# SYSTEMS FOR SUSTAINABLE AGRICULTURE: APPROACHES, TRADEOFFS AND NEEDS

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*All systems of agriculture practiced today can be seen as having a potential for improvement and contributing toward a more sustainable agriculture. The major differences in approach and in the types of services needed to serve the development of Sustainable Agriculture are between Industrial and Ecological systems rather than between organic and conventional systems (defined by inputs). Support services offered by private and public institutions are adequate for Industrial systems, but not for Ecological systems.*

Sustainable agriculture has been described as a systems approach to farm planning and decision-making.[1] I offer a perspective on the decision-making framework and the tradeoffs involved in managing biological processes on the farm under different approaches to Sustainable Agriculture. By decision-making framework, I refer to the knowledge base and support services and technologies that are drawn upon in making those decisions. Tradeoffs I will consider are those between the goals of Sustainable Agriculture pertaining to the biological functioning of the farm. I will consider those to be high yields, low need for and high efficiency in use of material inputs, minimal adverse effects on human and ecosystem health, and provision of ecosystem services.

## The 3 R's

Stuart Hill and Rod MacRae and others [2,3] thought this out in the 1980s and their concepts are still very relevant. At the turn of the century, we are still talking about what's involved at a very fundamental level in the conversion to Sustainable Agriculture, and about the type of support services required. MacRae et al.[3] described the conversion from conventional to sustainable farming as involving three overlapping strategies or stages: Efficiency, Substitution and Redesign (box 1) or the 3 R's: Reduce, Replace and Redesign. They viewed conversion as an evolutionary, more or less unidirectional change, from non-sustainable to sustainable practices and systems.

**Box 1:**

**Efficiency, Substitution and Redesign (Reduce, Replace and Redesign)**

Transition to sustainable practices involves three overlapping stages: efficiency, substitution and redesign. Of the three, redesign is the most important but has received the least attention. In the efficiency stage, conventional systems are altered to reduce both consumption of resources and environmental impact, for example by banding fertilizers, monitoring pests, optimal siting of crops and fields, and optimal timing operations. In the substitution phase, finite resources and environmentally disruptive products are replaced by those that are more environmentally benign, for example, replacement of non-specific pesticides by biological control. The redesign stage avoids problems by site and time-specific design and management approaches. The farm is made more ecologically and economically diverse, self reliant in resources and self-regulating.

(Adapted from MacRae et al.[3]).

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In the short interval since these concepts were elaborated, there have been far-reaching changes in farming systems, and in the technologies and concepts related to farming.

- It is now generally accepted that "conventional" farming, as we have known it, especially the more industrial forms is highly environmentally degrading.[4]

- The concept of "ecosystems services" has become popularized and quantified monetarily. It is the idea that ecological systems provide essential services such as water purification and a supply of pollinators free of charge and that if we lose those systems we will have to pay to replace them with constructed systems. Globally, the value of ecosystem services provided free of charge is estimated as at least two times the world's GNP.[5]

- There is a high level of awareness about food quality, and a high demand for nutritious, safe food. One result has been the introduction and wide adoption of organic certification codes that make certain guarantees about the types of inputs used to produce food, and that encourage environmentally sound practices.

- There has been considerable response to environment and food issues within the context of "conventional" agriculture both conceptually and in practice. Some of that response has involved adoption of practices that have been maintained or developed by organic agriculturalists in the interim such as the use of cover crops and compost. Some of the response involves divergence in approaches, most notably the introduction of transgenic organisms (GMO's), and some of it involves new kinds of tools that have considerable value for both types of systems, such as computer modeling, and arguably,[6] Precision Agriculture.

- There is far more acceptance of organic approaches within the institutional context, and even more so within business. We are seeing rapid growth of small-scale organic enterprises and at the same time an aggressive pursuit of what could be called Industrial Organics. Like other forms of the new wave of industrial expansion, Industrial Organics are fueled in large part by modern information and control technologies and global trade.

## A matrix of farm types

Thus today, I suggest that it is appropriate to superimpose the 3R's on a matrix of farm system types (Table 1, Figure 1). Each type has some inherent limitations in relation to the goals of Sustainable Agriculture. Other limitations are ones that could potentially be resolved through application of Reduce and Replace strategies. Moving from one system to another involves Redesign.

The matrix distinguishes on the one hand, types of material inputs (Conventional/Organic) and on the other, a management gradient going from Intensive/Industrial to Extensive/Ecological modes. The boundary between Conventional and Organic amendments is sharply defined to correspond to the preciseness of prohibitions for certified organic production and for which all amendments must meet certification standards; on the conventional side, amendments could range from 0-99% organic but would not be 100% organic. Associated with the Industrial/Ecological axis are gradients in the degree to which farms are integrated into and dependent on the landscape, the quantity of inputs, the degree to which cultivars and breeds are locally adapted, and in the reliance on external control agents. The Intermediate category corresponds to farms that include components of both Ecological and Industrial systems. For example, the barn in a dairy farm could operate in Industrial mode, and fields in Ecological mode. Most family farms would probably fall in the Intermediate category.

