

Sustainable Agriculture: Interpretations, Analyses and Prospects

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The World Commission on Environment and Development (1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet those of the future". Since that time, much attention has been devoted toward better defining the concept, and developing measures to facilitate its assessment (for example, Daly and Cobb 1989; Liverman et al. 1987). While the permutations are many, the common underlying premise relates to the interdependencies and compatibility among environment, economy, and society.

Agriculture is a globally occurring activity which relates directly and powerfully to the present and future condition of environments, economies, and societies. While agriculture has provided for basic social and economic needs of people, it has also caused environmental degradation which has prompted a burgeoning interest in its sustainability.

Like the concept of 'sustainable development', the term 'sustainable agriculture' has been interpreted and applied in numerous ways. At the broadest level there is some consistency in definition. Most analysts and practitioners would probably accept that sustainable agriculture has something to do with the use of resources to produce food and fibre in such a way that the natural resource base is not damaged, and that the basic needs of producers and con-

The authors gratefully acknowledge the support of the Social Sciences and Humanities Research Council of Canada, the Ontario Ministry of Agriculture and Food, and the Tri-Council Eco-Research Program through the Agro ecosystem Health Project at the University of Guelph.

sumers can be met over the long term.

The general notion that sustainable agriculture is a multidimensional concept which includes environmental, economic, and social components has been expressed in various ways. For example, Crosson (1992) has recently described a sustainable agricultural system as one "that can indefinitely meet demands for food and fibre at socially acceptable economic and environmental costs". The Science Council of Canada defines the concept of sustainable agriculture as "agri-food systems that are economically viable, and meet society's need for safe and nutritious food, while conserving and enhancing Canada's natural resources and the quality of the environment for future generations" (Science Council of Canada 1992). Other definitions or descriptions of sustainable agriculture (sustainable agricultural systems) have identified more explicitly particular elements of sustainability. Francis and Youngberg (1990), for instance, describe sustainable agriculture as a philosophy, based on human goals and knowledge of impacts, which leads to "integrated, resource conserving, equitable farming systems which reduce environmental degradation, maintain agricultural productivity, promote economic viability in both the short and long term, and maintain stable rural communities and quality of life". While such definitions define several ingredients or goals of agricultural sustainability, they also suggest implicitly that they are achievable simultaneously.

Within this general concept, there has been a great deal of postulation, analysis, and prescription about particular interpretations of sustainable agriculture. For some, sustainable agriculture is about field level cropping practices; for others it is an issue of national or global proportions, relating to environmental health or food security. This paper identifies and briefly reviews several of the more prevalent interpretations of sustainable agriculture. We begin by demonstrating differences in approaches which are attributable to what is meant by 'agriculture', to the spatial scale considered, and to the concept of sustainability which is adopted. Four prominent paradigms in the field of sustainable agriculture are highlighted: eco-farming, agroecology, food sufficiency, and social equity. The paper then considers potential impediments or threats to sustainable agriculture in Canada, providing a summary of issues apparent in the growing literature. Methodological challenges in the analysis of sustainable agriculture are illustrated via description of a numerical modelling approach to assessing sustainability from a food sufficiency point of view.

Agriculture

The meaning of sustainable agriculture depends largely on what is meant by agriculture, or how the salient attributes of agriculture are perceived. These attributes range from specific soil - plant relations at the level of the farm field to international trading arrangements and distribution mechanisms for agricultural commodities at a global level (Table 1).

TABLE 1 Meanings of Agriculture by Dimensions and Scale

Dimension	Scale		
	Micro		Macro
Natural Resource Base	field level soil fertility, moisture...	agro-ecosystems, regional land capability...	continental water and land resources, global climate...
Crop Production	field yield, management...	regional production, land use patterns...	global food supplies...
Economic Return	farm level production costs, viability...	regional economy, value of production...	trade marketing, policies...
Rural Community	farm level tenure, family involvement...	rural community size and function, access to food...	global poverty, hunger, equity

For some, agriculture is essentially defined and understood through a focus on plants and the process of plant growth. In such cases, interest centres on the effects of various conditions (for example, soil erosion, climate, pests, etc.) on the rate and vigour of plant development (Biswas 1980). A related, but somewhat different, interest in agriculture pertains to crop production or yield levels (that is, output per unit area). In this case, the health of agriculture is described in terms of the effects of various management practices and environmental conditions on yields. It is commonly held that one of the most noteworthy achievements of modern production agriculture in North America over the past forty years has been the dramatic increases which have been achieved in crop productivity (Dumanski et al. 1986). Much research on agricultural sustainability has addressed the prospects for maintaining or improving current levels of productivity in the face of changing conditions.

Often, the focus of interest in agriculture is not on the biophysical conditions and processes of crop growth, but rather, on the outcomes of these processes (Table 1). Among the obvious outcomes are economic returns to farmers and the production of food. Indeed, the viability of farming as an economic activity, and the ability of agriculture to produce sufficient quantities of food to meet demands represent common definitions of agriculture with obvious implications for sustainability.

For those with a predominantly economic perspective, agriculture is characterized as a enterprise at the level of the farmer or farm business, and an important economic sector at the regional and national level (McEwen 1986; Repetto 1987). In these cases, sustainability is considered in terms of the adequacy of economic returns to farming relative to the costs of production, and of the prospects for continuing economic viability in the face of changing environmental, social, and economic conditions. The perceived threat to agriculture if farms cease to exist for economic reasons has focused attention, in both scholarly research and public policy, on the process of agricultural re-

structuring and the financial well-being of farmers and farming (Buttel 1989; Commins 1990).

