

Agroecology: The Ecology of Food Systems

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Abstract

We present a compelling rationale for defining *agroecology* as the ecology of food systems. Our purpose is to provide a framework that will guide research, education, and action in the multiple and interacting facets of an increasingly complex global agriculture and food system. To accomplish such goals, it is essential to build bridges and connections among and beyond our disciplines in production agriculture, as well as beyond the farm gate into the rural landscape and community. Fields of sociology, anthropology, environmental sciences, ethics, and economics are crucial to the mix. They provide additional vantage points from which we can view the food system anew, as well as insights on how to establish valuation criteria beyond neoclassical economics. Examples from Mexico, California, and the Nordic Region are used to illustrate the successful implementation of this educational strategy in universities. Design of individual farms using principles of ecology is expanded to the levels of landscape, community, and bioregion, with emphasis on uniqueness of place and the people and other species that inhabit that place. We conclude that *defining agroecology as the ecology of food systems* will foster the development of broader interdisciplinary research teams and attractive systems-based courses for tomorrow's best students. In contrast to the narrow focus on crop-soil interactions, this definition will help us raise higher-level research questions whose solutions will advance the development of a sustainable agriculture and food system.

Key words: agricultural systems, holistic research, action learning, interdisciplinary studies

Introduction

We define agroecology as the integrative study of the ecology of the entire food system, encompassing ecological, economic and social dimensions. This definition will lead to a practical approach that encourages researcher, educator, and student to embrace the wholeness and connectivity of systems, and will stimulate a focus on uniqueness of each place, and solutions appropriate to its resources and constraints. The definition expands our thinking beyond production practices and immediate environmental impacts at the field and farm level.

Agroecology has been variously defined as the ecology of agriculture, the study of ecological functions in farming, and the marriage of agriculture and ecology. More specifically, "Agroecology is defined as the application of ecological concepts and principles to the design and management of sustainable agroecosystems" (Gliessman, 1998). This concept has captured the imaginations of farmers and academics who are searching for innovative ways to increase productivity and sustainability of agriculture while maintaining an environment that must endure as well as provide quality of life. Short of dealing with the complexity of improving today's food systems, most research projects and university courses – even in agroecology -- focus on the narrow components of agricultural production and their immediate environmental impacts. Such focus does not reflect our expanding vision of how ecology can inform the design and management of the total food system, nor does it build on the ecological foundation that has been used in several educational programs to support the development of sustainable agroecosystems. Study of the ecology of food systems can provide insight on how to deal with questions at the systems level and contribute to development of sustainable societies.

Natural ecological systems have evolved over centuries to take efficient advantage of natural resources. Interacting plant and animal species survive well together in each given environment, including its climate and soils. They provide a model of survival and relative stability on which we can model modern agroecosystems. Natural systems are essentially local, and they are most often biologically diverse. Clues gleaned from natural systems can be blended with attentive human innovations to design future food systems.

Many instructive production practices are found in traditional agroecosystems that represent a co-evolution of culture and nature. The intricacies and potential value of indigenous systems were

studied extensively by the Mexican ethnobotanist Efraim Hernandez X., who defined agroecosystems as the interaction among ecological, technological, and socio-economic factors. He explained why modern agricultural systems have lost their ecological foundation, as socio-economic factors became the dominant driving forces in the food system (described in Hernandez X., 1977). The maize/bean /squash system of Mexico and Central America is an example of biological efficiency as well as contribution to family diet.

In what ways can we recapture the knowledge developed over centuries of traditional agricultural production experience, and link these with the efficiencies of natural systems and with new technologies? Gliessman (1998) suggested that, "The greater the structural and functional similarity of an agroecosystem to the natural ecosystems in its biogeographic region, the greater the likelihood that the agroecosystem will be sustainable." One of our challenges in research is to discover how the principles, the design, and the functions of natural systems can be used as benchmarks or guides to development of productive, future systems (Gliessman, 1990, 2001). The Land Institute in Kansas provides one example of a research scenario based on the prairie as a model ecosystem (Jackson, 1980; Soule and Piper, 1992). Their national network of 125 scientists is exploring how an understanding of natural systems can be used to inform our search for productive future perennial-based agroecosystems that operate in harmony with the environment and natural resources.

When we focus only on the production sector in agriculture, the analysis of current systems and design of future alternatives is severely constrained. Such focus ignores the large investment in energy and materials that are integral to the processing, transportation, and marketing steps in the food chain. In the industrial food system, it is a practical impossibility to reincorporate many of the waste products in this chain back into the production cycle due to distance, cost, and logistical complications. A global system may bring us bananas every day of the year, if we can afford them, but it obscures the principal of seasonality in food production in each place and the cycles that are both inherent and efficient in natural systems. Building on principles of ecology and uniqueness of place, agroecology and analysis of agroecosystems can provide methods for broadening the focus to analyzing all components of the food system and how they interact.

