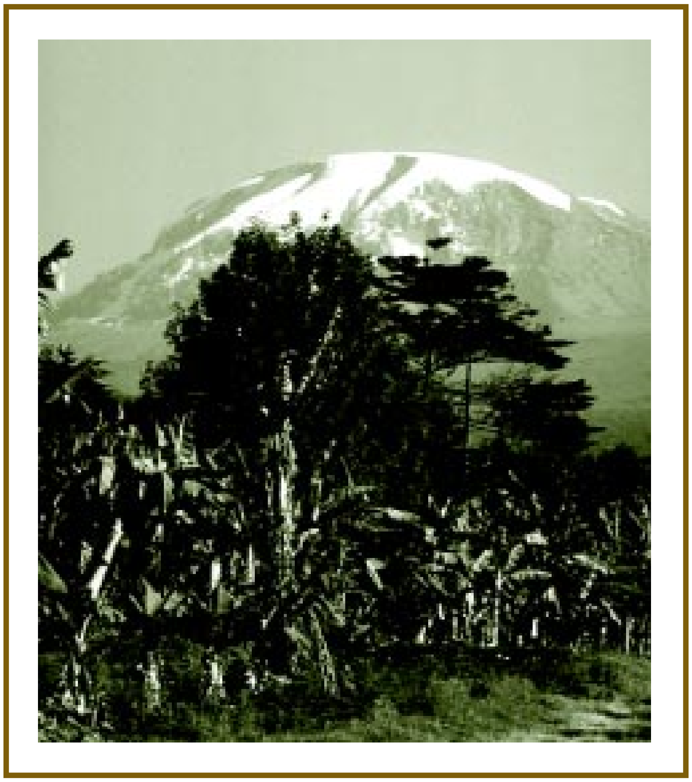
ECOAGRICULTURE

A Review and Assessment of its Scientific Foundations



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Sustainable Agriculture and Natural
Resource Management
Collaborative Research Support
Program

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Development

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A Review and Assessment of its Scientific Foundations

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Chapter 1

Overview

1.1. Introduction

To deal with global problems of hunger and malnutrition, natural resource degradation, loss of biodiversity, and rural decline, alternative visions for land use and natural resource management are needed as present practices and systems are making slow or no progress in achieving these objectives. New combinations of policies, institutions, technologies and values are required, linking individual interests and efforts with those of the communities and societies they live in, better balancing the competing aspirations for raising agricultural productivity, ensuring ecological sustainability, and promoting rural vitality. Growing awareness of the global-level impacts of current natural resource uses, enhanced through imaging and communication technologies and stimulated by recognition of the increasingly globalized nature of socioeconomic systems, has motivated innovative management strategies which reconcile increased agricultural productivity with environmental protection and greater livelihood opportunities.

Ecoagriculture is an approach to land use that seeks "to square the circle," to achieve productive and sustainable reconciliations among objectives that are usually in competition. The concept grew out of a comparison and convergence of conclusions drawn by Jeffrey McNeely, a conservation scientist, and Sara Scherr, an agricultural economist, as they were reviewing spatial information developed through the Millennium Ecosystem Assessment.[1] They saw that the lands and resources required for an expanding agriculture to support still-growing human populations, who need to earn their living by these means, largely coincide on a global level with the lands and resources needed to secure protected areas for wildlife habitat and species preservation. This realization led them to look for and to formulate management strategies that could accommodate both objectives.

Their book *Ecoagriculture: Strategies to Feed the World and Save Wild Biodiversity* (2002) proposed that ecoagriculture be accepted and expanded as a set of inclusive resource management strategies for landscapes that can both produce more food and preserve ecosystem services, with a special concern for wild biodiversity (p. 6). While the strategies identified to date often have been appropriate for smaller-scale units of production, relying more on local resources than external ones, there is nothing in the concept of ecoagriculture that limits it to such production systems. Indeed, a concern for both food production and the environment means that larger-scale units, presently highly dependent on external inputs, should be well within the purview of ecoagriculture.

1.2. Varieties of Ecoagriculture and Relation to Biodiversity

McNeely and Scherr regard ecoagriculture as a considered response to the worldwide challenge of meeting the well-recognized crisis of conserving global biodiversity while at the same time producing sufficient food and livelihoods to support the increasing human population. It is not a single practice or particular kind of farming system but rather an aggregation of approaches to the production of food, fiber, and other benefits that all aim to integrate biodiversity conservation into agricultural development efforts. McNeely and Scherr identify six main strategies for doing this. Three of the six are concerned with making space for wildlife preservation within agricultural landscapes; the other three focus on how to enhance the wildlife habitat value of productive farm lands themselves. The strategies can be summarized as follows:

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[1] *The Millennium Ecosystem Assessment (MEA) is an international program designed to generate scientific information regarding the consequences of ecosystem change on human well-being and options for addressing these changes. It focuses broadly on global ecosystem health. The objective of the MEA is to meet the needs of decision-makers and the public for such information.*

1) **Creating biodiversity reserves that benefit local farming communities.** This strategy involves choosing areas for protection in places where there are clear immediate benefits, including environmental services, livelihood support, farmland protection for unique agricultural habitats, and enhancing benefits obtainable from protected areas for local farmers through market and compensation mechanisms.

2) **Developing habitat networks in non-farmed areas.** Improving the biodiversity value of agricultural landscapes will encompass areas in and around waterways, abandoned fields and forest sites. Other landscape niches for biodiversity may include schoolyards, "sacred groves," parks, areas around roadways, industrial or hospital sites, and agro-ecotourism locations.

3) **Reducing land conversion to agriculture by increasing farm productivity.** Enhancing agricultural productivity growth and sustainability in high potential areas may encourage reduction or abandonment of farming in environmentally-sensitive lands. In more marginal lands, technology that enables farmers to replace shifting cultivation with permanent, higher yielding fields may allow former fallow land to revert to natural forest, woodland and grassland, or will prevent further clearing.

4) **Minimizing agricultural pollution**. Reducing agrochemicals in high-input systems may be achieved through advances in organic farming, integrated pest management (IPM), and soil conservation. Use of pollutants can be reduced through improved efficiency of pesticide application, use of natural compounds in producing them, and employment of IPM techniques. Whole-farm planning and related waste mitigation methods can reduce their impact on biodiversity.

5) **Modifying management of soil, water, and vegetation resources**. This strategy builds on agroecology, conservation agriculture, agroforestry, and sustainable rangeland and forest management as well as wildlife biology and ecology to increase farmers' natural capital, and thereby long-term flows of farm outputs. Increasing the diversity of crop, tree, and livestock components can increase the habitat value of farms and the prospects for co-management of livestock and wildlife.

6) **Modifying farm systems to mimic natural ecosystems.** This strategy focuses on increasing the use of perennials to create an agriculture that provides many of the environmental services of natural systems, including wildlife habitat. Agricultural landscape design is an emerging science for configuring perennials, spatially and temporally, to provide desired services. New propagation and domestication techniques can increase the economic value of perennial crops.

