

# Farms as Ecosystems

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*Organic farming provides ecosystem services as well as food. The weakest points of organic farming systems are limited use of livestock and declining genetic resources. Organic farming has special research and service needs. On-farm experimentation is needed to fully optimize each system.*

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Through the 19th and 20th centuries, the Earth's landscape has been fundamentally transformed. Where we once had nodes of human activity set in a mosaic of natural or quasi-natural ecosystems, we now have a mosaic of human settlements, domesticated landscapes, and fragmented natural ecosystems. At the end of the 20th century, an agroindustrial model is the norm for management of agriculture, and also for residential and recreational lands, silvicultures, and aquacultures. This specialization model separates major components of the farm ecosystem – most notably livestock and crops – for the sake of production efficiency. It substitutes chemical inputs for natural processes such as the return of nutrients to the land, and control of pests by natural enemies.

Although we generally accept that agroindustrial systems have low “ecosystem value,” we still expect that they should not seriously degrade other ecosystems that provide us with non-costed services (Table 1), estimated to be worth at least twice the world GNP (Costanza et al., 1997). In practice, however, with very few exceptions, the agroindustrial systems have proved to be strongly degrading. They are major factors in the non-potability of surface and ground waters, eutrophication of coastal ecosystems, increases in greenhouse gases, loss of biodiversity (Matson et al., 1997; Vitousek et al., 1997) and degradation of the productive capacity of land by erosion, salinization, compaction and loss of organic matter (Lal, 1997). In turn, environmental degradation has led to greater disparities in wealth and social well-being both between and within nations (Vosti and Reardon, 1997).

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Table 1 “Ecosystem services” cited by Constanza et al. (1997)

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1	Gas regulation	10	Pollination
2	Climate regulation	11	Biological control
3	Disturbance regulation	12	Refugia
4	Water regulation	13	Food production
5	Water supply	14	Raw materials
6	Erosion control	15	Genetic resources
7	Soil formation	16	Recreation
8	Nutrient cycling	17	Cultural
9	Waste treatment		

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There is growing recognition that these problems cannot be resolved within the framework of industrial agriculture. A recent study (van der Voet et al., 1997) examined how the European Union might substantially reduce N pollution of the Baltic Sea, the atmosphere and the groundwater. They looked at four options: no import of fodder crops, the maximum reduction of technological emissions, no use of N fertilizer, and no livestock. Only cessation of fertilizer use or cessation of livestock production in their model achieved EU target levels, but those options entailed a large reduction in food self-sufficiency. They proposed a compromise package that included maximum technological emission abatement, 40% reduction in fertilizer use and 50% reduction in livestock production; they predict that it would meet the targets for reducing atmospheric emissions and inputs to the Baltic, but fall slightly short of the desired 50% reduction of leakage of N to groundwater – and there was uncertainty whether reductions much greater than 50% would actually be required. They did not explore the implications of full-scale conversion to organic agriculture.

Kawashima et al. (1997) examined the implications of world population growth and changing consumption patterns on fertilizer demand. They concluded that

fertilizer use would increase approximately threefold by the middle of the next century and that environmental deterioration would inevitably accelerate. Not yet, given serious attention are the potential long-term consequences for agriculture itself from narrowing of the genetic base (Simmonds, 1993), and loss of pollinators due to pesticides and habitat destruction (Allen-Wardell et al., 1998).

Organic farming is a system of management that seeks to increase production, limit the need for inputs, and control pests by intensifying the processes that maintain natural ecosystems (Hodges, 1982). An important benefit of this approach is that it allows a high level of ecosystem services to be maintained such as soil conservation (Reganold et al., 1987) and conservation of biodiversity of insects and herbs (reviewed in Lampkin, 1990). In parts of Europe, organic practices have been legislated or encouraged by special incentives in order to reduce nitrate pollution of groundwater (IFOAM, 1997).