People in Agroecosystems

Our societies are open systems that result from human actions and are based on demands, wishes, and vision. It is essential that we integrate human behavior as an important driving force in the system. Our current system separates most people from their sources of food and from the production environment. In current urban culture, food may be the only remaining connection to nature. This separation and lack of awareness of how and where food is produced and processed contribute to people's decisions to consume fast food while discounting the importance of health as well as other human and environmental impacts (Nestle, 2002; Schlosser, 2001). In addition, the global food system does not currently provide adequate food to the tables of the majority of people on the planet. We must consider global equity in terms of nutrition, health, and food security. A broader, interdisciplinary focus in agroecology as the study of food systems will help us identify the real human costs and benefits of the current system and help account for what are often considered externalities, both in the short and long terms. These issues are already being addressed through the Common Agricultural Policy (CAP) of the European Union, where emphasis is placed on multifunctional landscapes including cultural values in each location.

With increasing global human population, there is growing awareness of the need to increase food production while protecting biodiversity and the natural environment. Humans have the opportunity and responsibility to evaluate food systems in new ways, to recognize the need to balance the system with available resources, and to accept a moral obligation to manage outputs from the system in an equitable manner. When people are viewed as an integral part of the ecosystem, subject to all the natural laws and consequences of system success, there is a compelling reason to make agroecosystems as sustainable as possible for the long term. Beyond our current disruptive power in the ecosystem, we are capable of designing systems that close nutrient cycles, depend more on renewable energy, reduce inefficiencies in production, and promote environmental health. We can meet our goals by using some system design principles and properties that resemble those of natural ecosystems.

In this context, agroecology has appeal because it helps us focus on structure and processes at each

relevant systems level. Careful study can lead to better analyses of the sustainability or potential negative long-term environmental impacts of current agricultural practices and systems. There are growing concerns by the public, often expressed through regulations, that lead to requirements for agricultural practices that will reduce the loss of soil and nutrients from fields and minimize the entry of pesticides and their residues into surface and groundwater. Learning more about the cycling processes and designs of natural systems can help us improve managed agroecosystems. Up to the present, the focus in agricultural science has been primarily on components of the production process, and maximizing net returns of single products per unit of land or labor. All other resource use and environmental effects have been considered "externalities," and have been excluded from system design. The production focus is also reflected in design of most current agroecology courses.

The agricultural system is an open system, interacting with nature and with society, and the development of a sustainable food system will require more attention to the efficiency of the entire process of converting natural resources to what reaches consumers' tables. This includes analysis of food production, processing, marketing, and consumption. When agroecology is defined as the ecology of food systems, we are obligated to look at more than the efficiencies of resource use in production, the short-term environmental impacts of practices, and annual enterprise economics. Most of the energy (perhaps >75%) in the food system involves steps after the field production process (Johansson et al., 2000). We need to consider the energy used and waste generated at each step in the food chain, the potentials for cycling materials back into primary production, and the emergent properties of a complex system that is basic to human survival. We need to employ such tools as materials life cycle analysis (Audsley et al., 1997), emergy analysis (Odum, 1996), environmental footprint calculations (Wackernagel et al., 1999), and alternative economic and other valuation schemes (for review see Doherty and Rydberg, 2002). Beyond looking at only the energy and materials flows, we must consider other driving forces in the system such as economics at the farm, national, and global levels, the environmental consequences of systems on all plant and animal species, and the social and health impacts of systems on people. An interdisciplinary, integrated approach is essential to adequately address the complexities of interactions in the total food system (Allen et al., 1991).

Evolution of the Agroecology Concept

Gliessman (1998) traced the history of agroecology to the early part of the past century when people in ecology and agronomy found common interests. The area of crop ecology included scientists exploring where crops were grown and climatic conditions where each was best adapted. Some proposed using the term *agroecology*. Both early and recent publications using this term and related concepts are shown in Table 1 (based on Gliessman, 1998).

These publications date back to the linking of the terms ecology and agronomy in Klages' 1928 article "Crop Ecology and Ecological Crop Geography in the Agronomic Curriculum." Gliessman describes how groups of scientists diverged after World War II, with the ecologists giving more focus to experiments in the natural environment and agronomists dedicating their attention to cultivated systems in agriculture. This separation of interests endured until the 1970s when books and articles began to appear using the term agroecology and the concept of the agroecosystem.

There were many indications from this new generation of authors that agroecology would evolve to include more than the biogeochemical environment and the crops grown there. Gliessman (1990) described the pioneering work of Prof. Efraim Hernandez X. and his students in Mexico who developed research based on indigenous systems and knowledge, and how this led to education programs in agroecology (Hernandez X., 1977; Gliessman, 1978). In *Agroecología del Trópico Americano*, Montaldo (1982) suggested that biological problems in designing agricultural practices are inseparable from the socioeconomic context in which agricultural systems are used.

In *Sustainable Agriculture and Integrated Farming Systems* (Edens et al., 1985), there were sections devoted to economics of systems, ecological impacts, and ethics and values in agriculture. These supplemented the expected papers on crop/animal integration, levels of input use, and marketing alternatives that dominated the proceedings. Altieri (1985) discussed pest management in the context of a changing structure of agriculture, including consolidation of farms, planting of monocultures, and how these impact pest populations. Gliessman (1985) added that "Socio-economic, technological, and ecological components constantly interact, creating a complex feedback mechanism that through time has selected for the types of food production systems that we observe

today." These agroecologists laid the foundation for what has become in some programs a comprehensive study of the food system. Parallel to this development was the emerging literature on agricultural systems (e.g. Spedding, 1979, 1996).

