IN SEARCH OF A SUSTAINABLE GLOBAL AGRI-FOOD SYSTEM

D. Peter Stonehouse
Department of Agricultural Economics & Business
University of Guelph
Guelph, Ontario, N1G 2W1
Canada
Telephone: 01-519-824-4120, ext. 2204
(Fax: 01-519-767-1510)
e-mail: stonehou@agec.uoguelph.ca

ABSTRACT

The potential to meet global food demand fully exists through global development of the high-technology (HT), high-intensity type of agriculture and food processing system prevailing in developed countries. This system unfortunately is also responsible for much natural resource degradation, environmental damage and ecological imbalance. Meantime the Earth's human population continues to grow, placing ever-increasing demand on global natural resources, not only for food but also for living and recreational space. A more sustainable agri-food system must evolve.

Sustainability is complex, and ought to be approached from a multi-disciplinary perspective and compromise sought in resolving the obvious conflicts amongst biological, environmental, ecological, socio-economic, and other individual disciplines and competing philosophies. These form the basis for comparing three different agricultural production systems: high technology (HT); reduced input (RI), and organic (ORG). The three systems are compared empirically using primary data from farms in each group in southern Ontario, Canada.

HT systems prevalent in Canada is highly productive, but its sustainability is questionable. It was concluded that the HT system should not be the model for the future. The ORG system is the least inimical to the environment, ecology, and human operators. It was concluded that the ORG system is sustainable except for its requirement for extensive use of land. The RI system causes minimal environmental and ecological damage. It is most profitable and is supportive of rural farm community viability. It was concluded that the RI system holds the best potential for meeting overall sustainability for the global agri-food system.

PROBLEM STATEMENT

Much effort has been expended throughout the 20^{th} century on making the global agri-food system more productive. Yet perhaps as many as a quarter of the 6 billion people in the world suffer from malnutrition. This is not to state that we do not have the capability to meet adequate nutritional requirements for the entire world population. Indeed, the high-technology (HT) system of agriculture and food production prevalent in developed countries (DCs) has the capacity to feed satisfactorily many more than 6 billion people, were the HT system to be adopted on a global scale (Waggoner, 1994). The malnutrition problem is more a distributive one, rooted in a lack of purchasing power through insufficient economic development in many less developed countries (LDCs). Inadequate purchasing power prevents the theoretical demand for food, based on reasonable nutritional standards, from being translated into actual demand.

Masked by this question of global food production capacity is a far more troubling question related to system sustainability. The same HT system with its tremendous capacity for food output is also responsible for much natural resource despoliation, environmental degradation, and ecological damage (Napier et al., 1994; Sfeir-Younis and Dragun, 1993; Crosson and Brubaker, 1982). In particular, the Achilles heel of the HT system of agriculture and food processing is its extreme dependence on (depletable) fossil fuel energy resources (Giampietro et al., 1992; Pimental and Pimental, 1979). Thus, the sustainability of the HT system should be questioned on environmental, ecological and energy efficiency grounds.

Furthermore, the profit-driven HT system focuses on short-term economic gains, largely ignores externalities, and engenders an industry structure favouring fewer but larger enterprises. Near-term economic gains will always be preferred over longer-term gains as long as discount rates (based on market interest rates) cause future economic gains, expressed in present value terms, to appear smaller than nearer-term gains (Stonehouse and Bohl, 1990). This is a major factor in discouraging wider adoption and use of many conservation technologies in agriculture (Napier et al., 1994), and in encouraging natural resource exploitation throughout the agri-food system (Paoletti et al., 1993; Sfeir-Younis and Dragun, 1993). Externalities, or the indirect (positive and negative) consequences for the public at large of the activities of the agri-food system entrepreneurs, can be largely ignored because these are not traded in the marketplace, so that the open market supply-demand mechanism does not ascribe any price to them. Natural resource, environmental, and ecological damages wreaked by the HT agri-food system represent examples of negative externalities: their negative values are not included in the price of food that we all buy (Stonehouse and Bohl, 1990; Crosson and Brubaker, 1982). They ought to be, simply because they are an integral part of the cost of doing business in the agri-food industry. We may be able to ignore such costs for the time being, but eventually these environmental and ecological damage costs will have to be accounted for. By continuing to degrade the natural resource base today, we pass on the damage costs to future generations. By maintaining food prices at artificially low levels through exclusion of most negative externalities, the economic sustainability of the HT agri-food system becomes questionable.