There are many ways in which agricultural practices, on a large scale or small scale, affect the flora and fauna, macro to micro, in and around the areas cultivated, grazed or fished. In general, agricultural practices simplify the landscape relative to the natural condition—a simplification of plant diversity, of physical structure and dimension, and of chemical mosaic. An illuminating schematic is one developed by Gilbert (1980), which shows the hierarchical and interacting nature of organisms in a tropical landscape. The schema has been simplified enormously relative to the real world, but the complexity remaining is still astounding. For contrast, compare this image to a typical agricultural landscape.

1.3. The Development of Ecoagriculture as an Approach

In *Ecoagriculture* McNeely and Scherr lay out considerable evidence from numerous case studies, supported by analyses and proposals about the synergies that may be gained through ecoagricultural practices. Since the book was published, a network known as Ecoagriculture Partners (EP) has taken shape (http://www.ecoagriculturepartners.org). It draws together 25 institutions and some 20 individual partners as well as over 1,000 people on a growing and active listserve who agree that knowledge and understanding need to be advanced to support the extension of ecoagriculture practices on a wider scale. Ecoagriculture Partners and numerous collaborators have planned an international Ecoagriculture Conference and Practitioners' Fair to be held in Nairobi in September 2004.

Following the publication of *Ecoagriculture*, an international group of scientists meeting in Switzerland concluded that an assessment of the scientific foundations for ecoagriculture was warranted. The assessment would help clarify misperceptions that might be forming about the approach and begin building a more extensive and systematic knowledge base for evaluating the effectiveness of ecoagriculture practices evaluated agronomically, environmentally, economically, and socially. Such an assessment should also help determine priorities for investment in research related to ecoagriculture.

Subsequently, the Sustainable Agriculture and Natural Resource Management (SANREM) collaborative research support program funded by USAID arranged for faculty at Cornell University to prepare a review paper as background for deliberations at the September 2004 conference. The Cornell International Institute for Food, Agriculture and Development (CIIFAD) has worked since 1990 on interdisciplinary initiatives to expand the knowledge and practice for sustainable agricultural and rural development, with special attention to the joint satisfaction of conservation and development objectives. This report thus is prepared for the Ecoagriculture Conference and Practitioners' Fair.

1.4. Purpose and Methodology of this Assessment

The aim of this assessment is to review and summarize the scientific knowledge base for ecoagriculture in the following ways:

1) to determine to what extent the concept of ecoagriculture has sound scientific knowledge and understanding;

2) to evaluate claims that have been made about the benefits of ecoagriculture on the basis of scientific evidence;

3) to characterize capacities for evaluating, with scientific rigor, the tradeoffs and synergies among objectives addressed within an ecoagriculture framework;

4) to identify significant gaps in knowledge and corresponding methodological and institutional limitations in knowledge generation; and

5) to identify promising institutional opportunities and methods for improving knowledge and understanding about ecoagriculture.

The report is the product of an inquiry into diverse disciplinary literatures and project initiatives that are related to ecoagricultural land use and consistent with its precepts. We have gone beyond the operational definitions of ecoagriculture in the McNeely-Scherr volume to look at the generic conflicts and complementarities among agricultural production, environmental conservation, and livelihood generation. The definitions that McNeely-Scherr put forward were based on induction (from an assemblage of case studies) and deduction (making a synthesis of values and goals). To provide an assessment of ecoagricultural strategies in general, we took a few steps back, not limiting the literature review and analysis to the parameters set in the first attempt, by McNeely and Scherr, to formulate a new field of knowledge and practice. As the review team, coming from a variety of disciplines—agronomy, natural resources, agricultural economics, sociology and political science, with inputs from colleagues representing still more disciplines—we wanted to take a more encompassing view of this terrain.

Our methodology for preparing this report was to work in and with three entities:

1) the Ecoagriculture Assessment Team (EAT);

2) the Ecoagriculture Assessment Advisors (EAA);

3) the Ecoagriculture Working Group (EWG).

The EAT was comprised of four Cornell faculty members and four research assistants from fields and disciplines that are instrumental in the development of a sound knowledge base for ecoagriculture: 1) conservation biology; 2) international agriculture; 3) agricultural economics; and 4) natural resources. This group undertook to plan, research, and produce the report.

The EAA were nine researchers and practitioners who accepted an invitation by the leadership of Ecoagriculture Partners to provide guidance and assistance in shaping the assessment. Each advisor was asked to respond to an initial set of questions concerning what they construed to be the most important issues to be addressed in the review. In addition, advisors agreed to provide further information upon request. Each contributed ideas for literature to examine and agreed to review and comment on a draft report. The names and affiliations of these advisors are provided in Annex 1-A, as well as their responses to the questions posed to them.

The EWG included 27 Cornell faculty and two graduate students who volunteered to provide information and guidance to the EAT. Early during the assessment period, EWG members attended a half-day seminar on ecoagriculture presented by Dr. Sara Scherr and facilitated by members of the EAT. Copies of the McNeely-Scherr book were provided to EWG members prior to the seminar so they could engage knowledgeably and critically with issues raised by ecoagriculture concepts and practices. The seminar generated substantive feedback through group processes and prepared EWG members to participate in the following assessment. Many were interviewed by members of the EAT to get their input to the assessment and to identify the most relevant scientific literature to pursue. Annex 1-B lists EWG members and their research interests pertinent to ecoagriculture.

In addition to interviewing EWG participants and other Cornell faculty members, EAT members interviewed representatives of international organizations based in the Washington, D.C. and New York City areas whose activities are related in some way to the domain of ecoagriculture. The EAT sought to learn about initiatives that would shed light on the trials, successes, and limitations of multi-objective planning and analysis and to characterize those that appear most insightful or promising. Our criterion for inclusion in this purposive sample was that initiatives be concerned with at least two of the three objectives of ecoagriculture, and ideally all three. Annex 1-C lists the external organizations contacted. Annex 1-D provides names and affiliations of internal and external expertise consulted.

1.5. Organization of this Report

This report is organized around the three interlocking objectives of ecoagriculture:

1) Agricultural productivity;

2) Biodiversity conservation; and

3) Livelihood support, poverty reduction, rural vitality, and contributions to human well-being.

We liken these objectives to three legs of a stool that depend on one another to support the ecoagriculture enterprise. The stool can only serve its function if all three legs are intact and working together.

We consider in Chapters 3, 4 and 5 each leg of the stool, characterizing its particular contributions and concerns. Each of these chapters lays conceptual, theoretical, and empirical groundwork for assessing how ecoagriculture alternatives may affect the respective objectives of sustained agricultural productivity, biodiversity conservation, and livelihood support in particular situations.

