europe. These can be much more efficient than internal combustion powered units. Sourcing electricity from renewable sources becomes the next step. Some farms with packing facilities or other large buildings have installed solar roofs as one strategy.

Production of biofuels is possible, but competes with land for fruit production. Plants can capture about 5% of the solar energy that hits the earth's surface, and this is a current limitation on the role that biofuels can play. In a 10-year study of on-farm energy budgets on a 150-acre crop and livestock farm in Kansas, USA, the farm used 263 GJ energy per year for its operations and was able to generate 236 GJ of energy supply, about 90% of its operating needs (Bender, 2002). Another 154 GJ of energy was 'embodied' in the various machines and tools when they were manufactured, and the farm could not supply energy for that.

In closing, tree fruit production has clear evidence that it has become more sustainable. These changes can and should be documented, and can provide a baseline for evaluating future changes. Conducting more Life Cycle Assessment studies of tree fruit production would make a useful contribution towards understanding the sector-wide impacts and the variation in impacts by geography, scale, system, etc. These studies can provide key insight into the parts of the system where the biggest sustainability gains can be made, encouraging more research and grower investment to achieve these gains. Eliminating impacts often eliminates waste and improves efficiency; for example, improved soil moisture monitoring can reduce water use, pumping costs, and nitrogen leaching, all of which improve economic sustainability while protecting water resources. Changes in one area, such as social sustainability, can have unexpected benefits in others, such as economic and environmental, as illustrated by the experience at Fetzer Vineyards in California, USA (Dolan, 2003). Sustainability in tree fruit production represents a journey rather than a destination, a journey which orchardists are well prepared to make.

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Table 1. Economics of high density 'Fuji' apple production, Washington State, USA. Based on a 40 ha farm. **(**Schotzko and Granatstein, 2004)

Variable costs	$7350 / ha
Fixed costs	$6867 / ha
Labor	$ 3.12 / box
Total growing + harvest	$10.28 / box
Warehouse costs	$ 7.50/ box
Breakeven	$17.78 / box
Ave. price 2000	$12.75 / box
Loss	$6916 / ha

1995-2002 – price > breakeven in 4 of 8 years

Table 2. Changes in pest management in Washington State apple production.

	Total kg a.i. per year	
Pesticide	1989	2000
Azinphos-methyl (Guthion®)	193,270	117,680
Dimethoate	5,410	0
Malathion	28,820	1,730
B.t. (*Bacillus thuringiensis*)	370	11,090
Spinosad	0	3,000
Practice	% of growers using	
Field monitoring	91	99
Economic threshold	37	92
Use biocontrols	34	81

Table 3. Life Cycle Assessment results for greenhouse gas impacts for apples.

	Author	**kg CO_2e/MT apple**	**kg CO_2e/ha**
New Zealand	Milia i Canales et al.	40-98	2560-4802
New Zealand	Saunders et al.	185	9250
Great Britain	Saunders et al.	272	3808
Europe	Kägi et al.	100-170	3157-5490

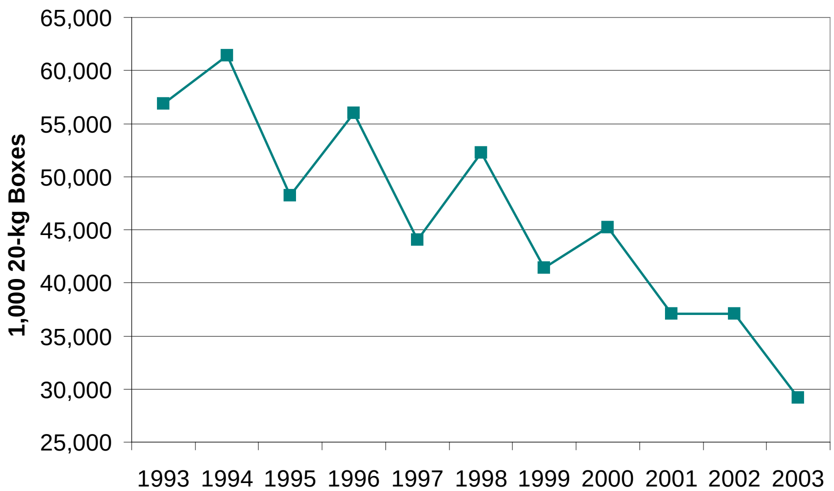

Figure 1. Decline in production of 'Red Delicious' apples in Washington State, USA. Data source: Wenatchee Valley Traffic Association.