A wholesale restructuring of the agri-food industry toward fewer but larger enterprises is a consequence of he profit-driven search for economies of scale, size and scope. This same restructuring causes outmigration of farm operators and labourers, and thereby jeopardizes the viability of rural farm communities. This renders the HT agri-food system questionable on sociological sustainability grounds.

Exacerbating the problem of questionable sustainability are the twin issues of human demographic trends and rising economic expectations globally. Almost all projections point toward an increase in human population to at least 9 billion by mid-21st century. All these people will presumably wish to consume at the rate presently enjoyed by US inhabitants. The extra demands on the global resource base for living room and recreational space, coupled with the need for more food production, will place tremendous burdens on the natural resource base. The challenge facing humankind is to accommodate the aggregate requirements of a burgeoning population in such a way that environmental and ecological integrity remain intact and overall sustainability is achieved.

OBJECTIVES OF PAPER

Given the questionable sustainability of the HT agri-food system prevalent in DCs, as argued above, and the challenges of additional human requirements, alternatives to the HT agri-food system should be investigated for their potential sustainability, as outlined by Ruttan (1993), Edwards et al. (1990) and Daly and Cobb (1989). The objectives of this paper are to:

1. define what is meant here by the term sustainability;
2. define and describe three alternative approaches to agricultural production and food processing;
3. compare these three alternative agri-food systems from the viewpoint of sustainability.

RESEARCH METHODS

It transpires that sustainability of the agri-food system can be interpreted in many different ways, depending on one's disciplinary background, lifetime experiences, and philosophical bent. A careful definition to suit the specific contextual needs of this study would therefore seem imperative.

Defining Sustainability of the Agri-Food System

In order to sustain the agri-food system that supports the human species and ultimately, to sustain the human species itself, a holistic, comprehensive view should be adopted (Stonehouse, 1999). Such a view acknowledges the interdependence among all species of flora and fauna. It acknowledges the need for humans to be good stewards of the natural resource base, environment, and ecological systems of which they are an integral part, so that the human species can, in turn, continue to be supported on an indefinite basis. Whilst it acknowledges the need for on-going economic development to support the rising material living aspirations of a growing global population, it also recognizes that such economic development cannot be open-ended. Provisions must be made for the needs of other species, both those in the wild as part of the natural ecosystem and those involved in our own agri-food system as cultivated and domesticated species.

The definition of sustainability must therefore be sufficiently broad to encompass all inherent perspectives: biological (maintenance or improvement in physical productivity or yields); environmental (protection of the natural resource base and habitat nurturing other species); ecological (preservation of individual species and biological diversity); animal welfare (care of domesticated species in our agri-food system); economic (efficient long-term use of resources); sociological (maintenance of rural farm community viability); medical (maintenance or improvement of human health and longevity); and political (support of and empowerment to the rural farm community to fulfill its multi-functionality role as food producers, landscape managers, resource stewards and species protectors (Figure 1). Given some rather obvious inherent conflicts amongst all these perspectives, careful searching for compromise is critical to obtaining overall sustainability (Stonehouse, 1999).