Preceding consideration of the three core concerns, we discuss in Chapter 2 the concepts, opportunities and challenges in the production of food and ecosystem services, biodiversity conservation, and economic evaluation of multi-objective production systems to improve social and human welfare. This places our review of ecoagriculture in a broader context, offering perspectives on how to know to what extent ecoagricultural approaches, applied globally and in respective regional settings, are likely to improve or to worsen existing conditions. It informs consideration of the potential value added by these new approaches, and what are the uncompensated costs incurred within an ecoagricultural framework and toolbox. Chapter 2 serves as a reference point for understanding and assessing ecoagricultural performance and potential.

We follow the three core chapters with an amplification in Chapter 6 of the emerging opportunities seen within the agricultural sector for practices and farming systems that are more eco-friendly, capitalizing on productive potentials embedded in natural processes. Then in Chapter 7 we examine possibilities for integrating the three sets of concerns into a coherent analytical whole. Our focus is on state-of-the-art methods for multi-objective, multi-scale land-use planning and the potential for integrating scientific and planning knowledge into adaptive management frameworks.

Chapter 8 offers some conclusions and suggests ways to go forward in further evaluating the potential of ecoagriculture alternatives. Suggestions are provided for advancing research and learning in this domain to expand the empirical basis for assessment, while seeking the prospective gains from these promising approaches to land use.

1.6. **Definitions**

In our efforts to forge a more integrated, interdisciplinary assessment of ecoagriculture, it became clear that one of the hurdles to getting agreement was that key terms, particularly biodiversity, agricultural intensification, and degradation meant different things to different people.

1.6.1. **Biodiversity**

Inside the fronstispiece of each issue of the journal *Conservation Biology* is the following mission statement of the society of the same name: "….to help develop the scientific and technical means for the protection, maintenance, and restoration of life on this planet—*its species, its ecological and evolutionary processes*, and its particular and global environment" (emphasis ours). We subscribe to that goal and detail the following definition of biodiversity as: all species of native organisms, plant and animal, vertebrate and invertebrate, macro- and micro-, as well as the genetic and morphological variation within the populations of each of those species. In addition, biodiversity includes the biological processes (e.g., predator-prey, plant-pollinator) that produced those organisms and of which those organisms are a part. To avoid confusion, however, we will usually refer to the above as wild biodiversity and to the variety of crop and livestock varieties, landraces, and species as agrobiodiversity**.**

Biodiversity has been popularly understood in quantitative terms, perhaps because of the emphasis on preservation of endangered species. If any species becomes extinct, this reduces biodiversity, framing evaluation in simple numerical terms. But there are "scale" questions and "value" questions that quickly make evaluation more complex.

a) It is possible that cutting down an old-growth forest, for example, could result in an *increase in local biodiversity*, letting or getting more plant species to grow, and with them possibly a more diverse array of vertebrates, arthropods, etc. But *the loss of a few species that are already scarce* when the old forest is cut down could reduce the total number of species existing on a more global scale. Indeed, the newly replanted, more-biodiverse landscape could be populated with species that are already abundant elsewhere. So local and more global biodiversity can be inversely correlated. Numbers alone are no adequate criterion.

b) Another way in which quantitative measures can be misleading is that *not all species have the same biological or ecological value*. Many species are differentiated from one another in small ways, while other species are very important because (i) they are unique, perhaps the only surviving species from a previously existing taxonomic group, or (ii) they fill a particular ecological niche that has positive implications for other species, for example, within a food chain.

Most biologists are reluctant to make any judgments that would diminish the importance of any species, yet almost all agree that some are more important than others. Thus a practice or farming system that would preserve a "more critical" species even if local biodiversity were diminished would be positively evaluated. Conversely, any practice or farming system that compromises such a species, even if that farming system is beneficial for biodiversity in some general way, would be less desirable.

Evaluating the biodiversity associated with a particular agricultural practice or farming system in a certain location thus has qualitative as well as quantitative dimensions. Economists have tended to want unambiguous quantitative measures to use in evaluation; environmentalists usually put more emphasis on qualitative aspects when evaluating biodiversity.

In addition, most conservation biologists, and the public generally, tend to think in terms of preserving species. The "species" has long held a central position in biology and, therefore, it is this unit of biodiversity to which we have been naturally attracted for keeping score of how we are doing. The danger of this focus, however, is that humans manage or manipulate "habitats," which contain hundreds of species. Rarely is a single species managed in isolation from the biological community of which it is a part (although certain exceptions come to mind, e.g., California condor, *Gymnogyps californianus*). We tend to count the number of species that are threatened or endangered, and we discuss the effect of certain land use practices on particular species. However, we are really making decisions about how to change vegetative communities, or habitats, with our agricultural practices, and this has wholesale effects on many species in addition to those that are the immediate topic of discussion. We are drawn, therefore, to making informed decisions about entire landscapes, which contain numerous different habitats. A detailed explication of the concept of habitat and analytical approaches to its investigation can be found in Morrison et al. (1998).

There is a tension between two views of biodiversity, as having instrumental vs. ultimate value. The first attributes importance to biodiversity for the multiple benefits and services that it can produce, while the second assigns the existence of biodiversity some incalculable, transcendental worth. Persons who take the first perspective are prepared to assign economic values to biodiversity and consider tradeoffs against other valued outcomes, while persons with the second perspective tend to resist or discount such assessments.

There is a tenable middle position because even with the first view—that biodiversity is important for the ecological processes and functions it preserves which are valuable to people—it is clear that we cannot say with any confidence just which species, or how many, are needed to maintain particular functions (Lawton 1999). This gives weight to the second view—which accords significant but unknown worth to preserving biodiversity—even though it does not negate the basis for thinking instrumentally about biodiversity. We have not taken either extreme position because neither seems tenable. Instead, we work with both conceptions and valuations, attributing instrumental and intrinsic value to biodiversity even if their combination is often an uneasy one.

1.6.2. **Intensification**

Intensification is multi-dimensional and needs to be identified with regard to specific contexts. While the term typically refers to the amount of inputs devoted to production, several different frameworks exist from which intensification is assessed.

a) The most common reference is to the relative amount of one input e.g., labor, capital, or land—used in a particular production process *compared to the use of all other inputs*. We say that a good or service is produced in a labor-intensive way for example, if relatively more labor is used per unit of capital or other inputs, compared to another good produced with the same inputs. Intensification within this frame of reference always needs to specify which input is being increased or intensified, relative to others, to raise production.

b) In the agricultural sector, the land input is often of central interest, and production is considered either more intensive (or more extensive) in terms of the ratio of non-land inputs relative to land. "Intensive" production systems *concentrate larger quantities of inputs*, particularly labor, on a given amount of land. "Extensive" production systems, such as mechanized agriculture, have usually larger scales of production, applying lower amounts of non-land resources per hectare. Even though greater inputs of capital (and fuel) are employed, the labor per unit of land is reduced and often so are other resources.

c) A third use of the term refers to the *increased use of purchased or external inputs*, substituting mechanical or chemical inputs for labor. This involves expending more capital for equipment and on fuel for tractor operations as well as on fertilizer (instead of compost), and chemical sprays (instead of hand weeding or crop protection). Not using such "modern" inputs typically makes agricultural operations more labor-intensive (in the sense of the first meaning discussed). The term "intensification" should always be used with appropriate specification of what resource is the reference point. External-input-intensive agriculture is very different from labor-intensive production, having different implications for soil and for other kinds of biodiversity. As this third meaning of the term implies, it is not the fact of intensity but rather the kind of intensity that is important.