Apart from its economic dimensions, agriculture is also viewed -- first and foremost by many -- as a producer of food, reflecting a basic societal benefit from farming. Here, the focus is on the ability of agriculture to satisfy requirements for food and fibre (Table 1). Consequently, agriculture is described in such terms as aggregate levels of production, regional production potential, food quality standards, distribution and pricing mechanisms for domestic markets, and institutional arrangements for the provision of food aid to others (Avery 1985; Smit et al. 1988). In this interpretation, sustainability is associated with the prospects for meeting national and global food needs, the quality and safety of food supplies, the transfer of technology both at home and abroad, and the efficiency and fairness of food distribution systems.

Finally, agriculture is often considered in a more sociological context, as a distinct 'way of life'. Agriculture is not so much defined in terms of biophysical processes, productivity, or economic performance, but rather as an activity which maintains a particular social system, the 'rural community' (Table 1). In this view, the notions of sustainable rural communities and sustainable agriculture are inextricably interwoven (Keating 1991; Smit and Brklacich 1989). The future of rural farming communities has been examined in terms of the survival or demise of family farms, and adjustments in production activities, labour and capital (Ilbery 1991; Lobao 1990; Marsden et al. 1989; Swanson 1988).

All of these perspectives on agriculture represent legitimate dimensions of the broad concept. To a large degree the adoption of perspective depends on the spatial scale being considered (Table 1). Indeed, many of the attributes noted above are only meaningful at particular scales. At the scale of the farm field, 'agriculture' has to do with soil conditions, nutrient levels, water availability and plant growth. At the farm level, agriculture means crop and livestock production, management practices and the structure and viability of farm operations. At a regional scale, agriculture may refer to patterns of land use, aggregate food needs, or the nature of farm communities. At an international or global scale, the same term conjures up questions of trade, equity and food sufficiency.

There have been attempts to integrate these various interpretations and scales of agriculture, both conceptually and analytically. Agricultural systems can be conceived hierarchically as "enterprises, farms, plantations, regional and national agricultures" (Spedding 1979). Conway (1985) adopts this philosophy in describing agriculture in terms of a nested hierarchy of agroecosystems, each possessing characteristics and properties which distinguish it from other levels. Some conceptual models (for example, Bryant and Johnston 1992; Olmstead 1970) focus on the farm as the fundamental unit of agriculture which interacts with physical, economic, social and institutional environments at scales from the local to the global. Other approaches to research on farming

systems incorporate the broader social and environmental contexts within which farming functions (Flora 1992; Turner and Brush 1987). Empirical studies have also recognized linkages among different components and scales of agriculture to study the effects of various shocks or stresses (for example, Kulshreshtha and Klein 1989; Williams et al. 1988). However, despite the integrating framework offered by systems analysis, most empirical research on sustainable agriculture adopts a particular scale and interpretation of agriculture. It is no wonder that there is little agreement on the meaning of 'sustainable agriculture'. There is little agreement on the meaning of 'agriculture', and we have not yet reached the sticky term, 'sustainable'.

Sustainability

The notion of 'sustainability' in agriculture has a number of distinct, and not always compatible interpretations (for example, Douglass 1984; Harwood 1990; Neher 1992; Stenholm and Waggoner 1990). The perspectives reflect a diversity of concerns, interests, goals and opinions about the sustainability of agriculture. Three broad groups of interpretations are highlighted here, relating in turn to the adequacy of food production, the physical environment with which agriculture interacts, and the socio-economic dimension of agricultural sustainability.

Food Sufficiency

One interpretation of sustainability concerns food sufficiency, or the ability of agriculture to produce food in sufficient quantities to meet demands. In the case of the developing world, meeting demands often means meeting basic household or community needs in the short term in order to avoid hunger. In the industrialized world, meeting demands more often means providing both a sufficient quantity and variety of food to satisfy current consumer demands and preferences, and to assure a safe and secure supply of food. Interest is frequently expressed in attaining (or maintaining) food self-sufficiency. This implies not only that sufficient food is produced to meet demand, but also that those food supplies are available from existing or potential domestic production in order to reduce any vulnerability which might be associated with uncertain supply or price shocks (Altieri 1987; Busch and Lacy 1984).

The question of food sufficiency also has a temporal dimension. It is argued by some that a sustainable food production system must not simply sustain current production levels, but must also keep pace with increasing global demands for food. There is concern that continued population increases, and improvements in per capita income in less developed countries will significantly increase world demand for food, and will severely challenge food pro-

duction systems (Crosson 1992; Grigg 1986). Consequently, there is interest in estimating future demand for food as well as the potential for increased food production, in order to assess the prospects for agricultural sustainability. Food sufficiency is a relative concept, based on food production potential compared to present or future food needs.

Environmental Stewardship

Increasingly, the notion of sustainability has come to be associated with the maintenance of environmental quality both on and off the farm. Here a variety of definitions have been adopted.

One notion relates to the effect of agriculture on the productive capacity of land resources. It is commonly held that modern commercial agricultural systems, characterized by intensive tillage and cropping practices, and high rates of mechanization and chemical input use have resulted in excessive amounts of soil erosion and nutrient loss, impairing the productive capacity of soil resources and placing greater emphasis on the use of purchased inputs (Dumanski et al. 1986; Lal et al. 1988). Such systems of agriculture are increasingly regarded as unsustainable. In these cases, sustainability is defined as the preservation of the productive capacity of the land resource.