Can organic agriculture offer an alternative on a global scale to industrial agriculture? I am skeptical that any food-producing system can keep up with population growth for much longer, if at all – certainly not without further and drastic undermining of global ecosystem services, and without pushing the population well beyond what is sustainable in the long term. Agroecosystems now occupy 35% of the land area. If we exclude ice, desert and rocks, this number jumps to 48% (Table 2). By fragmentation effects alone, agriculture threatens survival of thousands of species (Dobson et al., 1997).

Domestication of crops and livestock and the growth of civilization as we know it has occurred only in the last 10,000 years and that has been an interval of exceptionally favorable climate. Evidence suggests (Kelts, 1992; Parry, 1978) that we cannot expect the climate to remain so favorable, or even to change gradually. So, although the human species, through sheer numbers, would survive any catastrophe, we are ensured of a steep decline in our population at some point.

However, leaving aside the question of what our ultimate limits might be, I suggest that an objective analysis would show that organic agriculture can produce more food more sustainably than an industrial agriculture. The maximum yield of some crops per unit area may be lower, but other benefits such as greater production from marginal land, greater food chain efficiencies for livestock

production, greater long-term stability and sustainability, fewer detrimental effects on fisheries and aquaculture, and greater access for rural poor – would more than compensate, and there would be less damage to other ecosystems. If we accept this argument – which many farmers and consumers do – then it is pertinent to ask how can we improve the functioning of organic systems so that they can realize their full potential to produce food and simultaneously provide ecosystem services.

I offer three comments on this question.

## 1. The Weak Points of Organic Agriculture

Table 3 lists key aspects of the functioning of organic farms as ecosystems under three “umbrella concepts.” These are general principles or practices that if followed, help to ensure that a lot of other things “go right” on the farm, and that a high level of ecosystem services is maintained. The two with asterisks are ones that I perceive as the weakest points of organic systems currently.

### The Livestock Challenge

Livestock is underrepresented on organic farms in two regards – the first being in relation to the functioning of the farm itself. When the concept of organic agriculture as distinct from a chemically based

Table 2 World land distribution in billions of hectares

Major Biomes	Area		
Desert	1.93		
Tundra	0.74		
Ice, rock	1.64		
Urban	0.33		
Wetlands	0.33		
Lakes & rivers	0.20		
Forest	4.86	..... Plantations	0.15
		.... Other, exploited	0.50
Grass/rangeland	3.90	. Extensive grazing	2.2
		.... On mixed farms	1.1
Crops*	1.4	..... Rainfed	1.2
		..... Irrigated	0.2
Total	15.3		

Sources: biomes – Constanza et al. (1997); forests – Noble and Dirzo (1997); grass/rangeland and crops – de Haan et al. (1997).

\* According to de Haan et al., 1/4 of the produce from cropland is used to feed livestock.

agriculture was elucidated in the 1940s, livestock was seen as an integral component of organic farming (e.g., Howard, 1940; Turner, 1951). We appear to have moved away from that concept, probably because many farmers now adopting organic techniques are beginning with specialized crop production systems. While there are some good examples of stockless organic farms, many farmers in this situation end up adopting some livestock because of the many benefits they offer (Lampkin, 1990; Table 4). This does not mean that livestock must be a

**Table 3 Umbrella concepts for practice of an ecologically sound agriculture**

- 1 Provide N via natural processes, including:
  - use of legumes to provide net additions of N
  - cover cropping to conserve N
  - use of livestock to accelerate cycling
- 2 Allow a high degree of “natural selection in agriculture” to operate in order to maximize site adaptation, and to generate and conserve genetic diversity
- 3 Diversify landscape to reduce runoff, moderate wind and temperature, retain nutrients, purify water, increase biodiversity with benefits for pollination and control of pests by natural enemies