Economists, when talking about intensification, most often are referring to meaning (a), while environmentalists often are focusing on (b). They may debate about (c). Intensification, in particular in (a) and (b), also relates to the economic concept of *total factor productivity*, which represents the total output that results from the application of *all productive inputs combined*. Use of this measure surmounts the well-known limitations in partial productivity measures (labor productivity, land productivity, etc.) that are associated with meaning (a). However, partial productivity measures are still often used because they give insights into relative factor usage.

1.6.3 **Degradation**

Degradation is another term that has several meanings. From a strict conservation biology point of view, any change in pristine ecosystems represents degradation. Economists, on the other hand, often think of degradation in terms of the decreased capacity of the environment to meet whatever demands are placed on it. These demands typically stem from two sources: (1) the use of resources in the production of direct economic benefits (agriculture, forestry, fisheries, etc.); and (2) the use of resources for intrinsic welfare-enhancing benefits (wilderness recreation, landscape enhancement, etc.). Soil erosion, for example, corresponds to the first type of demand because it diminishes agricultural productivity in direct and measurable ways; the degradation of "viewsheds" corresponds to the second type of demand, and is typically harder to measure and value, often requiring non-market valuation methods. We consider degradation here to be closer to the "economic" view, recognizing that pristine ecosystems are unlikely to represent an appropriate counterfactual, especially in agriculture-oriented ecosystems. However, there is a tenable middle position that sees natural ecosystems as having a multi-faceted productivity that can be compromised and reduced by many and varied resource management practices. Such reductions in any relevant aspect of this productivity, even in an agroecosystem, are what we consider degradation, and may well reduce a system's sustainability.

It is also important to recognize that environmental degradation may be understood in dynamic terms, which is why the degradation of natural resources needs to figure more prominently in agricultural planning and evaluation. It is not just the interactions among soil systems, hydrological cycles, vegetative cover, biodiversity, and microclimates that make adverse changes in any one of these significant, because others are then also adversely affected. In fact, biophysical degradation has additional externalities with feedback and interactive effects vis-a-vis malnutrition and hunger, income risks and losses, poor health and declining livelihoods, and social deprivation and poverty. While for scientific analysis, references to degradation may require some explicit biophysical definition, when thinking about this process and its outcomes, we need to keep the economic and social concomitants and consequences in mind.

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ANNEX 1-A: Ecoagriculture Assessment Advisors and Recommendations

Advisor and Organization	Issues/opportunities that the assessment should address (ranked)			Priority for advancing ecoagriculture science over next five years
	1	2	3	
Lee R. DeHaan Plant Breeder The Land Institute, Salina, Kansas USA	Development of new plant materials (especially perennials).	Do the necessary science to explore potentials of opportunity #1.	Address scientifically the role of biodiversity in agriculture.	Perennial seed crop breeding programs must be initiated for use in all major agricultural regions.
Sandra Gagnon Agrobiodiversity consultant International Union for the Conservation of Nature and Natural Resources (IUCN), Gland, Switzerland	Exploring interconnected habitat networks for biodiversity protection.	Linking social aspects to conservation, and indigenous knowledge related to incorporation of innovative technique.		Summarize the existing knowledge and regroup or categorize the different systems (organic, ecoagriculture, ecofriendly agriculture, agroforestry, FAO conservation agriculture…). Many initiatives and philosophies exist that are similar, interconnected and in some aspects, redundant.
Joanne Gaskell Researcher International Food Policy Research Institute (IFPRI), Washington, DC	How to balance the provision of food with need for ecosystem services.	Tradeoffs of opportunity #1 within cultivated areas as well as between cultivated and other areas.	Maximizing the services provided within cultivated systems, recognizing the critical role of food production.	Global collaboration and widecast ambitious thinking like the Millenium Assessment.
Barbara Gemmill Executive Director Environment Liaison Centre International Nairobi, Kenya	A new model of intensively-farmed agriculture is needed, one that supports biodiversity on-farm to promote ecosystem services.	To better determine what aspects and how biodiversity can contribute to agricultural productivity, we need a much better assessment of either crop loss or contributions to crop yields (and this over time, with a strong sustainability aspect).		

Advisor and Organization	Issues/opportunities that the assessment should address (ranked)			Priority for advancing ecoagriculture science over next five years
	1	2	3	
Roger Leakey Professor of Agroecology Agroforestry and Novel Crops Unit, School of Tropical Biology, James Cook University, Australia	Determine the role of biodiversity (planned and unplanned) in agroecosystem function.	Development of tree domestication and commercialization of agroforestry tree products as incentive for farmers to diversify with traditional/ indigenous trees.	Linkages between agricultural and commercial diversification.	Developing the integration of production agriculture with wildlife conservation and business development for the diversification of agriculture. Our Network for Sustainable and Diversified Agriculture may be a bit of a model for this.
Jules Pretty Professor Center for Environment and Society, and Dept. of Biological Sciences, University of Essex, UK	Getting national policies right, removing implicit discrimination against sustainable approaches.	Developing better scientific understanding of the applicability of ecoagriculture.	Understanding the roles of social capital for promoting collective action at landscape level.	More hard evidence on the costs vs. benefits of ecoagriculture.
Thomas P. Tomich Principal Economist and Global Coordinator Alternatives to Slash-and-Burn Programme (ASB), Nairobi, Kenya	What meso-scale ecological services are threatened by biodiversity reduction?	Which is better: segregation or integration of production and conservation?	What policies and institutions influential to land-use change?	

ANNEX 1-B: Cornell Ecoagriculture Working Group

Name and Title	Contact	Research Interests
Christopher Barrett Associate Professor, Applied Economics and Management	cbb2@cornell.edu http://www.aem.cornell.edu/profiles/barrett.html	Poverty-environment linkages; microeconomics of agricultural development
David Bates Professor, Plant Biology	dmb15@cornell.edu http://www.plantbio.cornell.edu/people.php?netID=dmb15	Ethnobotany
W. Ronnie Coffman Professor and Chair, Plant Breeding; Director, International Programs/CALS	wrc2@cornell.edu http://www.plbr.cornell.edu/PBBweb/Coffman.html	Plant breeding related to international agriculture
Paul Curtis Assistant Professor, Natural Resources	pdc1@cornell.edu	Wildlife management, pest control in agricultural systems
Stephen Degloria Professor and Chair, Crop and Soil Sciences	sdd4@cornell.edu www.css.cornell.edu/faculty/degloria.html	Geographic information systems; spatial planning and analysis
Laurie Drinkwater Assistant Professor, Horticulture	led24@cornell.edu http://www.hort.cornell.edu/department/faculty/drinkwater/index.html	Ecology of managed ecosystems, nutrient cycling
John Duxbury Professor, Crop and Soil Sciences	jmd17@cornell.edu http://www.css.cornell.edu/faculty/duxbury.html	Nutrient transformations; agronomic production
Lucy Fisher Extension Associate, CIIFAD/Intl. Programs	lhf2@cornell.edu	Information coordination and management
Theresa Fulton Director of Outreach, Institute for Genomic Diversity, Biotechnology Center	tf12@cornell.edu http://www.igd.cornell.edu/staff/Fulton.html	Genomics and bioinformatics in biodiversity conservation and food security