Another environment-related interpretation of sustainability concerns the effect of agriculture on the natural environment beyond the farm gate and apart from the productivity of cropland. Pollution of surface and ground water resources due to transport of chemical fertilizers from farm fields are two commonly expressed concerns related to sustainable agriculture (Miller et al. 1982; Weinberg 1990). Loss of species' habitat, and reduction in biological diversity are also concerns of those with an ecological orientation toward sustainability. In contrast to the concerns about reduced productive capacity, this ecological perspective on sustainability suggests that natural resources should be protected in their own right, and should not be placed at risk by agricultural activities which are not environmentally benign (Dover and Talbot 1987; George 1990; IUCN 1980).

Economic and Social Concerns

In addition to ensuring long term food production and environmental quality, the notion of sustainability is also applied to producers and rural communities. For many analysts, the sustainability of agriculture can be described by assessing the economic returns to farming. In commercial economies, farms which are unable to generate sufficient profits, because of low farm product prices, reduced yields, higher costs of production, or whatever reason, are not self-sustaining. Consequently, a requirement of agricultural sustainability is the

existence of economic returns which are sufficient to sustain farm businesses, and to adequately reward producers (Brklacich et al. 1991; Ikerd 1990; Repetto 1987).

A somewhat broader interpretation of sustainable agriculture extends the farm viability concept to the maintenance of rural community systems. This view holds that prospects for environmentally benign agriculture which is efficient in its production of food, and fair in its distribution of benefits are greatest when agriculture functions within a healthy rural community system which supports local decision-making and stewardship values (Berry 1984; Lobao 1990).

The notion of equity transcends food, environment and producer objectives, and is frequently adopted as the central characteristic to define sustainable agriculture. For many, the preservation over time of productive capacity, or environmental integrity, or family farming represents a fundamental element of sustainability. Hence intergenerational equity in agriculture refers to the protection of the rights and opportunities of future generations to derive benefits from resources which are in use today. Agricultural practices which diminish long term prospects for food production or impair water quality or other natural resources, regardless of their short term benefits, are not considered sustainable.

Equity concerns are not limited to safeguarding the future of agriculture. The principle has been applied to describe the rights of less advantaged groups in society to basic food supplies, and to the opportunities and resources required to farm in ways which enhance prospects for sustainability (Altieri 1987; World Commission on Environment and Development 1987). Thus, intragenerational equity refers to the fair and equitable distribution of benefits from agriculture among and between countries, regions or social groups. In contrast to the preservation of productive capacity -- a temporal issue -- this second interpretation of equity is a distributional issue.

Paradigms of Sustainable Agriculture

The preceding dissection of the terms 'agriculture' and 'sustainable' suggest why researchers and practitioners have adopted such a variety of interpretations of sustainable agriculture. It is not our intent to propose a universal definition, but rather to show that 'sustainable agriculture' has several quite distinct and legitimate meanings. From this variety we summarize four of the dominant paradigms: Ecofarming, Agroecology, Equity, and Food Sufficiency.

Ecofarming

One interpretation of sustainable agriculture which has received considerable

attention, particularly in North America, is ecologically based agriculture or 'ecofarming'. The term used here describes an approach to farming which seeks to identify and implement management practices at the farm level which minimize environmental impact while maintaining high rates of agricultural production and providing adequate economic returns to producers.

This approach to agriculture (or farming) is variously called Sustainable, Biodynamic, Alternative, Ecological, Organic, Regenerative, and Low-input. Lockeretz (1990) has observed that all of these terms have been used to describe agricultural systems that share some basic goals: "reduced use of purchased inputs, especially toxic or non-renewable ones, less damage to the environment, better protection of water, soil, and wildlife."

One variant within this group, low-input farming, has gained prominence, particularly in the United States, where it is incorporated in the U.S. Agricultural Productivity Act, and widely promoted through the research and extension efforts of the U.S. Department of Agriculture. Interest in a more environmentally benign agriculture has been driven by a growing recognition of the environmental costs of conventional high-input farming, and because of the rapid increase in the cost of those inputs relative to current product prices and low returns to farming generally.

The concept of low-input agriculture shares several objectives associated with agricultural sustainability including: increasing productivity, preserving productive potential and the quality of natural resources, reducing soil erosion and losses of plant nutrients, and increasing farm profits. This approach to farming involves a range of traditional and contemporary management practices to meet such objectives. Edwards (1989) has specified the following as the main components of lower input farming systems:

- fertilizers - dramatic reduction or elimination of inorganic fertilizers with corresponding increases in the use of legumes and forage in rotation, and organic fertilizers;
- pesticides - reduction and eventual replacement of pesticide use with integrated pest management techniques such as rotation, use of resistant varieties, pest forecasting, and biological and cultural pest control;
- cultivation - reducing the amount of cultivation to lessen fossil fuel use, improve soil structure, reduce erosion.

Specific techniques include the recycling of animal manures, use of crop rotations which include legumes, the development of hybrids which respond to lower input levels, and the adoption of modified planting techniques including strip cropping and underseeding. While this package of 'ingredients' suggests a well defined method of practising low-input agriculture, some authors con-

tend that this type of farming, because of its brief (recent) history, its high degree of site specificity, and its potential for reduced profits and increased risk in the short run, is best described as a philosophy or as a 'way of thinking' rather than as method (Schaller 1990; Stenholm and Waggoner 1990). Nevertheless, there is evidence that at least some elements of low-input farming are catching on. For example, significant adoption of soil conservation and other low-input practices, has been reported in Canada and the United States (Coleman and Roberts 1987; Francis 1990; Smit and Smithers 1992).

The increasing interest in low-input agriculture is attributed to two major motivations: concern over environmental problems associated with conventional agriculture, and the high costs of purchased inputs added to already acute economic difficulties in farming. Lockeretz (1990) has suggested a potentially important distinction between these two motivations. While shifts to low-input farming on environmental grounds may suggest a 'sustainable' interest in changing agricultural practices, economically motivated shifts designed to ride out the high costs of inputs and low profit margins may be only temporary.