**Table 1:**

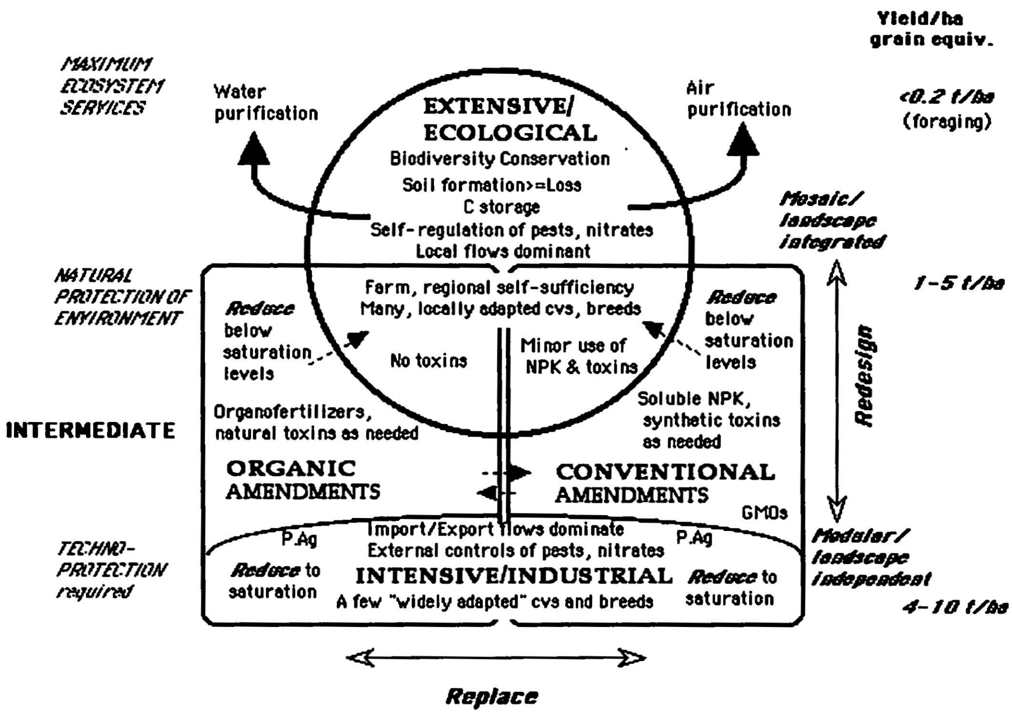
**Characterization of farm systems and the degree to which they achieve 8 goals* of Sustainable Agriculture**

Goal achievement is rated as routine ♦, possible (♦),or inherently not achievable X.
EP: Environmental Protection ES: Environmental Services.

| **Amendments:** <br><br> **Management** | **Conventional Amendments (+/-organic amendments)** | **Certifiable Organic Amendments (only)** |
|---|---|---|
| **Intensive/ Industrial** <br><br> --> Highly specialized <br><br> --> Large input/output flows of nutrients <br><br> --> Widely adapted cvs and breeds (dependent on high inputs) <br><br> -> External control agents | *Goal achievement* <br><br> Production.....♦ <br> Inputs...........X <br> Food Purity...(♦) <br> EP Excess.....(♦) <br> EP Toxins.....(♦) <br> EP Genetics....X <br> ES Diversity...X <br> ES Frag'n......X | *Goal achievement* <br><br> Production....(♦) <br> Inputs...........X <br> Food Purity....♦ <br> EP Excess.....(♦) <br> EP Toxins......♦ <br> EP Genetics....♦ <br> ES Diversity...X <br> ES Frag'n......X |
| ***INTERMEDIATE*** | *Goal achievement a combination of those above and those below* | *Goal achievement a combination of those above and those below* |
| **Extensive/Ecological** <br><br> --> Diversity of crops, livestock and wildlife <br><br> --> Local and internal flows of nutrients dominant <br><br> --> Locally adapted strains <br><br> --> Internal control of pests | *Goal achievement* <br><br> Production...(♦) <br> Inputs..........(♦) <br> Food Purity..(♦) <br> EP Excess.....♦ <br> EP Toxins....(♦) <br> EP Genetics...X <br> ES Diversity..♦ <br> ES Frag'n.....X | *Goal achievement* <br><br> Production...(♦) <br> Inputs..........♦ <br> Food Purity...♦ <br> EP Excess.....♦ <br> EP Toxins.....♦ <br> EP Genetics...♦ <br> ES Diversity..♦ <br> ES Frag'n....X |