The terms and concepts in Table 1 are limited to use of the term agroecology, and only touch on the closely related publications and strong growth in education and research in sustainable agriculture during this same time frame. An overview of the modern historical development of sustainable agriculture by Harwood (1990) described how an evolving resource base, social values, and market structure were causing us to move from the current industrial model to something both qualitatively and quantitatively different. This included a stable number of people in production agriculture, a growing number in food services, a shift from specialization toward enterprise integration, a change toward more biological processes, and a quantum increase in social and environmental considerations that influence public investment in the food system.

Conway (1985) articulated the importance of basing agroecosystem analysis on interdisciplinary study, using real farm cases in a workshop setting. The process leads to "a set of agreed key questions for future research or alternatively a set of tentative guidelines for development." Bawden (1991) pointed out that appropriate natural science approaches such as farming systems research and agroecosystems analysis can be enriched by social science methods that explore the cognitive issues in farmer decision making.

There are close links to economics, to structure of agriculture, and to ethical issues in food systems in the subsequent literature on sustainable agriculture. For example, Coscia (1993) described the ethical or moral obligation of each generation to preserve natural resources not used by their ancestors and to provide at least the same opportunities for their children and for succeeding generations. A practical series of field guides for farmers and students began with *Michigan Field Crop Ecology* (Cavigelli et al., 1998), a set that will soon include a volume on social/political linkages and the social contract. *Interactions between Agroecosystems and Rural Communities* (Flora, 2001) illustrates the rise in awareness of connections to the human community and human capital. Integrative thinking is central to the current writings in sustainable agriculture, and those involved in teaching agroecology should be aware of new research and education programs in this related arena.

The importance of interdisciplinary approaches and incorporation of social systems methodology into research and education is summarized by Dalgaard et al. (2002). In their paper, a compelling case is made for broadening the application of ecological principles using a hierarchy of scale to understand complexity in the production system. This approach is similar to that used by Gliessman (1998). Agroecology is suggested as the logical discipline to integrate across disciplines and different levels of scale. Natural science methods can be used to describe the decision-support tools that will inform design of ecologically sound agriculture, while social science methods can be used to integrate human dimensions and help us better understand the total system.

Texts and Resource Materials

The text *Agroecología del Trópico Americano* (Montaldo, 1982) was published by the Interamerican Institute for Agricultural Cooperation (IICA) and made widely available through their offices throughout the western hemisphere. Courses in Italy, especially in the University of Tuscia in Viterbo, have used the text by Fabio Caporali (1991), *Ecologia per L'Agricoltura: Teoria e Pratica*, for the past decade. They primarily deal with the production process and blending agriculture with ecology.

Writings of Miguel Altieri during the past two decades (e.g. Altieri, 1983, 1987; Altieri and Hecht, 1990) reflect a strong concern about the equity issues in agriculture. In his research, teaching, and graduate advising, Altieri has integrated the social concerns of farm scale, agricultural labor, and equity of benefits into the technical studies of IPM and integrated farming systems. The text by Gliessman (1998) is probably the most widely used in the U.S. at this time, and his edited reference volume is widely cited in the literature (Gliessman, 1990). He has also published a field and laboratory manual for teaching agroecology (Gliessman, 2000). The book series edited by Clive Edwards and published by CRC Press provides additional background and insight on many dimensions of agroecology (for example Buck et al., 1999; Collins and Qualset, 1998; Flora, 2001; Gliessman, 2001).

Courses and Curricula in Agroecology

Agroecology has its foundation in both ecology and in production agriculture, as well as a number of other specific disciplines. Therefore the development of educational programs depends in large part on the components that are already well known and included in many courses in the conventional curriculum. Agroecology, the ecology of food systems, provides a platform for the integration of numerous and complex elements of the system with the objectives of understanding the structures and functions of systems, how to improve their design for more sustainable, long-term production, and integrating goals for security and equity in food for the future. Education must shift emphasis from teaching how to maximize production of a single crop in a decontextualized environment with unlimited access to fossil fuels, toward a food systems level where the natural environment and society are recognized in all their complexity. We find it increasingly important to link methods from natural and social sciences in designing education to meet these goals.

Programs in Mexico: The importance of the ecological foundation of agriculture has long been the emphasis of educational programs for several undergraduate and graduate programs in Mexico. At the beginning of the 1970s pioneering studies at the National School of Agriculture in Chapingo (UACh) focused on the traditional agriculture of Mexican *campesinos* (peasant farmers). Graduate courses in ethnobotany developed the ideas that led to a national meeting "Agroecosistemas de Mexico" in 1976 (Hernandez X., 1977), and a subsequent call for courses in agronomic institutions country-wide that addressed the ecological, economic, and social issues facing Mexican agroecosystems and farmers. This approach was reviewed in a series of collected publications (Hernandez X., 1985, 1987).