Agroecology

Whereas the ecofarming interpretation is essentially anthropocentric, agroecology is more ecocentric. It is less about farms and their management practices, and more about ecosystems and their persistence in the face of perturbation or exploitation. Agroecology has emerged as a scientific discipline which defines, classifies, and studies agricultural systems from an ecological systems' perspective, recognizing the close relationship of these systems to surrounding social and economic environments (Altieri 1987). While low input agriculture represents a new direction in the agricultural mainstream, agroecology is something quite different. It might best be described as a research paradigm, or as a way of conceptualizing agricultural production systems, with the focus on principles of ecological systems.

Like low-input agriculture, agroecological approaches to sustainability share interest in the reduction or elimination of external purchased inputs in farming. However, agroecology is more radical in its prescriptions. Low input farming seeks to reduce the undesirable environmental effect of farming and to ensure continued productivity, within the current broad structure of agriculture. In contrast, agroecology is not concerned with maximizing the production of a particular commodity (even through low input methods), but instead focuses on optimizing the ecosystem as a whole, and on ecological sustainability of the production system (Altieri 1987). The approach does not hold as sacrosanct the basic tenets of capital intensive agriculture in the industrialized world, including the dominant role of technology, the structural nature of agriculture (large farms, agri-business, etc.), and the capital relations of production. For example, from an agroecological point of view, private ownership of individual

parcels of land, and hence the fragmentation of natural ecosystems, may be less desirable than some other form of land holding. Alternatively, the optimal species mix required to preserve genetic diversity in some agroecological areas could conceivably include elements which have little or no commercial value, thus imposing a cost to farmers in the form of foregone income. These rather dramatic possibilities place agroecological approaches to sustainability somewhat outside of the 'mainstream' of conventional production agriculture.

The concepts of agroecology are applicable at a variety of spatial scales and contexts. At the level of the farm field, basic ecological processes and interactions are of most relevance. However, ecological principles such as productivity, diversity, stability, tolerance, and persistence help define desirable attributes of agroecosystems at scales from the field through to the sub-continent (Conway 1985; Dover and Talbot 1987; Marten 1988).

Equity

For many commentators and analysts, the key feature of sustainable agriculture relates to distributional aspects of food and resources. The 'equity' theme focuses on the degree to which basic food needs are met among different groups, both over space and through time. The important questions are less about selection of management practices, production potential and such, and more about access to food stocks and the means of production. These are distributional issues, and deal with the moral obligations and rights of current and future generations. In contrast to agroecology, the environment is not an issue in its own right, but is relevant as it influences the meeting of human needs.

As suggested earlier, the equity view of sustainability carries with it two distinct interpretations. Intergenerational equity refers to the preservation of resources and production opportunities for future generations. For many, a fundamental principle of sustainable agriculture is that future prospects for food production should not be compromised, or similarly, that the quality of the natural environment should not be impaired so as to diminish its value to people in the future (Clark 1986; Lecuyer 1987). This view -- the obligation of current generations and the existence of 'rights' for future generations -- has been advanced by Burkhardt (1989), George (1990), and others, and invites questions about the limits to our use of resources, beyond which future prospects for food production, or ability to meet future needs will be harmed. There is considerable debate, and some research, on these questions in light of resource capability and uncertainty regarding future population growth, political conditions, technological progress, and the like (Crosson and Brubaker 1982; Smit et al. 1991).

Intragenerational equity refers to the fair distribution of food, or the means to obtain food (income, technology, land, etc.), among members of society,

particularly those who are most disadvantaged. At a minimum, intragenerational equity refers to the assurance of adequate levels of food to sustain life. This particular interpretation of equity overlaps with the food sufficiency perspective. Aside from limits on the ability to produce food in some regions, inequitable or inefficient food distribution mechanisms have been blamed widely for the persistence of hunger in the world today (Altieri 1987; World Commission on Environment and Development 1987).

Another interpretation of intragenerational equity relates to improvements in the distribution of income from farming in order to free agriculture from practices which are unsustainable. Altieri (1989) proposes that agroecosystem health is in part dependent on the redistribution of opportunities for participation in agriculture. Such widespread involvement is seen by some as a necessary condition for maintaining or expanding rural communities, and for reintroducing labour as an important input to agriculture.

In the industrialized world, lack of access to capital, absence of discretionary income, or high debt forces some farmers to forego environmentally superior farm management practices while other farmers are able to adopt them (Norris and Batie 1987; Smit and Smithers 1992). In the developing world, flexibility in revising agricultural practices is severely constrained by population pressures, institutional barriers, lack of capital, and appropriate technology, and especially the absence of adequate 'food buffers' to permit experimentation. For many farmers in the developing world, the consequences of an unsuccessful attempt to modify agricultural practices are not simply a reduction in farm profits, but also a shortfall in the availability of food needed for family survival.

Food Sufficiency

The food sufficiency perspective on agricultural sustainability considers the overall productive capacity of regions, and particularly their ability to meet basic food needs. Indeed, the provision of adequate food supplies is among agriculture's most fundamental purposes.

A common position on the food sufficiency theme maintains that the world may soon face severe food shortages as population increase races ahead of the current capacity for agricultural development (Burkhardt 1989; Grigg 1986). This concern is not new. One of its early appearances was in the work of Malthus who warned in the early nineteenth century of the fundamental problem of population growing geometrically and food production capacity increasing arithmetically. This concern has appeared periodically since that time, such as in the Club of Rome's report, 'Limits to Growth' (Meadows et al. 1972).