**Table 4 Some major benefits of livestock for ecological farming**

- Ruminants can use “inedible” food (leaves of grass, trees) growing on and protecting marginal land.
- Ruminants and monogastrics can consume culls and other food-processing by-products (using otherwise “inedible” food, producing fertilizer).
- Livestock accelerate cycling of nutrients via production of manure and compost, use of fibrous materials for bedding, distribution of nutrients via foraging activities.
- Land kept in sod for hay and pasture increases soil-building, N<sub>2</sub> fixation, erosion control, carbon storage.
- More diversified cropping options are possible.
- Livestock can be used for weed and pest control.
- Traction options (including rotoation by pigs).
- Conservation of biodiversity of large herbivores

major product of the farm; even keeping a small number for family or neighborhood consumption can greatly increase management options: e.g., on a potato farm, a small herd of beef can consume culls, allow some erosion-susceptible land to be kept permanently in sod, and allow more soil-building options for rundown land (Patriquin, 1991).

Secondly, livestock are underrepresented in relation to global food production: if organic farming is to become a mainstream force, it has to provide more meat and milk; I suggest both to satisfy consumer demand, and to provide models of livestock production that can stand as alternatives to the industrial systems. We particularly need those for hogs and poultry, which are the most rapidly growing sector of agriculture in absolute terms (de Haan et al., 1997; Table 5), and the most ecologically destructive. The provisions of the organic certification codes that deal with livestock welfare (e.g., those of the Organic Crop Improvement Association) are excellent, and should be touted as models for farming at large; however, the codes are generally weak in regard to the integration of livestock into farms.

Although rarely acknowledged, organic farmers have led the way in the development or reintroduction of many sustainable farming techniques that are now more widely used, e.g., cover cropping, various types of

**Table 5 Proportion of world meat production from different production systems and recent and expected growth**

<b>Current proportions</b>			
Grassland		53.9%	
Mixed Farming*		9.3%	
Landless		36.8%	
<b>Recent and expected growth in meat production</b>			
<u>Product</u>	<u>World</u>	<u>Developing</u>	<u>Industrialized</u>
	1983–93	1990–2020	1990–2020
Beef	15%	101–170%	11–14%
Pork	30%	131–225%	12–16%
Poultry meat	45%	126–211%	30–31%

Sources: de Haan et al. (1997)

\* 90% of dairy production occurs on mixed farms.

pest control and mechanical weed control, use of composts. There are many examples to be found on organic farms of livestock at once providing a product of the farm, while helping the farm to function more effectively as an ecological system and doing so without competing significantly with humans for food. Some fine examples of organic dairy, wild boar, and native prairie-based cattle production were presented at the Exploring the Alternatives Conference. Such examples need to be documented and promoted as alternatives to ecologically destructive or inhumane livestock production systems, and emulated and further developed in the way that the crop production component of organic farms has occurred.

Some very relevant theory and scientific data on use of "alternative feeds" by livestock has been presented by Preston and Leng (1987), and Preston (1995). They promote the concept that sustainable livestock production systems should be based on feeds that can be produced locally using available resources, rather than relying on expensive imported concentrates or on high-input cropping systems. They also suggest that a well-designed integrated livestock-crop system would link livestock systems to energy production systems, take into account the role of livestock in providing fertilizer and processing wastes, and consider their welfare and their impacts on the environment.

An integrated, multispecies livestock production system based on these concepts and incorporating many elements of traditional farming in the tropics was developed by CIPAV, a non-governmental organization with headquarters in Cali, Colombia in the late 1980s and early 1990s (Figure 1). The basic strategy is to keep livestock in semi-confinement and revegetate hillsides degraded by extensive grazing with productive perennial crops including sugarcane and leguminous trees, which serve as feedstocks for the livestock. The system makes use of industrial by-products and maximizes recycling within the system. It has proven to greatly increase the production of livestock per unit of land, while allowing the hillsides to regain ecological integrity. Farmers adopt the entire system or components of it, and it has proven to be adaptable to both small and large farms.

## Genetic Resources

Declining genetic resources appropriate for organic agriculture probably represents the single largest impediment to organic agriculture realizing its full potential.