The Ecology Department of the Colegio Superior de Agricultura Tropical (CSAT) in Tabasco offered courses in ecology, agroecology, and tropical agroecosystems, emphasizing the values of traditional agroecosystems (Gliessman, 1978). Classroom and laboratory learning were applied through a semester of full-time residence in a local farming community, showing students how an agroecological approach could link the ecology of food systems with the socio-economic reality being experienced by farmers. Agroecology in a cultural context was provided by the Graduate Program in Anthropology at the Universidad Iberoamericana in Mexico City (Gonzalez Jacome and Del Amo, 1999).

After an intensive short course in tropical agroecology in 1989 at the Colegio de Postgraduados in Tabasco (the former CSAT) and an international symposium on agroecology in 1990 (Ferrera-Cerrato and Quintero L., 1993), a Department of Agroecology was formed and a full curriculum inaugurated in 1991. Emphasis is on ecologically-based production processes and practices, with additional required courses in economic, social, and cultural components of sustainable agriculture. In ten years, 130 students have graduated and become the catalysts of agroecology programs and curricula throughout Mexico.

Program at University of California Santa Cruz (UCSC): The first course devoted specifically to Agroecology at UCSC was offered in 1981 as part of the Environmental Studies Program, and shortly thereafter the Agroecology Program (now Center for Agroecology and Sustainable Food Systems) was initiated. A primary goal of the course has been development and monitoring of indicators of agricultural sustainability. A concern for incorporating economic and social dimensions of agricultural production systems is reflected in the last chapter of *Agroecology*, titled "From Sustainable Agriculture to Sustainable Food Systems" (Gliessman, 1998). Students are encouraged to venture beyond the conventional economic bottom line to consider impacts of agriculture on the broader environment, the influence of agricultural policy, and the complications of how short-term thinking and decisions influence long-term system performance. Food system sustainability is viewed as more than reduced pesticides and chemical fertilizers, but rather as involving equity of outputs and benefits and how alternative systems affect diet and health.

The Agroecology and Sustainable Agriculture emphasis in Environmental Studies at UCSC has expanded and flourished. Courses have been added that promote ecologically-based methods of pest and disease control, as well as resource-conserving approaches to the design of production systems. Other courses promote awareness and incorporation of the economic, social, and cultural aspects of agroecosystem sustainability. Field internship experiences in agricultural communities are offered as part of the program.

We speculate that introducing agroecology into agricultural curricula is a large challenge to many conventional, discipline-oriented, reductionist scientists and educators. Agricultural specialists are more comfortable dealing with components of systems, simple cause-effect relationships, and questions that can be answered by standard experimental designs (Francis et al., 2001). Agroecology must involve interdisciplinary approaches, and these threaten the autonomy and budgets of our disciplinary departments. It is intriguing to observe the development of agroecology at UCSC in a non-landgrant, liberal arts university.

Nordic Model for Agroecology: A broad definition of agroecology is used to define courses in NOVA University (Francis et al., 2001; Lieblein, 1997; Lieblein et al., 1999, 2000). The courses "challenge the conventional metaphor of the food chain with its one-dimensional, linear linking across the components. In contrast a local program emphasizes the whole network of ecological (energetic and material), economic, and socio-cultural (roles of actors, information, communication) linkages 'vertically' from production to processing, to markets, and to communities consuming the goods, and their interdependence" (Francis et al., 2001).

The NOVA regional working group in ecological agriculture sponsored a series of courses titled "From Farming Systems to Food Systems" (Lieblein, 1997) that centered learning on student activities in the field, exploring and describing natural resources, production practices and potentials, processing, marketing, and consumer concerns in the Hedmark region of south-central Norway. A description of these modular courses is found in Lieblein et al. (1999). In these courses, we have applied principles of action learning as summarized by Schubert (1995). The NOVA working group is presently directing a regional research and education project, "Improving the Nordic Region Education in Agroecology." The goal is to develop an agroecological didactic for the region (Lieblein and Østergaard, 2001).

The current NOVA University MSc program in agroecology is designed as a two-year curriculum including a practical thesis project. Study includes courses in *Agroecology and Farming Systems* and *Agroecology and Food Systems* in Norway, and *Adaptive Management* in Sweden. In general, these courses 1) establish their focus at a systems level on farms and in the wider landscape, 2) look on systems in an interdisciplinary way – integrating natural and social sciences, 3) handle the system as open and interacting, and 4) use experiential learning as a pedagogical base for understanding complex systems and action learning as the starting point in the field. Using ecological agriculture and food systems as an alternative to the current system, they develop visions for a future, sustainable food system and action plans for how to get there. The courses use ecological agriculture as a case study approach because of its growing importance in Europe and elsewhere.

Integration into the U.S. Mainstream

Altieri and Francis (1992) explored how agroecology could be integrated into the mainstream agricultural curriculum in our landgrant system, urging educators to include topics linking production systems to economic, cultural, and political systems, and to study how policy can strongly influence practices and impacts of agriculture.