While one response to food deficits would be to stabilize or reduce population in those areas which are unable to feed themselves, the more widely accepted response is to increase food production. Assessments of the popula-

tion carrying capacity of various regions of the developing world have been made by the United Nations Food and Agriculture Organization (Higgins et al. 1982). Comparisons were made between estimated food production capacity and projected population levels to determine whether or not food shortages should be expected. In these studies, maximum population carrying capacity is seen as a function of several factors including population size, nutritional requirements, characteristics of the physical resource base, and the availability of technologies and purchased inputs. Some of these factors relate to the question 'how much food can be produced'? The other side of the question is 'how much must be produced?'.

Current UN population projections indicate a doubling of world population by the middle of the next century before levelling off. The combined effects of rapid population increase, and increased disposable income in the developing world (also an objective of sustainable development, and sustainable agriculture in particular) will lead to dramatic increases in the demand for food. According to Crosson (1992) these two factors alone could increase global food demand 2.5 to 3.0 times by the year 2050. This increase must come either from the expansion of the agricultural land base (which is limited in most countries) or from increases in productivity on land currently available for agriculture. Given the limited physical and economic prospects for greatly increasing the size of agriculture's land base, the importance of preserving existing productive capacity is clear.

The food sufficiency perspective suggests that a sustainable agricultural system must meet the food needs of the population over the long term. The discussion so far has dealt with the global population and hence the world agricultural system. However, food sufficiency can be addressed at finer spatial scales from nations to local communities. Crosson (1992) suggests that "sustainability cannot be discussed without specifying the spatial scale of production units and the possibilities for movement of goods and people among units". While local or regional production systems are often unable to meet their respective demands for agricultural commodities, the possibility of movement of goods and people effectively extends the boundaries of the system, and complicates analyses of food sufficiency.

Food sufficiency is a common theme in discussions of agricultural sustainability in the developing world (for example, Parikh and Rabar 1981; Shafi 1984). In these regions, food sufficiency deals foremost with the provision of adequate food supplies to meet basic dietary needs. However, the concept has also been addressed in the industrialized world, where it is usually couched in terms of food self-sufficiency, at least implicitly if not explicitly (for example, Busch and Lacy 1984). The self-sufficiency theme deals as much with economic security and domestic political strategy as it does with basic food needs. Thus, food self-sufficiency is promoted for such reasons as security of access, improved balance of payments, insulation from price shocks, and the stabilization of rural communities (Baumel and Hayenga 1984; Brklacich et al. 1991).

The four paradigms outlined above illustrate the conceptual diversity which exists in thinking about, and practising, sustainable agriculture in Canada and elsewhere. Ecofarming, or low-input agriculture, and agro-ecology are about farming methods, and the management of production units. The former emphasizes a production-oriented philosophy while the latter stresses ecological balance and environmental well being. The equity and food sufficiency themes, on the other hand, are not about techniques of farming, but rather deal with the protection of natural resource capability, the equality of access to food and economic rewards, and the assurance of adequate food supplies. Each theme implies a different emphasis and a distinct set of analytical questions regarding agricultural sustainability. Yet the various approaches address one or more components of what seem to have become the cornerstones of sustainable agriculture - environmental stewardship, economic viability and human welfare. Resolving incompatibilities among these themes, and among the goals of sustainable agriculture generally, remains a conceptual and analytical challenge.

Sustainability in Canada: Threats and Obstacles

Agricultural sustainability, however interpreted, is threatened by a host of physical, economic, social, political, and institutional factors, many of which have been alluded to already. Widespread environmental degradation in the form of soil erosion, desertification, salinization and contamination or exhaustion of water resources are but a few of the environmental threats to sustaining agricultural systems. Similarly, rapid population growth, lack of discretionary income (or income of any kind in much of the developing world), inefficient mechanisms of food distribution and technology transfer, and inequitable access to land and other factors of production are examples of human forces which threaten sustainable agriculture globally. Increasingly, there is concern regarding the ability of world agriculture to fulfil the variety of objectives which are commonly attached to agricultural sustainability.

There is also apprehension regarding the sustainability of agriculture in Canada as evidenced in recent reports by the Science Council of Canada (1991; 1992). Notwithstanding Canada's agricultural achievements and advantages relative to many other nations, it is widely held that agricultural sustainability in Canada faces a number of challenges. Some are related to the nature of agriculture itself while others arise from the broader social, economic, and physical environments within which agriculture operates. The following are illustrative of challenges to agriculture in various regions of Canada.

Soil Degradation - excessive rates of soil erosion and other forms of soil degradation such as salinization, acidification, compaction, and depleted organic matter, threaten to undermine agriculture by impairing the soil

resource upon which food production depends. These problems have been closely linked to many of the practices associated with conventional agriculture. Excessive tillage, monoculture row cropping, and declining numbers of farms with livestock (hence less forage in rotation) have been identified as common elements of conventional agriculture which have resulted in damage to the soil resource (Dumanski et al. 1986; Science Council of Canada 1986). In some areas of Canada, soil loss has already resulted in reduced yields, necessitating heavier applications of synthetic fertilizers - a trend which most 'advocates' of sustainable agriculture seek to reverse. Although it is often possible to sustain existing levels of productivity through various soil amendments, excessive use of purchased chemical inputs masks the fertility-related consequences of soil degradation and accounts for some damaging off-farm environmental effects, primarily on water resources. It is widely held that success in reducing agriculture's negative environmental impacts will require change in the attitudes and practices of producers and government alike.