Agroindustrial strategies for genetic improvement emphasize high yields of harvestable crop components, or rapid growth of livestock over other traits, and wide adaptability over local adaptation (Janssens et al., 1990; Preston and Leng, 1987). In crop production, its success has been highly dependent on the use of agrochemicals that modify the growing environment to make it more uniform and predictable from site to site. For livestock, it relies on specific, high-energy diets, use of supplements to guard against deficiencies, and use of drugs to protect against disease. It is an industrial strategy, which maximizes the returns on research and holders of patents or breeding

rights. At the same time, however, it works against the process of natural selection and local adaptation, which is the keystone of evolution in the natural world – a process that prevailed in agriculture until this century, producing a level of diversity approaching that in managed systems. Combined with the new crop breedings, seed production and reproductive technologies, the agroindustrial strategies have led to the control of genetic resources shifting from farmers into the hands of industry. This has resulted in the loss of thousands of locally adopted crop varieties and loss or endangerment of hundreds to thousands of breeds of livestock. The shift is nearing finality with the appearance of genetically modified organisms (GMOs) in the market place.

There has been relatively little concern with the generation and conservation of genetic resources for organic agriculture *per se*, perhaps because organic farming in the modern era has developed during a period when many of the older varieties and breeds were still available. Results from a trial of three traditional and three modern cultivars of oats on an organic farm illustrate this point: all three traditional cultivars but only one of the three modern cultivars were competitive with weeds (Patriquin et al., 1986). Modern high-yielding cereals, selected under chemically managed regimes are typified by shortened stems, reduced tillering and reduced root

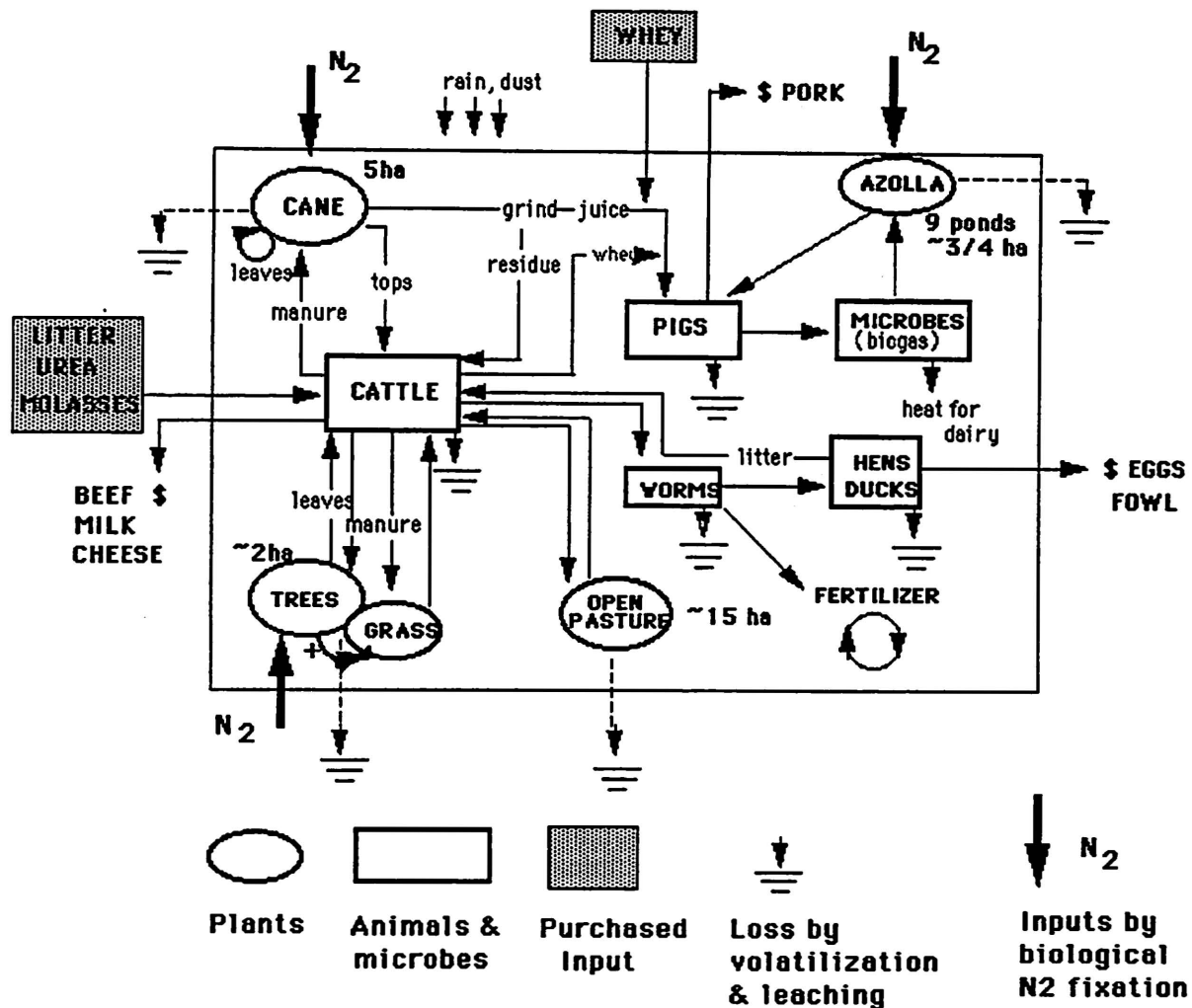
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**Nutrient and Material Flows at Arizona Farm, Colombia (200 cattle, 30 pigs, 30 ha land base) which adopted "CIPAV Technology".**