Name and Title	Contact	Research Interests
John Gaunt Senior Research Associate, Crop and Soil Sciences	john.gaunt@bbsrc.ac.uk jlg84@cornell.edu	??? need to put in something here
Charles Geisler Associate Professor, Rural Sociology	ccg2@cornell.edu http://www.cals.cornell.edu/dept/devsoc/facultyprofile.cfm?FacultyID=42	Tree tenure, forest tenancy, land tenure and common property systems
Andre Goncalves Graduate Student, Crop and Soil Sciences	alg47@cornell.edu	Agronomy, agroforestry, ecoagriculture
Robert Herdt Adjunct Professor, Applied Economics and Management	rwh13@cornell.edu	Economics
Peter Hobbs Visiting Professor, Crop and Soil Sciences	ph14@cornell.edu http://www.people.cornell.edu/pages/ph14/	Conservation agriculture
Quirine Ketterings Assistant Professor, Crop and Soil Sciences	qmk2@cornell.edu http://www.css.cornell.edu/faculty/ketterings.html	Nutrient management
Johannes Lehman Assistant, Professor, Crop and Soil Sciences	cl273@cornell.edu http://www.css.cornell.edu/faculty/lehmann/index.htm	Soil fertility management
Carl Leopold Professor Emeritus, Boyce Thompson Institute	ac19@cornell.edu	Plant development and seed physiology
Kenneth Mudge Associate Professor, Horticulture	kwm2@cornell.edu http://www.hort.cornell.edu/department/faculty/mudge/index.html	Multi-purpose tree propagation and symbiosis
Rebecca Nelson Associate Professor, Plant Pathology	rjn7@cornell.edu http://www.plbr.cornell.edu/PBBweb/nelson.html	Plant diseases

Name and Title	Contact	Research Interests
Alison Power Professor, Ecology and Evolutionary Biology	agp4@cornell.edu http://www.eeb.cornell.edu/power/power.html	Agroecology, insect-transmitted diseases of wild and cultivated plants
Susan Riha Associate Professor, Earth and Atmospheric Sciences	sjr4@cornell.edu http://www.geo.cornell.edu/eas/index.html	Root, soil, and water relations in agroforestry and cropping systems
Tammo Steenhuis Professor, Agricultural and Biological Engineering	tss1@cornell.edu http://www.bee.cornell.edu/faculty/faculty-bio.tss1.htm	Water and nutrient transport in agroforestry systems
Margaret Smith Professor, Plant Breeding	mes25@cornell.edu http://www.plbr.cornell.edu/PBBweb/Smith.html	Crop breeding and genetics
Janice Thies Associate Professor, Crop and Soil Sciences	jet25@cornell.edu http://www.css.cornell.edu/faculty/thies/Thies.html	Soil microbial ecology
David Thurston Professor Emeritus, Plant Pathology	hdt1@cornell.edu http://ppathw3.cals.cornell.edu/ppath/facultyinfo/Thurston.html	Disease management, mulchbased systems
Terry Tucker Assistant Director, IP/CALS and CIIFAD	twt2@cornell.edu http://ip.cals.cornell.edu/profiles/show_profile.cfm?personid=183	International extension, adult education
Harold van Es Professor, Crop and Soil Sciences	hmv1@cornell.edu http://www.css.cornell.edu/faculty/hmv1/s&wman/harbio.htm	Soil and water management
David Wolfe Professor, Horticulture	dww5@cornell.edu http://www.hort.cornell.edu/department/faculty/wolfe/index.html	Environmental physiology, soil and water management

ANNEX 1C: External Organizations Consulted

Organization	Ecoagriculture-related interests
Conservation International (CI)	Criticisms of ecoagriculture approach; defense of traditional separation of agriculture and conservation; certification programs; integrating conservation and agriculture in business; landscape-level planning with soy-growing farmers to maximize protection of habitat in set-asides.
Earth Institute, Columbia University (EI)	Soil quality; below-ground biodiversity; linking biodiversity at different levels; conservation and development problems in Africa
Food and Agriculture Organization (FAO)	Proposed activities for sustainable land use
Foundations of Success (FOS)	Monitoring and evaluation tools; determining means and goals for measuring biodiversity, and determining the success of projects
International Food Policy Research Institute (IFPRI)	Millennium Assessment; global environmental and agricultural strategies; using GIS-data to identify win-win areas; models or approaches used to integrate multiple objectives; efforts to look at landscape level issues in plant breeding studies
Northern Chiapas Coffee Network	Organic coffee; impediments to certification
Rainforest Alliance	Shade coffee; certification programs
The Nature Conservancy (TNC)	Evaluating bioindicators; cattle intensification; organic coffee; conservation measures; need for quantitative data on agriculture's impact on biodiversity; certified coffee/cacao
United Nations Development Program: Equator Initiative (UNDP-EI)	EI efforts to measure integration of multiple goals in projects related to ecoagriculture; Equator prize program; combining rural income generation and biodiversity conservation
United Nations University: People, Land-Management and Ecosystem Conservation (UNU-PLEC)	Biodiversity conservation and agricultural systems
U. S. Agency for International Development (USAID)	USAID involvement and guidance relevant to ecoagriculture
U. S. Department of Agriculture: Cooperative State Research, Education and Extension Service (USDA-CSREES)	USDA-CSREES goals and projects relevant to ecoagriculture; CRIS agricultural research database; environmental components of US agricultural research and extension; CGE and global spatial models to monitor and predict environmental; response to agro-economic policy changes
U. S. Department of Agriculture: Economic Research Service (USDA-ERS)	Valuation of ecosystem services; assessing ecological impact of the CRP (Conservation Reserve Program)
U.S. Department of Agriculture: Natural Resource Conservation Service (USDA-NRCS)	CEAP (Conservation Effects Assessment Program); NRCS effort to evaluate effectiveness of government programs for integrating multiple goals; CSP (Conservation Security Program)