Water Pollution - the transport of phosphorus, and other nutrients from cropland contributes to pollution of local and regional water resources, including both surface and ground water. While depletion of the productive capacity of soil is an 'on-farm' threat to sustainability, water pollution from agriculture is, for the most part, an 'off-farm' phenomenon. For example, approximately 70 per cent of the phosphorus input to the Great Lakes has been attributed to agricultural sources (Science Council of Canada 1991). The loss of soils and associated chemicals from cropland results in such impacts as increased eutrophication, damaged fish habitat, diminished opportunities for recreation and decreased storage capacity in water control facilities. Similarly, the contamination of ground water resources by nitrates and other chemicals threatens the availability of local supplies of safe drinking water in rural areas.

Urbanization - non-agricultural activities compete for the use of rural lands. The conversion of agriculturally productive lands to other uses represents a much discussed and studied issue, and affects both the supply (quantity) of land which is available for agriculture, and the character of the environment for farming (Cocklin et al. 1987; Joseph and Smit 1981). Typically, land which is well suited to agriculture is also well suited to many other uses and is frequently situated in close proximity to more heavily populated areas. Indeed, the expansion of urban areas in most of North America has come largely at the expense of land which possesses high capability for food production (Pierce 1990). Between 1966 and 1986, over half of the area taken for urban expansion in Canada was prime farmland (Science Council of Canada 1991). Rising land values, property tax increases, erosion of agricultural infrastructure, the fragmen-

tation of agricultural land holdings, and increased potential for conflict between farm and non-farm activities have been identified as possible consequences of rural non-farm development (Johnston and Smit 1985; Lapping and Fitzsimmons 1982). Given the limited supply of productive farmland in Canada relative to total area (2.5 per cent), it is generally held that the continued conversion of lands to urban uses, and the fragmentation of agricultural areas represent a threat to the prospects for agricultural sustainability.

Climate Change - a number of studies have considered the potential impacts on agriculture from climatic changes associated with accumulations of greenhouse gases in the earth's atmosphere (for example, Parry and Carter 1988; Smit et al. 1989; Rosenzweig 1985). Evidence suggests that predicted climatic change would have a significant effect on agriculture, although the precise nature of these effects would vary widely among regions depending on the magnitude of the change, the antecedent soil and climatic conditions, and the agricultural system in question. Despite the uncertainties, there is general agreement that climate change will manifest itself in the form of warmer drier conditions in the mid latitude regions, and a warmer wetter climate in the higher latitudes (Houghton et al. 1990). Hence the opportunities for agriculture in some areas will be expanded while in others they may be diminished because of the greater incidence of moisture deficiency and extreme events. Some analysts have suggested that the gains in agricultural productivity in the higher latitudes are unlikely to match the losses in lower and mid-latitude regions, resulting in a net reduction of food production, assuming current cropping patterns and technology (Houghton et al. 1990; Parry and Carter 1988). In Ontario, for example, global warming may expand the range of possibilities for agriculture in Northern Ontario (although gains in regional production are limited by the available land resource), while production prospects for major field crops in Southern Ontario may worsen due to increased moisture stress (Smit et al. 1989). In any case, sustainability in light of changing climate may well depend on developments in biotechnology and the adaptability of farmers.

Energy - Canadian agriculture is characterized by its reliance on external energy inputs, largely in the form of fossil fuels. The widespread mechanization of agriculture at the level of the farm, the commercial production of synthetic fertilizers and pesticides, and the transportation and handling of agricultural commodities for trade account for high levels of energy use. In Canada, the agri-food sector accounts for approximately eleven per cent of total energy consumption (Science Council of Canada 1991). While the use of fossil fuels and other 'inanimate' energy sources has dramatically increased the productivity of agriculture over the past several decades,

many now argue that continued dependence on non-renewable energy sources undermines the long term sustainability of agriculture (Pierce 1990). Concern regarding the use of non-renewable energy sources in agricultural operations relates to both the future supply of energy and the environmental consequences of heavy use of fossil fuels in agriculture. In the former case, it is argued that it is inherently 'unsustainable' to attach the long term productivity of agriculture to a depletable resource (Lockeretz 1984; Science Council of Canada 1991). With respect to the latter, the burning of fossil fuels in agriculture is seen to contribute to several environmental problems both directly and indirectly. These include the effects of continued fossil fuel use on global warming, the effects of commercially produced fertilizers on water resources, and the relationship between fossil fuel-fed heavy machinery and various processes of soil degradation discussed earlier.

Economic Uncertainty - economic conditions in agriculture, and in the broader economy, are commonly cited as significant threats to the sustainability of agriculture in Canada (Ashmead 1986; Brklacich et al. 1991; Science Council of Canada 1991). The combination of debt-financed farm expansion and mechanization, low product prices, and the uncertainty of foreign markets has resulted in severe debt loads for many Canadian farmers and increased incidence of bankruptcy. The high rate of failure of farm businesses in Canada over the past decade has led to growing concern over the long term prospects for farmers and farmland remaining in agriculture. These trends threaten to undermine both the food production process and the continued viability of many rural communities which service agriculture.

There are other potential obstacles to agricultural sustainability which vary in their significance among regions. Among the most notable are societal attitudes and values, and various 'institutional' issues such as access to markets and international trading arrangements, the role of tariffs and subsidies in supporting domestic agriculture, the direction and focus of agricultural research, and the nature of government support programs.

Modelling Agricultural Sustainability - The Case of Food Sufficiency

Much of the literature on sustainability, both in Canada and elsewhere, is of a conceptual or prescriptive nature, seeking to define the concept, suggesting performance criteria for sustainable agricultural systems, or proposing actions to promote sustainability. Notwithstanding the importance of clear definitions

in establishing the 'terms of the debate', this work does not, in itself, provide a measurement or assessment of sustainability. Numerical analyses of the sustainability of particular agricultural systems are not common, but their potential is illustrated in the case of the food sufficiency perspective.