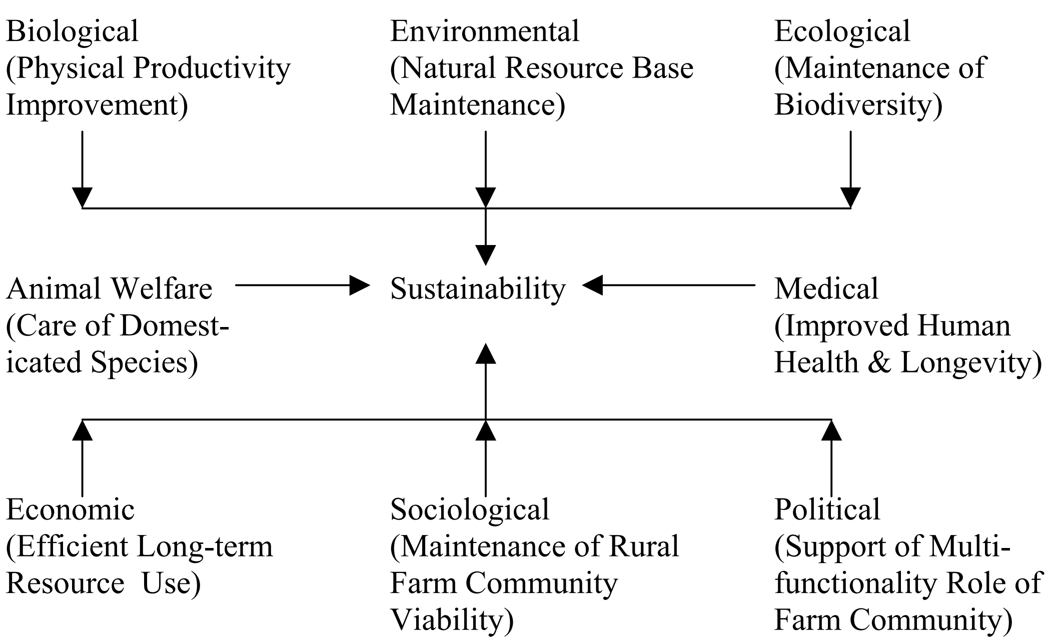

Figure 1: A Holistic View of Agri-Food System Sustainability (Source: adapted from Stonehouse, 1991).

Defining Alternative Farming Systems

A spectrum of alternative farming systems can be contemplated from the extreme at one end of high-technology, high-intensive-resource-use systems (HT) to extensive-resource-use, largely self-contained organic systems (ORG) at the other extreme. ORG systems are also referred to as bio-dynamic, ecological or biological. Varying degrees of resource use intensity/technology level systems lie in between. These might include integrated pest management (IPM), reduced-input (RI), low input sustainable agriculture (LISA), and perhaps other systems.

For this study, we selected HT, RI and ORG farming systems. The HT system is defined as that which depends most heavily on all the latest science and technology, including usage of genetically-modified organisms (GMOs), and which employs most intensively such imported inputs as synthetic fertilizers and chemical pesticides; synthetic feed additives, hormones and antibiotics; etc. Such inputs are applied routinely according to scientific, public sector or manufacturer recommendations.

The RI system is defined as one that also uses all the latest technologies and imported inputs, but at less intensive rates. Farm operators in this system strive to apply imported inputs wherever possible at less than recommended rates. Alternatives to imported inputs might include crop rotations, and increased soil tillage operations, plus greater reliance on one's own livestock for breeding animal replacements and on one's own crops for livestock feeds.

In the ORG system, all synthetic inputs are strictly proscribed, including the use of GMOs, use of sewage sludge on cropland, and irradiation of all food products, according to the national organic standard for Canada established with the financial support and administrative help of the federal government. To supplant the use of synthetic inputs, ORG farmers rely on crop rotations, cover crops, smother crops, cultivations and timing and timeliness of field operations for weed, pest and disease control. They rely on crop rotations, catch crops, plough-down crops, crop residues and livestock manures for soil fertility maintenance. The national organic standard requires all manures to be composted, as a means of stabilizing plant nutrient content and eradicating pathogens and weed seeds. Extensive use is made of pasture grazing and outdoor habitat for maintenance of animal health; otherwise homeopathic remedies are preferred as far as possible to antibiotics and vaccinations.