Today courses in agroecology are most often found in departments of agronomy or biological sciences and emphasize ecology of production. They focus on the ecology dimensions if taught by an ecologist, or on production details if taught by an agronomist. They not only reflect the backgrounds and disciplines of those doing the teaching, but also their departments and the students who are attracted to the courses. Several examples are listed in a compendium of educational materials (King and Francis, 1994).

At University of Nebraska, *Agroecology* is a capstone course in the Department of Agronomy and Horticulture. Its emphasis on the grassland ecosystem of the Great Plains features structure and function of the prairie, climate and weather, and comparisons of natural and managed ecosystems. Food processing and alternative local marketing systems are compared to the global food system. *Agricultural Ecology* at University of Maine uses rapid rural appraisal within the broad social context of systems. Use of indigenous ideas, biodiversity, pest management, and cover crops are specific topics, while industrialization, policy, and human ethics and values make this one of the most diverse courses now available.

Iowa State University (ISU), University of Minnesota, and University of Nebraska offer

Agroecosystems Analysis as a summer travel course that uses farm visits to provide a basis for analysis of production, economics, environmental and landscape impacts, and social viability of alternative practices and systems (Wiedenhoft et al., 2002). ISU also initiated new MS and PhD programs in sustainable agriculture in Fall 2001. *Agroecology* is a new course at North Carolina State University that will be part of a proposed interdisciplinary minor. In the eight-week residential course *Experiential Learning in Sustainable Agriculture* lectures are supplemented by hands-on experience in production, marketing, extension, and research in the field. This course includes a week that focuses on integrating societal dimensions of sustainable agriculture.

These courses are heavily directed toward the ecological processes in specific cropping patterns and the comparisons of conventional and alternative agriculture. They include economic and ecological impacts of systems as well as attention to the social impacts of systems on families. In only one course is agricultural policy featured as a major topic in the schedule. The courses illustrate current offerings in agroecology in U.S. universities, and they include limited treatment of the complex steps of processing, marketing, and consumption of food that lead to inefficiencies and costs of the global food chain. Likewise, there is uneven attention devoted to the multiple and complex issues of biological production, economics at different levels of geographic scale, and driving forces such as new biotechnologies, capital mobility and global markets, and eventual pressures due to inequities in distribution of benefits. Defining agroecology as the ecology of food systems will help to broaden the educational perspective in future courses.

Closing the Loop: Educating the Consumer

Agroecology needs to involve all parties, from scientist to producer to processor to marketer to consumer, if the goal is to base our food system on scientific foundations that can handle complexity and change. Although much of the groundwork for programs has been laid, a direct consumer involvement is most often missing. Only by closing such a loop by including the consumer will the agroecological cycle be completed. In particular, we need to get the attention of both urban and suburban consumers. Those of us with experience teaching undergraduates observe that students are under- or uninformed about the food system, especially from an environmental and health perspective. This is equally apparent with most community groups. Modern societies are organized around fossil fuels as the driving force. As impacts of current systems begin to threaten the life support base, interest will increase in less dense, natural and contemporary energy resources. This will increase public interest in rural areas and agricultural landscapes, and make the message more palatable to urban audiences and students.

More consumers need to understand the connections among agriculture, their food, their health, and their environment. To reach them we need to emphasize the personal health and environmental benefits for them and their families that are offered through better understanding of the food system. Students and the general public do connect with health issues such as benefits of fiber from vegetables and fruits, or relationship between pesticides and cancer. Once informed, they are receptive to information about local food systems including community gardens, farm stands, compost, organic products and community supported agriculture, as well as more complex ecosystem functions and services such as wetlands for clean water, windbreaks for clean air, intact soils that don't erode, and oxygen from green plants. Consumers will want to learn more about their food supply and the rural landscape, and ultimately will want information and choices from the system that an agroecological approach can supply.

Organic food producers and processors have already been successful in getting information to the public about the certified labels that identify their products in the market, as well as making direct connections for sale from the farm. Just as commodity groups have promoted their specific crop or animal product, organic growers and processors have pursued public education campaigns using grower fees and contributions. One result is that growers benefit from the premium price that organic products will bring in the marketplace, thus increasing incomes by advancing their labeled products. Organic food sales have increased by about 20% per year for more than a decade in U.S. and Europe (Lampkin, 1999).

Emphasis on consumer education should include explanations of how ecological approaches used by sustainable farmers can produce food without pesticides and with alternatives to chemical fertilizers, while protecting the ecosystem and producing healthy, safe food for consumers. The farmer can be portrayed as an environmental steward who is also concerned about consumer health, an ally of the

consumer who has made changes in farming practices to achieve these multiple goals. Customers can be affirmed when they make the choices to purchase food produced in this manner. Further education about how food is produced, where, by whom, and under what conditions will reinforce their decisions. Surveys in Norway have shown that consumers who regularly purchase ecological food are also concerned about overall pesticide and fertilizer use, about animal welfare, and about the conditions of farmers and families where food is produced (Torjusen et al., 2001). When agroecology studies the entire food system, these issues of consumer opinion and choice are part of the equation.