**Figure 1. Diagram of material and nutrient flows on a farm employing CIPAV technology.** Here is how it works: Sugarcane is grown using manure applied to the plant cane as the only fertilizer. The cane is ground and the juice, with whey added, is fed to pigs. The pig slurry goes into a biogas digester, which produces methane gas used in dairy and cheese operations. The effluent from the biogas digester goes into ponds to fertilize aquatic plants such as *Azolla*. The aquatic plants are harvested to provide high protein feed for the pigs; in the process, nutrients and organic matter are removed from the water. (On some farms, some of the *Azolla* is bled off into ponds to feed fish and ducks.) The cane tops and bagasse (cane residue left after grinding) are fed to cattle, which also receive a rumen nitrogen supplement from multinutritional blocks (urea/chicken litter/molasses) and are fed high protein leaves from trees as bypass protein. The trees include leguminous and non-leguminous species. There is some grazing of cattle in open pastures and under trees. The residues from the cattle operation are worm composted. Worms are fed to laying hens and ducks whose litter is used to make multinutritional blocks, or is applied to cane. The worm compost is used as a high-grade fertilizer. This diagram was prepared by D. Patriquin in consultation with T.R. Preston in 1991 (Patriquin et al., 1993). For more information on this approach, see Preston (1990, 1995), Preston and Leng (1987), and Murgueito (1990).

systems, all of which make them dependent on industrial inputs and poorly adapted to other regimes (Janssens et al., 1990). There is also evidence that modern wheat varieties respond negatively to mycorrhizae (Hetrick et al., 1993), which otherwise can enhance P availability on P-poor soils, and increase resistance to pests and diseases (Allen, 1991). Clearly the needs of organic agriculture are fundamentally different from those of industrial agriculture, and may require very different breeding strategies.

N.W. Simmonds (1993) proposes that we need to broaden the genetic base of agriculture at large. He classifies the use of existing genetic resources into two approaches. The predominant one, which he labels "introgression," involves backcrossing into adapted stocks of a few genomes controlling desired characters; while it has had obvious successes, Simmonds says it does nothing for the local genetic base. Simmonds advocates much more (but not exclusive) emphasis on a second approach that he labels "incorporation" or "base broadening," which covers "the *large scale development of locally adapted populations* good enough to enter the adapted genetic bases of the crops concerned" (emphasis added). Incorporation programs have been applied to only a few crops (notably potatoes, sugarcane and maize), but have been very successful. The incorporation approach is "simple but slow," involving "widely based populations, maximal recombination, weak selection, local adaptation, genetic isolation, quick turnover of generations aimed at producing parental stocks, economy of operation, acceptance of long-term commitment." This last point is a major stumbling block to more widespread application of this approach, which he considers vital to the long-term health of agriculture. Simmonds remarks,