Comparison Across Farming Systems

The three alternative systems were compared using primary data collected from farms in southern Ontario, Canada. These data included those for as many sustainability criteria as were available. Biological data on rates of resource input usage and crop and animal yields were readily available, as were economic data for product prices and costs of production marketing. Less readily available were data on other aspects. Proxies were used quite widely in place of accurate, scientifically-based measurements, due to lack of sufficient research resources. For example, breeding herd replacement rates represent a good proxy for animal longevity, and veterinary and medicines expenditures for general animal health. Degree of crop coverage of the soil throughout the year and of crop residue left on soil surfaces are a reasonable proxy for soil degradation, especially erosion, and downstream watercourse pollution. Labour inputs in relation to farm size is a proxy for farm community size, and hence a rough indication of community viability. It is acknowledged that many, more accurate measures of sustainability were not available and/or not collected in this study.

RESEARCH RESULTS AND DISCUSSION

Comparison of Farming Systems Based on Size Characteristics

Many anomalies and inconsistencies were revealed by the analyses of the Ontario primary farm data. For example, when dairy farms were compared across farming systems for size (based on land base, labour inputs, or herd size), organic farms were found to be marginally larger, but not statistically significantly so. However, when specialized HT and RI cash-cropping farms were compared for size of land base with organic farms, ORG farms were shown to be significantly smaller (Table 1). It should be noted that, whilst some 42% of HT and RI farms

Table 1: Size Characteristics Across High-Technology (HT), Reduced-Input (RI) and Organic (ORG) Cash-Crop and Dairy Farms in Ontario, Canada

	HT	RI	ORG
Cash-Crop Farms[a] (averages/farm)			
Total land base (ha)	261	215	151
Total tillable land base (ha)	245	195	120
Labour inputs (person equivalents[b])	1.4	1.3	1.8
Market value of total capital assets (Cdn $ '000)	1,372.1	1,109.8	879.6
Dairy Farms (averages/farm)			
Total land base (ha)	108	124	145
Tillable land base (ha)	89	130	121
Labour inputs (person equivalents[b])	2.1	2.1	2.0
Market value of total capital assets (Cdn $ '000)	1,007.8	1,105.6	824.3
Dairy herd size (number of mature cows/herd)	45	46	48

[a]About 42% of HT and RI farms in Ontario are specialized cash-cropping with no livestock; in contrast 100% of ORG farms in Ontario have at least one livestock enterprise

[b]Person equivalent is defined as 3,000 hr. labour/yr

are specialized cash-cropping with no livestock enterprises, all ORG farms have at least one livestock enterprise. Of the farms sampled for this study, 39% were specialized cash-cropping with no livestock. With the exception of dairy and poultry farms, sample ORG farms in Ontario were significantly smaller than their HT and RI counterparts in terms of land base. Dairy and poultry ORG farms require larger land base in order to supply the home-grown feeds to support the livestock output at 100% of the designated market-supply quota level in these supply-managed industries. Failure to fill completely one's quota allocation can lead to forfeiture of the unfilled quota portion, and ORG farmers strive to be as self-sufficient as possible in meeting animal nutrient requirements.

Using labour inputs as a measure of size, ORG farms were larger than HT and RI cash-cropping farms (Table 1). Labour inputs on dairy farms showed very little difference amongst the different farming systems.

In terms of market value of assets, both HT and RI dairy farms were found to be somewhat larger than ORG farms, but significantly larger asset bases on HT and RI farms than on ORG farms were the case outside of dairying (Table 1). Dairy herd size across all three types of farming systems showed no significant differences. Thus, depending on how one chooses to measure farm size, different rankings emerged across the three farming systems.