*Goals:
Production: High level of production of exportable product per unit area of farm
Inputs: Low levels of inputs/purchased services
Food Purity: Lowest possible levels of agrotoxins and no transgenic components in food
EP Excess: Environmental Protection-Lowest possible levels of nutrients and BOD in effluents
EP Toxins: Environmental Protection-Lowest possible levels of agrotoxins in effluents
EP Genetics: No possibility of transgenic escapes
ES Diversity: Environmental Services-high level of on-farm biodiversity
ES Frag'n: Environmental Services- fragmentation of natural habitat below critical levels for wild species.

**Label Figure 1:**
**Schematic representation of farm system types, their benefits, requirements and application of the 3R strategies (Reduce, Replace and Redesign).**




## Ecosystem services

An Industrial Organic farm in this scheme might be one that makes use of MSW (Municipal Solid Waste compost to support a large export flow, uses intensive monitoring and biological control to control pests and uses a constructed wetland to ensure that excess nutrients and BOD (Biological Oxygen Demand) do not reach waterways. Such farms - although not dependent on ecological processes at the landscape level to the extent that Ecological Organic farms are, make use of ecological processes internally. They also contribute ecosystem services by processing urban and other bulk organic wastes and through sparing effects. Thus they play a vital role in the global ecosystem in an overpopulated and highly urbanized world.

Sparing effects - the concept that if you can produce more food per unit area, less land is needed for agriculture and can therefore be given over to conservation uses - are often cited as a rationale for promoting Industrial Conventional farming. However, as currently practiced, the adverse effects of effluents from Industrial Conventional systems appear to outweigh the benefits of sparing effects.[7] Strategies to reduce negative impacts include ones that are common to both Organic and Conventional systems, e.g. cycling of wastes between specialized livestock farms and specialized crop farms,[8] and use of constructed wetlands or other types of biofilters to purify effluents. Unfortunately, the GMO issue is proving to be a major point of divergence in strategies. GMO's are fundamentally incompatible with Organic and Ecological systems of agriculture.

Costly high technologies and energy inputs are required to ensure minimal waste in the use of resources and to minimize adverse effects on the environment of Industrial farming, whether Organic or Conventional. In this sense, the ecosystem services that are or could be offered by Industrial systems are ones that we purchase, having displaced the natural systems that would otherwise provide those services free of charge. In contrast, Ecological farming systems maintain many of the natural ecosystem services, and thus offer (a largely unrewarded) benefit to society.

No approach to farming can reverse major losses in biodiversity associated with destruction and fragmentation of natural habitats - the human population is already too large for the sustainability of many other species.[9] However, appropriate management at the landscape level and reduction of toxic effluents from agriculture could do a great deal to conserve what we have for the near future as well as to contribute to ecosystem services.[10]

## The framework for Design and Redesign

In Figure 1, I have depicted the design of farm systems as gravitating towards two basic types: toward the industrial pole, a modular, landscape independent design and towards the ecological pole, a mosaic, landscape-integrated design.

The Modular design is one in which individual units maintain a high degree of control over the internal environment and are essentially "landscape independent," i.e., the same design is used regardless of where they are placed. Independence from environment is achieved by saturating the biological response systems, using externally supplied nutrients and control agents as necessary to maintain yields, and in some systems, by controlling temperature, light and moisture. Individual modules are specialized for one or a few products or functions. Hi-tech monitoring and control technologies offer the potential for such systems to be operated with a high degree of efficiency in use of material inputs, and to nearly if not completely eliminate negative environmental impacts exclusive of displacement by the structures themselves (I call this "Techno-protection").


*David Patriquin*
*(photo by Darryl Amey)*

Both Conventional and Organic modular systems may employ "biological modules" to purify wastes (e.g. oxidation ponds, solar aquatics, biofiltering of gases); these in turn may produce other products (heat, combustible gases, soil amendments, food or fiber). Design of such systems makes intensive use of science and technology as practiced today and of external expertise. Industrial Organic systems are more demanding of science and technology than Industrial Convention-al systems because of the additional variables involved in predicting responses to organic inputs, and because of more stringent requirements to eliminate contaminants both within the systems and leaving them. For both Organic and Conventional systems, high capital and maintenance costs tend to produce economies by scaling up the size of operations.