The progressive collapse of publicly supported agricultural research, as declining funds are diverted to biotechnological tricks, beyond potentially useful diagnostics and irrelevant to the genetic bases of our crops is but one aspect of the matter. In parallel, there is no evident reason why commercial plant breeding should, or ever will, support long-term projects which may vastly benefit crop improvement but, being commercially unprotectable, do nothing for company profits. . . . serious genetic resource work, including Incorporation programmes, demands long-term commitment to the interests of our successors, not just to ourselves.

## 2. The Special Research and Service Needs of Organic Agriculture

There are significant differences in ecosystem dynamics between ecologically and chemically managed systems, and these generate different needs and strategies for management of fertility, pests, and weeds, for raising livestock, and, as discussed above, for genetic resources.

Effective management of soil fertility in organic agriculture requires a very different approach from that for a chemically based agriculture, and one that is more system-oriented (Magdoff et al., 1996). For example, if N is limiting for a particular crop, it is appropriate to ask whether there is sufficient N coming into the farm as a whole to support higher yields; if an N budget indicates there is, then the next question to be answered might be, "How do we manage the cycling to relieve this limitation?" The solution might involve making changes in the tillage regime to improve aeration and plant uptake of N (Patriquin et al., 1986), factors that are much less critical when N is applied at saturating levels.

Managing the decomposition process is much more critical to organic farming than to chemically based farming because it is the main venue for supplying nutrients. In addition, nutrients can be immobilized by using microbes growing on nutrient-poor residues to reduce nutrient losses, or to increase N<sub>2</sub> fixation in legumes by reducing soil N (Patriquin et al., 1995). Decomposition processes are highly variable between sites, residue types and management regimes, so there is a need for techniques that can be applied readily on the farm to monitor these processes. Monitoring soil electrical conductivity is one approach (Patriquin et al., 1993). There is a wealth of research in this area; we need means to help us apply it, e.g., through development of diagnostic kits that can be used on the farm for assay of enzyme activities or for measuring levels of particular compounds.

For a period, organic and conventional agriculture seemed to take the same approach to pest control, with emphasis on enhancing control by natural enemies, and selection of resistant varieties. However, the wholesale abandonment of research in this area to private interests dominated by biotechnology companies is detracting from resources available to organic farmers, and threatens to undermine the stability of organic farming systems in other

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*Much could be gained by more interaction between ecosystem scientists and organic farmers.*

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ways, e.g., the incorporating of *B. thuringiensis* (Bt) genes into crops will inevitably generate widespread resistance to Bt, and make ineffective the selective use of Bt spores by organic farmers (Thacker, 1993).

In North America there are few publicly supported academic institutions that pursue more than a token level of research and education in organic agriculture. There is a growing number in Europe. Curiously, there has been a reluctance even within the life sciences to acknowledge the practical and theoretical contributions that have been made by organic agriculture. Discussions of “sustainable agriculture” and “new research” that invoke methods and principles that have long been pursued in organic agriculture commonly make no acknowledgment of that fact. A recent example is provided by a report in TREE (Trends in Ecology and Evolution) on a workshop entitled “Agriculture as a Mimic of Natural Ecosystems.” It concluded with the statement “This meeting and the book which will come from it represent a first bold attempt to come to terms with one of the most important issues facing humanity: how to have agriculture without eroding nature” (Dawson and Fry, 1998). It seems that organic agriculture has to be reinvented within the academic/scientific community to gain credibility in that same community!

These sorts of limitations have not been serious ones to date. They do affect the potential for organic farming to evolve and realize its full biological potential. However, they have little effect on the initial conversion to organic farming, which is still the main way in which organic production is increasing. These limitations will become more important with time. A farmer who has made a successful initial conversion to organic agriculture, and wants to improve its efficiency as an ecosystem, making it economically more competitive, has few resources to draw on – certainly none that are the equivalent of public and private services available to industrial agriculture. At the moment, it is difficult to see how this limitation will be addressed in the North American context.