Organization	Ecoagriculture-related interests
U. S. Environmental Protection Agency (US-EPA)	EPA efforts and challenges with integrating multiple goals
Wildlife Conservation Society	European experience for conserving wildlife in agricultural systems
Winrock International	Winrock efforts relevant to ecoagriculture; future research and practice; low-cost aerial imagery and relevance to ecoagriculture; terminology (in Europe, "ecoagriculture" = organic agriculture); Performance-Based Environmental Policy for Agriculture (PBEPA) program; trade-offs; problems arising from lack of below-ground and plant data
World Bank	ASB – Alternatives to Slash and Burn program; long-term analysis of trade-offs and linkages; WB efforts to integrate conservation and development; valuation projects; PROFOR activities; payments for ecosystem services; models for planning conservation
World Resources Institute (WRI)	Global analyses; nutrient trading; stakeholder involvement; analytical methodologies; nutrient management initiative; use of marginal cost curves in environmental evaluations; systems-based analyses; integrating ecosystem services; Millennium Assessment issues; integrating protected areas into larger working landscapes
World Wildlife Federation (WWF)	Collaborating with producers, e.g. Florida dairy cattle initiative, and Wisconsin certified “healthy” potatoes initiative

ANNEX 1-D: Experts Consulted

Expert	Title*	Interviewer	Topic
Albrecht, Greg	Extension Associate, Cornell Nutrient Mgmt. Program	WDH April 1-15, 2004	Integrated nutrient management
Alvarez, Angel and Miguel Gonzalez Hernandez	Northern Chiapas Coffee Network	FRW February 24, 2004	Organic coffee, impediments to certification
Anderson, Jon	USAID – Natural Resource Policy Advisor	FRW and DCB December 3, 2003	USAID involvement and guidance relevant to Ecoagriculture
Auburn, Jill	USDA-CSREES SARE Director/NPL-Sust. Agric. Economic & Community Systems	FRW and DCB December 2, 2003	USDA-CSREES goals and projects relevant to Ecoagriculture; CRIS - agricultural research database; environmental components of US agricultural research and extension
Barrett, Chris	Associate Professor, Applied Economics and Management	DCB February, 2004	Biocomplexity research project in Africa; livestock grazing models
Bedford, Barbara	Senior Research Associate, Natural Resources	WDH April 1-15, 2004	Landscape diversity; wetland processes and water management
Blockhus, Jill	World Bank – Natural Resource Management Specialist	DCB February 24, 2004	PROFOR activities
Bostick, Katherine	WWF – Researcher, Aquaculture and Agric. Conservation Strategies Unit	FRW and DCB December 1, 2003	Collaborating with producers: Florida dairy cattle initiative, Wisconsin certified “healthy” potatoes initiative
Brown, Douglas Ronald	Graduate Student, Applied Economics and Management	LEB and DCB December, 2003	Spatially-explicit bioeconomic modelling
Chomitz, Ken	World Bank – Development Research Group	DCB February 27, 2004	Payments for ecosystem services and models for planning conservation
Clancy, Kate	Winrock – Managing Director, Wallace Center for Agric. & Environ. Policy	FRW and DCB December 4, 2003	Terminology ("Ecoag"=organic in Europe); Performance-Based Environmental Policy for Agriculture (PBEPA); assessing trade-offs; lack of below-ground and plant data
Coffman,William	Professor, Plant Breeding. Director, IP/CALS	LEB April, 2004	Biotechnology in cereal and other food crops

Acronyms, initial, and abbreviations are listed at the end of Annex 1D

Expert	Title*	Interviewer	Topic
Cox, Steve	WRI – Executive Director, Global Forest Watch	FRW and DCB December 3, 2003	Global analyses; nutrient trading; stakeholder involvement; analytical methodologies,
Curtis, Randy	The Nature Conservancy	FRW and DCB December 2, 2003	Evaluating bioindicators; conservation measures
Darwin, Roy	USDA – CSREES Agricultural Economist	FRW and DCB December 2, 2003	CGE and global spatial models to monitor and predict environmental. responses to agro-economic policy changes
Degloria, Stephen	Chairperson, Crop and Soil Sciences	FRW and DCB December 17, 2003	GIS and agricultural impact on biodiversity
Drinkwater, Laurie	Professor, Horticulture	WDH April 1-15, 2004 DCB February, 2004	Cover cropping; below-ground biodiversity; microbial mediation of nutrient cycles
Duxbury, John	Professor, Crop and Soil Sciences	DCB February, 2004	Sustainable productivity to match global needs; soil health assessments
Fernandes, Erick	World Bank	FRW and DCB December 1, 2003	ASB – Alternatives to Slash and Burn; long-term analysis of trade-offs and linkages
Fisher, Lucy	Extension Associate International Programs	LEB February, 2004	Information systems for tropical soil biology and organic inputs
Gaskell, Joanne	IFPRI – Research Assistant, Environment and Food Production Tech. Division	DCB December 4, 2003	Millennium Assessment; global environmental and agricultural Strategies; using GIS-data to identify win-win areas
Geisler, Charles	Associate Professor, Development Sociology	LEB April, 2004	Tenure systems and property rights
Goncalves, Andre	Graduate Student, Crop and Soil Sciences	LEB March, 2004	Ecoagriculture policies and practices in Brazil
Greenhalgh, Suzie	WRI – Senior Economist	FRW and DCB December 3, 2003	Nutrient management initiative
Hansen, Leroy	USDA-ERS Agricultural Economist	DCB December 29, 2003	CRP and related targeting efforts
Hawkes, Christine	Post Doctoral Fellow, Univ. of California, Berkeley	FRW February 25, 2004	Biocomplexity and below-ground biodiversity

**Acronyms, initial, and abbreviations are listed at the end of Annex 1D*

Expert	Title*	Interviewer	Topic
Hellerstein, Dan	USDA-ERS Agricultural Economist	DCB December 29, 2003	CRP and related targeting efforts
Herdt, Robert	Adjunct Professor, Applied Economics and Management	DCB and LEB December, 2003	Economics references; biotechnology
Hicks, Frank	Rainforest Alliance, Director of Sustainable Agriculture	FRW and DCB February 17, 2004	Shade coffee; certification programs
Hobbs, Peter	Visiting Professor, Crop and Soil Sciences	LEB, DCB, WDH Mar/Apr, 2004	Conservation tillage/agriculture; soil biological matter
Hoffman, Bill	USDA-CSREES Program Specialist, Plant and Animal Systems	FRW and DCB December 2, 2003	USDA-CSREES goals and projects relevant to Ecoagriculture; CRIS - agricultural research database; environmental components of US agricultural research and extension
Hooper, Michael	UNDP - Communication Officer for the Equator Initiative (EI)	FRW and DCB February 16, 2004	EI efforts to measure integration of multiple goals in projects related to Ecoagriculture; Equator prize; combining rural income generation and biodiversity conservation
Hyberg, Skip	USDA -- Economics and Policy Analysis Staff	FRW April 2, 2004	Assessing ecological impact of CRP (Conservation Reserve Program)
Kadyszewski, John	Winrock – Senior Program Coordinator, Ecosystem Services	DCB (phone interview) January 7, 2004	Low-cost aerial imagery and relevance to Ecoagriculture
Kingsland, Nick	The Nature Conservancy (TNC) - Business and Environmental Policy Specialist	FRW and DCB December 2, 2003	Evaluating bioindicators; cattle intensification; organic coffee
Kiss, Agi	World Bank – Senior Ecologist	DCB February 24, 2004	WB efforts to integrate conservation and development; valuation projects
Lawrence, Patty	USDA-NRCS Council of Environmental Quality, Criteria and Indicators	FRW and DCB (email) December 25, 2003	CEAP (Conservation Effects Assessment Program)
Lehman, Johannes	Assistant Professor, Crop and Soil Sciences	DCB February, 2004	Soil characterization and soil health