Comparison of Farming Systems Using Biological and Socio-Economic Characteristics

Depending on the criterion, rankings across farming systems were again found to be inconsistent. Crop yields were highest on RI farms for maize, hay, and autumn cereal grains, but highest on ORG farms for beans (soybeans, white beans, red kidney beans) (Table 2). Crop yields on HT farms were lowest for maize and beans, and second-highest for autumn cereal grains and hay. These findings were consistent with those of other studies, such as Lampkin and Padel, 1994; Goldstein and Young, 1987; and King et al., 1986). Milk yields were found to be similar across farming systems, again corroborating the findings of some other studies (e.g. Lampkin and Padel, 1994).

Economically, ORG farms ranked highest for cash crops (maize, beans, autumn cereal grains) for gross income/ha, followed by RI farms, then HT farms (Table 2). Some of this superior performance can be attributed to the higher unit prices for products received by ORG farms. Rankings were reversed for gross income/cow on dairy farms. Far more significant were the much lower production costs/cow on ORG farms, with RI farms ranked next lowest, in both cases due to reduced expenditures on material inputs plus shipping and application. These lower costs were the principal contributor to the highest gross margins on ORG farms, dairy and non-dairy, followed by RI farms, then HT farms. Overhead costs were also lowest on ORG farms and highest on RI farms, but aggregate net farm incomes ranked highest on RI farms due to the larger scale of operations than on ORG farms. Despite the scale advantages of HT farms leading to highest aggregate gross income ranking, ORG farms earned significantly higher net farm incomes (Table 2).

An important attribute of farm economics, and indeed of all business economics, is the risk loading. Generally the more diversified an operation, the lower the risk loading. ORG farms were shown to be least risky, followed by RI farms, as measured by numbers of crops grown, length of crop rotation, and proportion of farms having at least one livestock enterprise (Table 2). ORG farms also exposed themselves to lower risk loadings through being largely self-sufficient in crop seeds, livestock replacements, plant nutrients and animal nutrients, and through having significantly lower veterinary and medicine expenditures. HT farms had highest risk loadings by being most heavily reliant on imported inputs of all types, and RI farms ranked as intermediate.

Table 2: Biological, Socio-Economics and Enterprise Diversity Characteristics Across High-Technology (HT), Reduced-Input (RI) and Organic (ORG) Farms in Ontario, Canada

	HT	RI	ORG
Crop Yields (average/farm)			
Maize (t/ha)	6.3	7.1	6.6
Beans (t/ha)	2.4	2.5	3.0
Autumn cereal grains (t/ha)	3.5	4.0	2.8
Hay (t/ha)	7.1	8.0	7.0
Milk Yields (average/farm) (l/cow/yr)	5,821	5,877	5,882
Crop Economics (average/farm)			
Maize, gross income ($/ha)	753	865	971
production costs ($/ha)	489	421	304
gross margin ($/ha)	264	444	667
Beans, gross income ($/ha)	646	697	877
Production costs ($/ha)	320	317	308
gross margin ($/ha)	326	380	569
Autumn cereal grains, gross income ($/ha)	528	613	613
production costs ($/ha)	338	269	261
gross margin ($/ha)	190	344	352
Dairy Economics (average/farm)			
Gross income/cow ($)	3,429	3,289	3,031
Production costs/cow ($)	1,970	1,725	1,130
Gross margin/cow ($)	1,459	1,564	1,901
Aggregate Farm Economics (average/farm)			
Total gross farm income ($ '000)	194.0	218.7	179.9
Total production costs ($ '000)	106.6	97.3	87.5
Total farm overhead costs ($ '000)	49.8	41.5	32.7
Total net farm income ($ '000)	37.6	79.9	59.7
Enterprise Diversity & Risk Loadings (average/farm)			
Number of crops grown	4.5	5.5	7.2
Length of crop rotation (yr)	4.2	5.1	7.6
Proportion of sample farms having ≥ 1 livestock enterprise (%)	44	32	100