One dimension of agricultural sustainability which has been subjected to systematic analysis is the ability of production systems to meet current or future demands for food. Crop productivity models have been used to estimate yield response to environmental degradation in light of various management practices (Battiston et al. 1987; Smit et al. 1988). Regional productive capacity has been analyzed relative to given land resources, climate and management practices (Williams et al. 1988), and relative to changing social and economic conditions (Pierce and Furuseth 1986). At the global scale, production potential has been estimated by integrating calculations of land supply and photosynthesis to estimate dry matter potential (Buringh et al. 1979).

Most of these analyses have focused on measuring current and prospective productive capacity in light of possible changes in the resource base or in management. However, measurement of productive capacity accounts for only half of the relationship implicit in the food sufficiency concept. To determine where food needs can and cannot be met under current and possible future conditions, requires assessment of aggregate production levels relative to demands. Various methods have been used to estimate the extent to which various food production systems approach or exceed target production levels or demands. At the global scale, Higgins et al. (1982) compared productive capacity of broad regions to population estimates in order to evaluate the human carrying capacity of different parts of the world. This accounting approach identified regions, such as in Africa, where food producing potential falls short of human needs, quite apart from internal distributional issues.

Numerical models provide an alternative method of assessing the adequacy of productive potential, particularly under future conditions. Mathematical programming models have been used extensively at both the farm and regional levels to assess allocations of resources, especially land, to meet objectives such as the maximization of production or profit (for example, Wise and Jones 1971). The most common purpose of conventional programming approaches in the agricultural context is to identify optimal allocations, subject to various constraints on resource availability and demands for products. In these cases, the models are prescriptive, and are not structured to evaluate the prospects for meeting food demands, or the sensitivity of food sufficiency to changes in resource conditions.

An alternative use of these programming models is to focus attention on the range of feasible solutions in an agricultural system, and use this as a basis for assessing productive capacity relative to demands, and for evaluating the sensitivity of the system to various biophysical and socio-economic conditions (Smit et al. 1991). This modelling approach directly addresses the food sufficiency perspective on agricultural sustainability. The numerical analysis evalu-

ates the long term adequacy of a regional resource base given selected adjustments to biophysical and socio-economic conditions. A brief review of this analysis serves to illustrate the logic and practicability of such techniques.

The analysis measures the degree to which specified food targets can be met or exceeded given a specified resource base. This 'gap' between demand and supply has been explored elsewhere (Pierce 1990; Pierce and Furuseth 1986), mostly focusing on constraints on the supply side, that is, production implications of environmental and technological conditions. The analytical challenge has been to measure the size of the gap between (future) food needs and (future) production capacity, and to assess the sensitivity of this gap to changes in conditions.

The programming method of Smit et al. (1991) specifies the supply and demand conditions in the form of constraints. Environmental conditions, resource supplies, management practices and associated productivity define supply, while specified food needs or targets represent demands. In contrast to conventional agricultural programming models, the production constraints are designed to permit the specified targets to be exceeded or underachieved by some proportion (p). The solution algorithm then serves an analytical, rather than prescriptive, purpose by identifying the degree to which this proportion (p) can be maximized across all commodities, given the specified conditions. Thus the solution value (Max p) describes the relative capacity of the system to meet the specified food needs. A value of Max p less than 1.0 indicates that it would not be possible to meet the production targets for all the desired commodities, and provides a measure of the deficit. From a food sufficiency perspective, such a system is clearly not sustainable or, more accurately, does not meet a key sustainability criterion in the food sufficiency theme - the ability to meet food requirements. A value of Max p greater than 1.0 indicates that there is some flexibility or excess production capacity or flexibility in the use of resources. From a food sufficiency point of view, such a system is sustainable for the conditions specified.

Of particular interest is how this value Max p varies as conditions change, for example, through reduction in land availability because of urban expansion, or land degradation, or perhaps improvements in production technology. The effects of such changed conditions on Max p, and hence on food sufficiency, are identified by changing the values in the constraints and observing their effects on the solution.

The general model has been implemented for the Ontario agri-food system and has been used to assess the ability of the production system to meet or exceed various food production targets, reflecting alternate projections of population growth and trade (Smit et al. 1991). Recent applications of the model have also examined prospective food sufficiency in light of several issues which may effect the productive capacity of Ontario's agricultural land base. These include soil erosion, acid rain, urbanization, and climatic change.

In a study of the implications of soil erosion for food production, the

evaluation model was used to estimate the effects of 25 years of soil loss on food production in Southwestern Ontario, given estimates of long-term erosion and crop yield response rates (Smit et al. 1988). This analysis suggested that soil erosion by itself did not substantially diminish the regional potential for food production, although soil erosion rates and yield responses did vary considerably throughout the region, indicating that productivity in selected areas may be impaired. Similarly, the model has been used in combination with estimates of the impacts of selected levels of rainfall acidity on crop yields, to investigate the potential effects of acid rain on food production in Southern Ontario (Ludlow and Smit 1987). This study concluded that current levels of acidity in rainfall represent in a \$43 million loss in production, *ceteris paribus*, but that changes in acidity (increase or decrease) would actually allow for a modest improvement of the productive potential of the regional agri-food system.

The effects of land conversion on the productive potential of the Ontario agri-food system have also been examined. Cocklin et al. (1983) estimated the amount of future land conversion, and the agricultural capability of affected areas, for the 30 largest urban centres in Ontario. It was found that most land likely to be converted to urban uses (50,000 to 100,000 hectares) possessed a high capability for agriculture, but the overall productive capacity of the system was only slightly reduced. However, for particular commodities, such as tender fruits, the loss in productive capacity was as much as 15 per cent over 25 year period. Furthermore, subsequent analyses which have incorporated higher production targets owing to population growth conclude that the productive potential of the Ontario food production system may be insufficient to meet future demands and even small losses may be significant (Smit et al. 1991).