Conclusions

We have defined agroecology as the study of the whole food system, embracing both natural and social sciences, and emphasizing systems thinking and ecological principles. Based on our collective experience in teaching and research, we find it impossible to deal effectively with the complexity of resource use and design of future systems if we only focus on the production aspects, short-term economics, and environmental impacts in the immediate vicinity of farm fields. It is logical to suggest that agroecology should deal with all actors in food systems as well as the total flow of energy and materials from their sources through production and other steps to the consumer, and the potential to return nutrients to the field. It is essential to carefully analyze the current global food system and explore local alternatives, as well as unique options such as organic farming. Concepts in agroecology can be also be applied to improving conventional farming systems.

Richard Harwood (personal communication, 2001) outlines the forces that are shaping the dynamics of development and the emerging global food situation in this new century. He lists the *driving forces* as new technologies, mobility of capital and people, global markets, and an infrastructure increasingly dominated by multinational corporations. In agriculture, some of the *supplemental forces* shaping the future include collection and manipulation of germplasm, new information on genomics, and dynamic breeding programs for our major staple crops. *Corrective forces* are those invoked by governments and include global, regional, and national policies as well as international oversight for trade, management of monopolies, and legislation that protects the environment. Harwood lists *sustaining forces* as research in production ecology, effective protection of natural resources, appropriate technologies and local food systems, and strong action by the civil sector. Narrow focus on specific technologies to increase food production or solve local environmental problems can help some farmers, but will provide little meaningful direction on how to design effective and sustainable systems for the future. A new definition of agroecology provides a rationale and brings intellectual resources to focus on some of the most difficult and complex issues that challenge our ability to provide a stable food supply for the indefinite future.

Most educators involved in agroecology and sustainable agriculture feel that a thoughtful analysis of the economic implications and long-term impacts of alternative systems will help us sort out the complexities of resource use and environmental impacts that result from alternative agricultural and food processing systems. A broad evaluation of productivity, economic return, environmental impact, and social equity that quantifies the multiple consequences of alternative food systems can help students and researchers ask the relevant questions, interpret the results, and apply this information to design of productive and sustainable agroecosystems. Moreover, it will be impossible to make substantial progress unless we also recognize the importance of literature, philosophy, ethics, and other reflections of culture that help explain the uniqueness of place, including people and resources. To introduce this concept to a broader student audience, we urge continued dialog on both the definition of agroecology and the development of innovative approaches to resource use and food systems for the future in our agricultural colleges and universities world wide.

References

- Allen, P., D.V. Dusen, J. Lundy, and S.R. Gliessman. 1991. Integrating social environmental, and economic issues in sustainable agriculture. *American Journal of Alternative Agriculture* 6:34-39.
- Altieri, M.A. 1983. *Agroecology*. University of California Press, Berkeley, California.
- Altieri, M.A. 1985. Diversification of agricultural landscapes—a vital element for pest control in sustainable agriculture. In: *Sustainable Agriculture & Integrated Farming Systems*, T.C. Edens,

C. Fridgen, and S.L. Battenfield, editors. Michigan State University Press, East Lansing, Michigan. p. 166-184.

Altieri, M.A. 1987. *Agroecology: The Scientific Basis of Alternative Agriculture*. Westview Press, Boulder, Colorado.

Altieri, M.A., and C.A. Francis. 1992. Incorporating agroecology into the conventional agricultural curriculum. *American Journal of Alternative Agriculture* 7:89-93.

Altieri, M.A., and S.B. Hecht, editors. 1990. *Agroecology and Small Farm Development*. CRC Press, Boca Raton, Florida.

Audsley, E. (ed), Alber, S., Clift, R., Cowell, S., Gaillard, G., Hausheer, J., Jolliett, O., Kleijn, R., Mortensen, B., Pearce, D., Roger, E., Teulon, H., Weidema, B. and van Zeits, H. 1997. Harmonisation of environmental life cycle assessment for agriculture. Final report. European commission concerted action AIR3-CT94-2028. Silsoe Research Institute. Bedford, UK.

Bawden, R. J. 1991. Systems thinking and practice in agriculture. *Journal of Dairy Science* 74:2362-2373.

Buck, L.E., J.P. Lassoie, and E.C.M. Fernandes, editors. 1999. *Agroforestry in sustainable agricultural systems*. CRC Press, Boca Raton, Florida.

Caporali, F. 1991. *Ecologia per L'Agricoltura: Teoria e Pratica*. UTET Libreria, Torino, Italy.

Carroll, C.R., J.H. Vandermeer, and P. Rosset, editors. 1990. *Agroecology*. McGraw-Hill Publications, New York.

Cavigelli, M.A., S.R. Deming, L.K. Probyn, and R.R. Harwood (editors). 1998. *Michigan Field Crop Ecology: Managing Biological Processes for Productivity and Environmental Quality*. Michigan State University Extension Bulletin E-2646. 92 p.

Collins, W.W., and C.O. Qualset, editors. 1998. *Biodiversity in agroecosystems*. CRC Press, Boca Raton, Florida.