Comparison of Farming Systems Using Environmental Care Characteristics

Although no direct measurements of environmental care were taken on the sample farms in the study, many farming practices can imply degrees of care. Practices used in this study as proxies for environmental care include a) crop diversity, rotation length, and degree of soil surface coverage; b) inclusion of livestock in farm enterprise mix; and c) composting of livestock manures; d) extent of dependence on imported inputs; and e) labour inputs in ratio to land base. The greater the number of crop grown and the longer the crop rotation, the likelihood is that more effort is being expended on plant nutrient cycling and soil fertility maintenance, whilst degree of soil surface coverage throughout the year, by standing crop and crop residue following harvest, indicates attempts to minimize soil degradation and associated downstream watercourse pollution. Inclusion of semi-permanent crops like pasture/hay in the rotation is particularly indicative of good soil management. Based on the widest crop diversity, longest rotation, and highest degree of topsoil coverage, ORG farms ranked best for Ontario farms, followed by RI farms (Table 3).

Having livestock enterprises reflects attempts to diversify to ameliorate risk and may indicate attempts to recycle plant nutrients through crops used as feeds for livestock, and return of livestock manures to cropland. Much depends on farmers' decisions to break this cycle through exporting or importing nutrients. Environmental care is dependent on having a nutrient cycle with good balance throughout. ORG farms in Ontario transpired to have the best nutrient cycle programme, with an attempt to be self-contained in both plant and animal nutrients (Table 3). RI farms were next best.

Composting of livestock manures prior to land application is considered superior to applying raw manure to cropland because composting reduces bulk, thereby improving transportation economics, stabilizes plant nutrient content, and helps suppress pathogens and weed seeds. All ORG farms surveyed in Ontario composed their manures; none of the HT or RI farms did so (Table 3).

Table 3: Environmental Care Characteristics Across High-Technology (HT), Reduced-Input (RI) and Organic (ORG) Farms in Ontario, Canada

	HT	RI	ORG
a) Crop Diversity and Soil Management			
Total number of crops grown (average/farm)	4.5	5.5	7.2
Length of crop rotation (average yr/farm)	4.2	5.1	7.6
Proportion of year soil covered by crop or residue (%)	72	79	86
Proportion of tillable land in pasture/hay (%)	19	22	39
b) Inclusion of Livestock Enterprises			
Proportion of farms having livestock enterprises (%)	44	32	100
Proportion of animal nutrients from internal sources (average %)	63	78	95
c) Livestock Manure Management			
Proportion of livestock farms composting manure (%)	0	0	100
d) Extent of Dependence on Import Inputs			
Proportion of crop seeds supplied internally (average %)	5	8	87
Proportion of plant nutrients supplied internally (average %)	15	22	91
Average expenditures on synthetic pesticides ($/ha till. Land)	45	29	0
Proportion of tillable land under high-energy-using maize (average %/farm)	42	41	6
Average ruminant breeding herd replacement rate (%)	24	22	19
e) Support of Rural Farm Community Viability			
Labour inputs in relation to total land base (number of person equivalents/100 ha land)	0.95	1.0	1.28

The more reliance is placed on imported inputs, including animal nutrients (for which, see above under livestock enterprises), crop seeds, plant nutrients, synthetic pesticides to control weeds, pests and diseases, and fossil-fuel energy, arguably the greater the risk of nutrient imbalances, natural resource depletion, and environmental damage. In all respects, ORG farms in Ontario reflected greatest efforts to be self-sufficient in all importable inputs, whilst HT displayed the highest reliance on outside sources of inputs (Table 3). It is possible to gleam from livestock replacement rates in ruminant breeding herds an indication of longevity, which may also imply degree of livestock health and well-being. Based on this criterion, ORG farms could be argued to have the best animal welfare ranking.

For viability of rural farm communities, some indication can be obtained from the size of the farm labour force in relation to the farm land base. Higher ratios are indicative of greater viability, as in the case of ORG farms in Ontario. Apparently, ORG farms depended more heavily on labour inputs than HT or RI farms. These last two farm types were, by implication, contributing more actively to a long-term trend in Ontario toward farm consolidation and rural farm out-migration, especially HT farms. This trend generally undermines rural farm community viability.