**Acronyms, initial, and abbreviations are listed at the end of Annex 1D*

Expert	Title*	Interviewer	Topic
Luz, Karen	The Nature Conservancy – Central America Division	FRW and DCB December 2, 2003	Need for quantitative data on agriculture's impact on biodiversity; certified coffee/cacao
Lynch, Sarah	WWF	FRW and DCB December 1, 2003	Collaborating with producers: Florida dairy cattle herd management, Wisconsin certified "healthy" potatoes
Mausbach, Maurice	USDA-NRCS Deputy Chief, NRI – Resource Assessment	FRW and DCB (email) December 25, 2003	NRCS effort to evaluate effectiveness of government programs for integrating multiple goals; CSP (Conservation Security Program)
McLeod, Donald	USDA-CSREES National Program Leader, Economics and Community Systems	FRW and DCB December 2, 2003	USDA-CSREES goals and projects relevant to Ecoagriculture; CRIS - agricultural research database; environmental components of US agricultural research and extension
Melo, Cristian	Graduate Student – Natural Resources	FRW March 2, 2004	Eco-certification of bananas in Ecuador
Menale, Andy	US EPA	FRW and DCB November, 2003	Models and efforts to integrate multiple goals; challenges
Mudge, Kenneth	Associate Professor, Horticulture	LEB February 2004	Agroforestry and tree domestication
Nelson, Rebecca	Associate Professor, Plant Pathology	DCB March, 2004	Insect pest management and diversity
Nowierski, Robert	USDA-CSREES National Program Leader, Bio-based Pest Management	FRW and DCB December 2, 2003	USDA-CSREES goals and projects relevant to Ecoagriculture; CRIS - agricultural research database; environmental components of US agricultural research and extension
Pagiola, Stefano	World Bank	DCB February 24, 2004	Payments for ecosystem services
Palm, Cheryl	Earth Institute – Senior Research Scientist	FRW and DCB February 16, 2004	Soil quality; below-ground biodiversity; linking biodiversity at different levels; development challenges in Africa
Parry, Roberta	US EPA- Office of Water Quality	FRW and DCB (email) November 28, 2003	Models and efforts to integrate multiple goals; challenges
Pender, John	IFPRI - Senior Research Fellow, Environment and Production Technology Div.	FRW and DCB December 4, 2003	Models or approaches used to integrate multiple objectives

**Acronyms, initial, and abbreviations are listed at the end of Annex 1D*

Expert	Title*	Interviewer	Topic
Pereira, Christy	USDA – CSREES	FRW and DCB December 5, 2003	USDA-CSREES goals and projects relevant to Ecoagriculture; CRIS - agricultural research database; environmental components of US agricultural research and extension
Pimentel, David	Professor Emeritus, Entomology and Natural Resources	FRW February 23, 2004	Issues of soil degradation; soil biodiversity
Piñedo-Vasquez, Miguel	UNDP (PLEC) – Associate Research Scientist and Lecturer	DCB (email)	PLEC web information
Pinstrup-Andersen, Per	Professor, Applied Economics and Management and Nutritional Science	FRW and DCB December 2003	Expanding organic agriculture to developing countries
Poe, Greg	Assoc. Professor, Applied Economics and Management	DCB February, 2004	Environmental economics; valuation tools
Powers, Alison	Professor, Ecology and Evolutionary Biology	FRW and DCB December 17, 2003	Biodiversity/ecosystem services and agriculture links
Powers, John	US EPA – Economist, Office of Water Quality	FRW and DCB (email) November 28, 2003	EPA efforts and challenges with integrating multiple goals
Redford, Kent	Wildlife Conservation Society	FRW March 5, 2004	European experience for conserving wildlife in agricultural systems
Ribaudo, Marc	USDA – ERS	DCB December 29, 2003	Valuation of ecosystem services; CRP
Rice, Dick	Conservation International – Chief Economist	FRW and DCB December 1, 2003	Criticisms of Ecoagriculture approach; defense of traditional separation of agriculture and conservation
Riha, Susan	Associate Professor, Earth and Atmospheric Sciences	WDH April 1-15, 2004	Integrating agricultural intensification and conservation; environmental thresholds.
Salafsky, Nick	Foundations of Success	FRW and DCB December, 2003	Monitoring and evaluation tools; determining means and goals for measuring biodiversity; determining success of projects
Scialabba, Nadia	FAO	DCB (email) February 13, 2004	Proposed activities for sustainable land use

**Acronyms, initial, and abbreviations are listed at the end of Annex 1D*

Expert	Title*	Interviewer	Topic
Sebastian, Kate	IFPRI	FRW and DCB December 4, 2003	Millennium Assessment; global environmental and agricultural Strategies; using GIS-data to identify win-win areas
Semroc, Bambi	Conservation International	FRW and DCB December 1, 2003	Certification programs; integrating conservation and agriculture in business; landscape-level planning with soy farmers to maximize protection of habitat in set-asides
Smale, Melinda	IFPRI/IPGRI Research Fellow	DCB February 27, 2004	Efforts to look at landscape level issues in plant breeding studies
Steenhuis, Tammo	Professor, Agricultural and Biological Engineering	LEB and DCB March, 2004	Watershed systems
Sydenstricker, John M.	Teaching Coordinator, Rural Sociology	DCB and LEB	Spatially-explicit modeling in forest and agroforestry-based landscapes in the Amazon
Thies, Janice	Associate Professor, Crop and Soil Sciences	DCB December 2003	Tools for biodiversity evaluation.
Thurston, David	Professor Emeritus, Plant Pathology	LEB May, 2004	Agrobiodiversity in traditional agricultural systems
Tucker, Terry	Associate Director, IP/CALS and CIIFAD	LEB May, 2004	International extension communication systems
Van Es, Harold	Professor, Crop and Soil Sciences	WDH April 1-15, 2004	Soil health
Warner, Katherine	Winrock – Managing Director, Forestry and Natural Resource Mgmt.	DCB December 30, 2003	Winrock efforts relevant to Ecoagriculture; future research and practice.
Wolcott, Rob	WRI	FRW and DCB December 3, 2003	Evaluation of marginal cost curves; systems-based analyses; integrating economic services; Millennium assessment; integrating protected areas into larger working landscapes
Wolfe, David	Professor, Horticulture	WDH April 1-15, 2004	Soil health; IPM; cropping system diversity
Wood, Stanley	IFPRI – Senior Scientist, Environment and Production Technology Division	FRW and DCB December 4, 2003	Millennium Assessment; global environmental and agricultural strategies; using GIS-data to identify win-win areas