Conway, G.R. 1985. Agroecosystems analysis. *Agricultural Administration* 20:31-55.

Coscia, A.A. 1993. *Agricultura Sostenible*. Editorial Hemisfero Sur S.A., Buenos Aires.

Dalgaard, T., J.R. Porter, and N. Hutchings. 2002. Agroecology, scaling, and interdisciplinarity. *European Journal of Agronomy* (in review)

Doherty, S. and Rydberg, T. (ed), Ekblad, G., Grönlund, E., Ingammarsson, F., Karlsson, L., Nölsson, S. and Strid Eriksson, I. 2002. Ecosystem Properties and Principles of living Systems as Foundation for Sustainable Agriculture – Critical Reviews of environmental assessment tools, key findings and questions from a course process. Report Ekologiskt lantbruk, No 32. Center for Ecological Agriculture, SLU. Uppsala, Sweden.

Edens, T.C., C. Fridgen, and S.L. Battenfield, editors. 1985. *Sustainable Agriculture & Integrated Farming Systems*. Michigan State University Press, East Lansing, Michigan.

Ferrera-Cerrato, R., and R. Quintero Lizaola, editors. 1993. *Agroecologia, Sostenibilidad y Educacion*. Colegio de Postgraduados, Montecillo, Mexico.

Flora, C.B., editor. 2001. *Interactions between Agroecosystems and rural Communities*. CRC Press, Boca Raton, Florida.

Francis, C.A., G. Lieblein, J. Helenius, L. Salomonsson, H. Olsen, and J. Porter. 2001. Challenges in designing agriculture education: a Nordic perspective on change. *American Journal of Alternative Agriculture* 16(2):89-95.

Gliessman, S.R., editor. 1978. *Agroecosistemas con énfasis en el estudio de tecnología agrícola*

tradicional. Colegio Superior de Agricultural Tropical, Cardenas, Mexico.

Gliessman, S.R. 1985. Economic and ecological factors in designing and managing sustainable agroecosystems. In: *Sustainable Agriculture & Integrated Farming Systems*, T.C. Edens, C. Fridgen, and S.L. Battenfield, editors. Michigan State University Press, East Lansing, Michigan. p. 56-63.

Gliessman, S.R., editor. 1990. *Agroecology: Researching the Ecological Basis for Sustainable Agriculture*. Springer-Verlag, New York.

Gliessman, S.R. 1998. *Agroecology: Ecological Processes in Sustainable Agriculture*. Ann Arbor Press, Chelsea, Michigan.

Gliessman, S.R. 2000. *Field and Laboratory Investigations in Agroecology*. Lewis Publishers, Boca Raton, Florida.

Gliessman, S.R., editor. 2001. *Agroecosystem Sustainability: Developing Practical Strategies*. CRC Press, Boca Raton, Florida.

Gonzalez Jacome, A., and S. Del Amo Rodriguez, editors. 1999. *Agricultura y Sociedad en Mexico: Diversidad, Enfoques, Estudios de Caso*. Plaza y Valdes Editores, Mexico, D.F. Mexico.

Harwood, R.R. 1990. History of sustainable agriculture: U.S. and international perspective. Ch. 1 in: *Sustainable Agricultural Systems*, C.A. Edwards, R. Lal, P. Madden, R.H. Miller, and G. House, editors. Soil & Water Conservation Society, Ankeney, Iowa. p. 3-19.

Hernandez Xolocotzi, E., editor. 1977. *Agroecosistemas de Mexico: Contribuciones a la Ensenanza, Investigacion, y Divulgacion Agricola*. Colegio de Postgraduados, Chapingo, Mexico.

Hernandez Xolocotzi, E. 1985. *Xolocotzia: Obras de Efraim Hernandez Xolocotzi. Tomo I*. Revista de Geografia Agricola, Universidad Autonoma de Chapingo, Texcoco, Mexico.

Hernandez Xolocotzi, E. 1987. *Xolocotzia: Obras de Efraim Hernandez Xolocotzi. Tomo II*. Revista de Geografia Agricola, Universidad Autonoma de Chapingo, Texcoco, Mexico.

Jackson, W. 1980. *New Roots for Agriculture*. University of Nebraska Press, Lincoln, Nebraska.

Johansson, S., Doherty S. & Rydberg, T. 2000. Sweden Food System Analysis. *Proceedings to the First Biennial Emergy Research Conference: Energy Quality and Transformities*, September 2-4, 1999, University of Florida, Gainesville

King, J.W., and C.A. Francis, editors. 1994. *Extension and education materials for sustainable agriculture*, Vol. 2. North Central Region Sustainable Agriculture Research and Education Program, Univ. Nebraska, Lincoln, NE. p. 239-338.

Klages, K.H.W. 1928. Crop ecology and ecological crop geography in the agronomic curriculum. *J. Amer. Soc. Agron.* 20:336-353.