CONCLUSIONS AND IMPLICATIONS

Given the complexity and extent of the empirical findings, some sort of cohesive summary may be helpful. For each of the sub-components under the sustainability criteria used in this study, namely size (land, labour, capital) (per Table 1); biological, socio-economic and enterprise diversity characteristics (per Table 2); and environmental care characteristics (per Table 3), a simple ranking method was applied to the three farming systems. Highest contributions to sustainability were assigned a ranking of "1", and lowest contributions a ranking of "3" (Table 4). Whilst more top rankings were assigned to ORG farms than to either HT or RI farms, some of the (arguably) most crucial sustainability criteria were top-ranked for RI farms. These crucial criteria included the biological and economic. RI farms were found to be most productive, despite the lower intensity of input usage, as reflected in lower costs, compared with HT farms. Even though ORG farms were ranked ahead of RI farms on environmental care, animal welfare, and sociological grounds, overall ranking for ORG farms was dropped from top position because of their extensive land requirement. This implies a need to cultivate more land globally under the ORG farming system than under a global RI system. With a trend toward rising human population, and a trend toward rising per-capita economic expectations, one should question the adequacy of the global land base to supply food adequately under an ORG system, plus provide sufficient living room for both human and all other species.

Table 4: Ranking High-Technology (HT), Reduced-Input (RI) an Organic (ORG) Farms in Ontario Canada by Sustainability Criteria

	HT	RI	ORG
Size - land base	3	2	1
- labour inputs	2	3	1
- capital	3	2	1
Biological - crop yields	2	1	3
- milk yields	2	1	3
Economics - production costs/unit input (ha or cow)	3	2	1
- aggregate production costs/farm	3	2	1
- aggregate gross farm income	1	2	3
- aggregate net farm income	3	1	2
Enterprise diversity/degree of operation & riskiness	3	2	1
Environmental care - crop diversity/soil management	3	2	1
- inclusion of livestock	2	3	1
- livestock manure management	2	2	1
- imported inputs dependence	3	2	1
Animal welfare - breeding herd replacement rate	3	2	1
Sociological - rural farm community viability	3	2	1

RI farming systems admittedly post higher risks to human operators on farms and to food consumers through chemical residues affecting food safety, as well as to the ecology and environment, than ORG systems. However, these risks can be viewed as reasonably low, certainly compared with HT farming systems. In almost all sustainability respects, HT farms were ranked lowest across the three systems. Therefore a definitive conclusion was to rate HT systems as leas sustainable. High-technology, high-intensity farming systems are not good for the resource base, the environment, or for farmers themselves. The HT system serves much better the needs and goals of the imported farm input suppliers and food processors beyond the farm gate, the moreso if these suppliers and processors are large agri-business corporations.

Given the modest environmental and human health risks of RI farms, plus their top rankings economically and biologically, and reasonably supportive impacts on rural farm community viability, RI systems were concluded most sustainable overall. One final word about ORG systems, with their favourable disposition toward natural resources, the environment and food safety, they are likely not easily adoptable and adaptable for many farmers presently in the HT system. Management demands and philosophical approaches to farming for ORG systems are so totally different from those for HT systems that, for many HT farmers, the differences would prove to be impossibly wide.

BIOGRAPHICAL SKETCH

Born in Yorkshire, England and educated in England and Scotland, Peter Stonehouse emigrated with his family to Canada in 1966. Practical farm work in southern Ontario was enjoyable and healthy, but seemed to hold poor prospects. A return to formal education at the Ontario Agricultural College in Guelph led to baccalaureate and Master's degrees, then a doctoral degree at the University of Manitoba in Winnipeg. Three years' experience with the federal agriculture department was invaluable in discerning how government operates in a democracy. Professional an personal fulfillment have been obtained with 23 years' experience teaching and researching in agriculture at the University of Guelph. Favourite research topic are environmental and ecological economics, and agri-food system sustainability.

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