### 3. The Role of On-Farm Experimentation

Ecological farming systems are characterized by a much higher degree of site variability in the way they respond to management, and to different cultivars and breeds than are conventionally managed systems. While on the one hand this requires farmers to experiment more in order to fully optimize their systems, it also offers a high potential for improvements in productivity and ecological functioning through on-farm experimentation.

Although it may not be thought of as such, establishing a regular rotation of crops on the farm is an “experiment,” and, in my view, a crucial one for organic farming. It is crucial because, when we do not saturate the soil environment with fertilizers or use chemical control agents as needed, the longer term, carry-over effects of different crops become important, and the only way to discriminate those effects and hence to be able to adjust to them, is to observe them repeatedly. A regular crop rotation provides replicates in both time and space. For example, at Tunwath farm in Nova Scotia, after several years, poor oat yields on different fields and years were identified as related to phytotoxic/immobilization effects of residues from the previous crop. The solution was not to change the rotation, but rather the management of residues (Patriquin et al., 1986). Had the crops been rotated on an ad hoc basis, it is unlikely that the limitation would have been identified. (I have since seen evidence of phytotoxic/immobilization effects of residues on crops on many other organic farms, but they are not recognized as such by farmers, though it is sometimes recognized that yields are lower than they would have expected.)

Adoption of a regular rotation does not have to restrict production options. To meet production needs and special conditions on different blocks of land, a farm can employ several different rotational sequences. Also, fields can be taken out of a rotational sequence for a period of time to serve special needs. In either case it is important that they eventually go back into the rotational sequence at the stage they would have been at had they not been taken out (Patriquin, 1990).

There is much that could be gained by more interaction between ecosystem scientists and organic farmers and their organizations. Crop rotations with each phase represented in several different fields constitute an ideal experimental design from a scientific ecology perspective. Organic farms should be attractive to

ecologists as “ecosystem-level experiments”; the boundaries are defined, the practices and histories are documented in the process of applying for certification each year, and most farmers are natural experimenters and want to learn more about the functioning of their systems, even if it doesn’t have immediate, practical value. Organic certification codes, always under review, provide a dynamic, ecosystems-oriented framework that can serve as a basis for farmers and scientists to work together to further develop and test the relevant concepts. Recent advances in ecological theory, in our understanding of processes at the molecular level, in analytic techniques, computer modeling and electronic communication, could greatly assist this process. Hopefully we will soon see such collaboration and move more quickly towards a global agriculture which is at once productive and nurturing of the earth ecosystem.

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# **Exploring Organic Alternatives: Meeting the Challenges of Agriculture, Health and Community**

Based on the proceedings of a conference on organic  
agriculture held in Saskatoon, February 8–10, 1998



University Extension Press  
University of Saskatchewan

**Wordstream**  
*associates*  
*publishing support services*



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Cover design by Eyecatcher Graphics and Design, Saskatoon, SK.

Printed in Canada.

### **Canadian Cataloguing in Publication Data**

Main entry under title:

Exploring organic alternatives: meeting the challenges of agriculture, health, and community

Based on the proceedings of a conference on organic agriculture held in Saskatoon Sask., Feb. 8–10, 1998.

Includes bibliographical references.

ISBN 0-88880-399-0

1. Organic farming – Saskatchewan – Congress

**S605.5.E87 1998**

**338.1'62**

**C99–920181–6**

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# Acknowledgments

We wish to acknowledge the assistance of the following people in coordinating the conference and assembling the proceedings.

- Hart Haidn: co-ordination of the conference
- Perry Millar: manager and coordinator of the production of the book
- Wilma Groenen: copy editing and rewrites
- Michelle Boulton: administrative editorial assistance
- Rapporteurs:
  - Michelle Boulton
  - Chéney Cawkwell
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Publication of this book was made possible through the support of



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