Lampkin, N. H. 1999. Organic farming in the European Union: overview, policies and perspectives. Invited keynote paper in: *Organic Farming in the European Union – Perspectives for the 21st Century*. Proceedings of EU Commission/Austrian Government conference, Baden/Vienna, May 1999. EuroTech Management, Vienna, pp. 23-30.

Lieblein, G., editor. 1997. *From Farming Systems to Food Systems: Third Nordic Postgraduate Course in Organic Farming*. Dept. Horticulture & Crop Science, Agric. Univ. Norway (NLH), P.O. Box 5022, N-1432 Aas, Norway.

Lieblein, G., C. Francis, and J. King. 2000. Conceptual framework for structuring future agricultural colleges and universities. *Journal of Agricultural Education and Extension* 6(4):213-222.

Lieblein, G., C.A. Francis, L. Salomonsson, and N. Sriskandarajah. 1999. Ecological agriculture research: Increasing competence through Ph.D. courses. *Journal of Agricultural Education and Extension* 6(1):31-46.

Lieblein, G., and E. Østergaard. 2001. Shifting focus: experiences from the NOVA MSc in agroecology. Course evaluation document, Agricultural University of Norway (NLH), Aas, Norway. 17 p.

Montaldo, P. 1982. *Agroecología del Trópico Americano*. IICA, San Jose, Costa Rica.

Nestle, M. 2002. *Food politics: How the Food Industry Influences Nutrition and Health* (California Studies in Food and Culture). Univ. California Press, Berkeley, California.

Odum, H.T. 1996. *Environmental Accounting - Emergy and Environmental Decision Making*. John Wiley & Sons, Inc. New York.

Schlosser, E. 2001. *Fast Food Nation: The Dark Side of the All-American Meal*. Houghton Mifflin Company, Boston.

Schubert, W.H. 1995. Students as action researchers: historical precedent and contradiction. *Curriculum & Teaching* 10(2):3-14.

Soule, J.D., and J.K. Piper. 1992. *Farming in Nature's Image: an Ecological Approach to Agriculture*. Island Press, Washington, DC.

Spedding, C.R.W. 1979. *An introduction to agricultural systems*, First edition. Elsevier Publ., London, U.K.

Spedding, C.R.W. 1996. *Agriculture and the citizen*. Chapman and Hall Publ., London, U.K.

Torjusen, H., G. Lieblein, M. Wandel, and C.A. Francis. 2001. Food system orientation and quality perception among consumers and producers of organic food in Hedmark County, Norway. *Food Quality and Preference* 12:207-216.

Wackernagel, M., Onisto, L., Bello, P., Callejas Linares, A., López Falfán, I. S., Méndez García, J., Suárez Guerrero, A. I. And Suárez Guerrero, M. G. 1999. National natural capital accounting with the ecological footprint concept. *Ecol. Econ.* 29:375-390.

Wiedenhoef, M., S. Simmons, R. Salvador, G. McAndrews, C. Francis, J. King, and D. Hole. 2002. Agroecosystems from the inside-out: a multidimensional experiential learning course. *Journal of Natural Resources & Life Sciences Education*. (in review)

Table 1. Landmark publications using the term or the concept of agroecology (modified from Gliessman, 1998; not all publications are cited in Reference section).

<i>Year</i>	<i>Author(s)</i>	<i>Title</i>
1928	Klages	Crop ecology and ecological crop geography in the agronomic curriculum
1939	Hanson	Ecology in agriculture
1956	Azzi	Agricultural ecology
1965	Tischler	Agrarökologie
1973	Janzen	Tropical agroecosystems

1974	Harper	The need for a focus on agro-ecosystems
1976	Loucks	Emergence of research on agroecosystems
1977	Hernandez Xolocotzi	Agroecosistemas de Mexico
1978	Gliessman	Agroecosistemas y tecnologia agricola tradicional
1979	Hart	Agroecosistemas: conceptos básicos
1979	Cox & Atkins	Agricultural ecology: an analysis of world food production systems
1980	Hart	Agroecosistemas
1981	Gliessman, Garcia & Amador	The ecological basis for the application of traditional agricultural technology in the management of tropical agroecosystems
1982	Montaldo	Agroecologia del trópico americano
1983	Altieri	Agroecology
1984	Lowrance, Stinner & House	Agricultural ecosystems: unifying concepts
1985	Conway	Agroecosystems analysis
1987	Altieri	Agroecology: the scientific basis of alternative agriculture
1990	Allen, Dusen, Lundy, & Gliessman	Integrating social, environmental, and economic issues in sustainable agriculture
1990	Gliessman	Agroecology: researching the ecological basis for sustainable agriculture
1990	Carroll, Vandermeer & Rosset	Agroecology
1990	Altieri & Hecht	Agroecology and small farm development
1991	Caporali	Ecologia per l'agricultura
1991	Bawden	Systems thinking in agriculture
1993	Coscia	Agricoltura sostenibile
1998	Gliessman	Agroecology: ecological processes in sustainable agriculture
2001	Flora	Interactions between agroecosystems and rural communities
2001	Gliessman	Agroecosystem sustainability
2002	Dalgaard, Porter & Hutchings	Agroecology, scaling, and interdisciplinarity