The mosaic, landscape-integrated design involves a very different approach. Rather than displace the indigenous systems, diverse farm operations are integrated into the landscape in a mosaic pattern, and are highly dependent on ecosystem services provided both within the farm boundaries, and by adjacent ecosystems. Because of their site specific nature and largely unknown history, mosaic systems are much less amenable to precise scientific analysis and prediction than are modular systems. Aber and Melilo's comments[11] on application of systems analysis to ecosystems are pertinent:

> *"... in human-made systems, all of the subparts can be described clearly because they have been constructed to particular specifications. This is not true of ecosystems. Often the response of individual components are only dimly known for a fairly narrow set of conditions. So systems analysis of ecosystems is not as clean and precise and is always dependent on accurate measurements and studies by field researchers from many disciplines working at many different levels. In that sense, the analysis of ecosystems is more of a continuing set of approximations, hopefully becoming more complete and accurate as the information base accumulates."*

How then are ecological farming systems designed? In practice, this type of design draws heavily on models and practices offered by traditional farming and on holistic concepts, particularly the concept that farming should use natural systems as models.[12] The conceptual models that have emerged for this purpose during the 20th century were chosen for or focused on different aspects of natural system structure and functioning, which is reflected in the terminology used to describe them: e.g. regenerative-, organic-, biological-, biodynamic-, ecological- and nature-farming; permaculture.[13] Most or all have proven to be success-ful within the context in which they were developed. The resultant farm systems can be very different in the way they are structured and might be considered as "multiple equilibria" or alternative equilibrium states considered characteristic of complex, non-linear systems including ecological systems.[14]

Can these holistic models be considered "scientific"? Smuts regarded holism as non-scientific in itself, but complementary to science.[15] In most cases, scientific interpretations or rationale for these systems of thought, which often incorporate cultural and religious values, can be elaborated, just as biologically adaptive values can be attributed to many traditional belief systems and values. Beyond that, scientific methods, concepts and tools can be used to elaborate the underlying processes in more general terms and make them more readily usable or transferable across different cultural or belief systems. Thus, there has always been a strong effort to incorporate as much science as possible into the precise recommendations and rationale of the certification process.

There is an important further need or function for science and technology in relation to ecological farming: to analyze existing systems and reveal the potential for improvements in yield and consistency of production that might be archived without substantially increasing inputs or reducing ecosystem protection and ecosystem services.[16] The analysis of farm systems in this context is a type of "ecosystem analysis," which incorporates natural history, experimental, comparative, budgeting and modeling studies.[17] University based research programs are the main venue for this type of science. The 1990s have seen a rapid increase in institutionally based research of this nature.

Because of the high degree of site specificity of processes in ecological systems, research conducted at institutions, to be usable, must be complemented by studies and trials on individual farms. Thus, a major challenge is to operationalize agroecosystem analysis so that it can be applied at the individual farm level without having to obtain large grants.[18]

## Support Services

Industrial systems, whether Organic or Conventional, are highly dependent on external expertise and research in the short term and the long term. In general that need is being met by private enterprise or by private enterprise in collaboration with institutions. Ecological systems are not highly dependent on external expertise in the short term, but have a long term dependence on support services, some of which are best provided by public institutions (e.g. non-proprietary breeding programs), and some that are probably more effectively provided by private enterprise (e.g. soil monitoring). Overall, these needs are not being met. Major needs are for recognition of the role of holistic reasoning in design of Ecological farming systems, operationalizing ecosystems analysis for on-farm use, strategies to promote more integration of crop and livestock farming,[19] and strategies and tools to promote natural selection and genetic conservation at the farm level.[20]

## Conclusion

All systems of agriculture practiced today can be seen as having a potential for improvement and contributing toward a more sustainable agriculture. Probably all systems are necessary components of agriculture as long as we maintain our numbers at current levels. However, use of transgenic organisms creates incompatibilities (conflicts) between the different approaches. The major differences in types of services needed to serve the development of Sustainable Agriculture are between Intensive/Industrial and Extensive/Ecological systems rather than between organic and conventional systems (defined by inputs). Support services offered by private and public institutions are adequate for the former, but not for the latter. ✪

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## Speaker Profile

*David Patriquin is professor of Biology at Dalhousie University, Nova Scotia. A marine biologist by training, he became interested in organic farming in the 1970s through his work on nitrogen cycling and out of concern about the degradation of aquatic systems associated with industrial farming techniques. Organic farms are system level experiments in ecology, he says, and getting them to realize their full potential for producing food and nurturing the planet is the ultimate test of our understanding of ecology.*

*He has conducted on-farm research in collaboration with individual farmers and groups of farmers attempting to reduce reliance on agrochemicals or to improve functioning of certified organic farms, and has served as a Certification Agent for several organic farming organizations in the Maritimes and Maine.*

This publication contains presentation given at conferences held in Saskatchewan in 1999 and 2000. In addition several related articles have been used that were not presented at the conferences.

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