Programming methods have also been used to assess the implications of climatic change on food production potential in Southwestern Ontario (Brklacich et al. 1989; Brklacich and Smit 1992). Climatic data were modified on the basis of outputs from global circulation models (GCMs) reflecting a doubling of atmospheric CO₂, and crop productivity models were employed to estimate the response of selected field crops to altered climatic conditions. The programming model was then used to estimate the relative food production capacity levels for the region given base conditions and climatic change. A changed climate in Southwestern Ontario was found to significantly limit opportunities for current types and levels of production. Increased moisture stress associated with a warmer regional climate would reduce average yields for major grains and oilseeds, resulting in a contraction of the productive capacity of the food production system to approximately 87 per cent of current levels (Brklacich et al. 1989).

Taken together these analyses demonstrate the potential contribution of mathematical programming techniques for assessing the productive potential of agri-food systems, and for examining the implications of alternative future

scenarios. While these analyses have been used to isolate the influence of various changes in either the demand or supply-side conditions, the approach also permits examination of the combined effects of various factors in food production environment (for example, Brklacich et al. 1989; Smit et al. 1991). In particular, potential exists to use programming techniques to assess the compatibility of various medium and long term goals regarding environmental quality, food production and farm economic viability. Identification of such relationships serves two important purposes: first, to make the various goals of sustainability explicit and measurable, and second, to identify and clarify compatibilities and tradeoffs among goals thus clarifying the nature of the debate. In addition, programming models of the type described above facilitate the integration of results from previously independent analyses of biophysical attributes of agri-food systems with socio-economic and policy-related research, thereby providing an opportunity for systematic integration of some of the paradigms of sustainable agriculture.

Prospects

This review has explored several dimensions of sustainable agriculture, including interpretations of the sustainability concept, alternative methods of pursuing sustainability in the practice of agriculture, and analytical options for assessing the performance of food production systems in the face of changing conditions. Given the diversity of elements and meanings which exist in the concept of sustainable agriculture, what can we conclude about the prospects for its advancement in Canada? Four key issues are suggested as central to understanding and perhaps achieving sustainable agriculture.

First, the question of who should underwrite the cost of a transition to more sustainable agricultural systems is problematic. Many wish that farmers, in Canada and elsewhere, would adopt farming practices consistent with certain principles of sustainability, including the preservation of the productive capacity of soil and the avoidance of off-farm pollution and environmental degradation. Yet, the literature suggests that the adoption of more environmentally benign farming practices may result in lower yields and foregone income in the short run (and perhaps in the long run). If this is indeed the case, and farmers are asked to shoulder the costs of sustainability alone, then we might expect that changes in the status quo will be slow in coming. However, the benefits of sustaining agriculture accrue not only to farmers, but also to societies generally, now and in the future. Achievement of desired shifts in the methods of agriculture may well require a new definition of the role and responsibilities of both farmers and other members of society in sustainable food production.

Second, sustainable agriculture is not just an analytical question, defined in terms of environmental quality, productivity, sufficiency or whatever, but it is also a philosophy toward farming. By its nature, the concept is goal oriented

and value laden. However, it is unlikely that all goals and values associated with sustainable agriculture will be achievable simultaneously, or even sequentially. For example, should farmers be required, or even expected, to adopt practices which would yield environmental benefits at the possible expense of economic viability? Notwithstanding the value of analytical procedures in providing information, much future action in pursuing agricultural sustainability will be determined by decisions and trade-offs made among and between goals, both individual and societal.

Third, much of the thinking regarding sustainable agriculture has been done in the context of the 'supply side' of the food production equation. Analysts have sought to assess the productive capacity of land, and the impacts of various phenomena in order to measure the potential for food production. While much is now known about the implications of such supply side factors as soil erosion and land conversion, the more important and intractable questions may be on the demand side of agriculture. For example, world population growth, or rapidly increasing demand for food because of improvements in income may have a far greater impact on the ability of agriculture to meet demands for food than do the biophysical limits to production. Consequently, understanding of the prospects for sustainable agriculture globally and in Canada requires further progress in forecasting, and perhaps dampening, future levels of demand. This is complicated by uncertainties regarding population growth, and even more so by several 'wildcards' such as government policies, agreements on tariffs and trade (for example, GATT, NAFTA) which affect access to foreign markets, and the role of regional agri-food systems in supplying food aid in the developing world.

Finally, there is a need to better understand the nature of agricultural system response to perturbations of all types in order to anticipate how agriculture might be effected by various changes in the future. The Canadian agri-food system is not now, and will not be, shaped by singular forces acting independently. Some analysts have begun to consider the combined influence of various forces on the prospects for future production of food. These integrative approaches provide a more accurate understanding of the realities of agriculture's operating environment, and strengthen the accuracy of impact prediction. In addition, the impacts of some forces, such as climatic warming, on the prospects for sustaining food production have typically been predicted with some bold assumptions on how farmers, or the agricultural system generally, will respond to changed conditions. For example, it is often assumed that technological innovation will allow agriculture to continue to achieve high outputs of food, or that farmers operating in an altered climate will know precisely how best to adapt to new opportunities for food production, and that they will do so. In reality, little is known about the processes of response and adjustment in agriculture, particularly at the aggregate scale. Improved understanding of these adaptive processes in agriculture would enhance assessments of agricultural sustainability and improve prospects for achieving it.

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