**Acronyms, initial, and abbreviations are listed at the end of Annex 1D*

Acronyms, Initials, and Abbreviations

CIIFAD	Cornell International Institute for Food, Agriculture and Development
CRP	Conservation Reserve Program
FAO	Food and Agriculture Organization
IFPRI	International Food Policy Research Institute
IP/CALS	International Programs, College of Agriculture and Life Sciences, Cornell University
USAID	United States Agency for International Development
USDA–CSREES	United States Department of Agriculture–Cooperative State Research, Education and Extension Service
USDA–ERS	USDA–Economic Research Service
USDA–NRCS	USDA–Natural Resources Conservation Service
US EPA	US Environmental Protection Agency
Winrock	Winrock International
WRI	World Resources Institute
WWF	World Wildlife Fund

Chapter 2

Opportunities, Concepts, and Challenges in Ecoagriculture

> The struggle to maintain [wild] biodiversity is going to be won or lost in agricultural ecosystems. Management of agricultural landscapes will be the litmus test of our ability to conserve species…Integrating human exploitation with conservation through the diversification of types and intensity of land-use is a realistic way of minimizing extinctions in the absence of detailed knowledge of individual species. (McIntyre et al. 1992:606).

2.1 Environmental Concerns

The history of biodiversity conservation over the past century has focused on protection of particular geographic locations or sites (e.g., national wildlife refuges, national parks), regulation of activities on public land, or on protection of particular high-profile rare species (e.g., the Endangered Species Act of 1973). Emphasis has been placed on the subset of biodiversity known as "wildlife," i.e., vertebrates with obvious recreational or economic value.

The U.S. has provided the basic model for this strategy, which has since been repeated throughout the developed and developing world in various forms. Trefethen (1975) describes the American history in eloquent narrative form, and Table 1-1 in Shaw (1985) sketches a 350-year history of such initiatives in the U.S. up to 1982, which was about the time that modern conservation biology was born. In the past 20 years, additional legislation and international treaties relevant to the conservation of biodiversity, e.g., the Convention on International Trade in Endangered Species and the Convention on Biological Diversity, have been enacted. More land has been set aside under strict protection, and the role of non-governmental organizations in conservation has increased significantly (da Fonseca 2003).

The growth of protected areas over 1,000 hectares worldwide in IUCN categories I-VI, from 1970 to 2000, is traced in Groombridge and Jenkins (2002:198, Figure 8.1). The growth trend appears somewhat asymptotic, with a dramatic slowdown in the addition of new protected areas in recent years to the worldwide protected list, both in number of accessions and in total acreage. However, no decline in the creation of new areas has probably occurred yet, as 5,000 protected areas that UNEP became aware of after Groombridge and Jenkins published their data were omitted from their figure (M. Cordiner, pers. comm.). So it appears that the era of setting aside large areas as parks and reserves is not over, but the handwriting is on the wall. Even with a resumption in the number of land set-asides, it is difficult to imagine that more than a small fraction of the earth's surface will ever be protected in this way. Therefore, those interested in conserving biodiversity should direct attention to the much larger area that is and will remain in private hands, most of which is under some form of agricultural management, or could be. This point is at the center of ecoagriculture thinking as proposed by McNeely and Scherr (2003).

It is remarkable that conservation biologists have not paid more attention to the interface between conservation of wild biodiversity and agriculture until recently, given that such a large proportion of species, perhaps even most of the individuals, reside in land that is managed for agriculture (Western and Pearl 1989; Pimentel et al. 1992). This interface is important for two principal reasons: agricultural lands sustain a great deal of the biodiversity in this world that is valued for many "non-practical" reasons; and much of the biodiversity maintained on these lands, especially micro-biodiversity in the soil, is an important contributor to agricultural productivity itself (Wall and Moore 1999; Wardle et al. 1999; Alkorta et al. 2003). It is almost as though the field of conservation biology, which was "born" about 1980, needed to hone its theoretical skills by focusing on *relatively* simple environments, such as large tracts of land containing mostly natural habitat and owned by the government. If one steps outside such an "ecological laboratory," one is immediately confronted with large areas of degraded and fragmented habitat, and human populations desperately trying to eke out a living by using whatever wild or domestic biodiversity exists there.

Fortunately, concepts and techniques in conservation biology matured during the 1990s, as indicated by the appearance for the first time of several notable texts written for classroom use. It is telling, however, that not more than a handful of pages in those texts are devoted to the problems of conserving wild biodiversity on agricultural land. By our count, out of a total of 2815 pages collectively in the texts by Fiedler and Jain (1992), Primack (1993), Hunter (1996), Meffe and Carroll (1997), and Fiedler and Kareiva (1998), only 34 pages directly discuss biodiversity and agriculture, a little over 1 percent. There are, in contrast, many pages and chapters devoted to the biological principles for designing nature reserves, with many other writings devoted solely to this topic (e.g., Shafer 1990).

McNeely and Scherr (2003) have, therefore, raised an important problem that should engage and challenge conservation biologists as well as agriculturalists. How can conservation of wild biodiversity be made to work within agricultural systems, given the practical constraints? Because most of the world's agriculture is practiced on operational units with small acreages, conserving biodiversity on such parcels sets some upper limit to the body size of animals that could possibly be conserved in these places, because body size is directly related to an animal's requirement for habitat size. For plants, small parcels means small population size, which generates the attendant problems of maintaining demographic and genetic viability for those populations. For both kinds of populations, small habitat size means greater vulnerability and susceptibility to a single natural or anthropogenic event that might wipe out the population. Large agricultural operations, by contrast, are usually managed monoculturally, automatically conflicting with the conservation of biodiversity.

If neighboring farmers could be enlisted to adopt certain agricultural techniques or farming systems with a broader spatial perspective, however, it may be possible to regard an entire neighborhood of farms, even small ones, as a landscape and to manage this as a more or less intact ecosystem. How to get neighboring farmers to adopt and adapt agricultural practices that are compatible with the conservation of biodiversity, and how to fit and cumulate these operations into larger spatial units so that more biodiversity gets conserved than would otherwise be possible, presents a collective challenge for agricultural economists, agronomists, conservation biologists, policy makers, and concerned citizens.

Domesticated biodiversity, or agrobiodiversity, is important not just for the preservation of ecosystems as fundamental parts of the earth's heritage and for the many environmental services that these ecosystems provide, but also for their evident utility to farming enterprises globally. There are perhaps 30 million species of biota on earth (e.g., Erwin 1982), and most of these are comprised of numerous varieties (or subspecies), so that there are tens of millions of varieties and species of wild biodiversity that are worthy of conservation. Domestic biodiversity is an incredibly small proportion of all the biodiversity on earth. To accept the idea that it is possible and wise only to conserve domesticated varieties of plants and livestock on agricultural land is to concede the battle for this planet's unique living resources without offering any resistance. McNeely and Scherr (2003) have proposed some concrete steps that can be taken to turn the current losing tide of extinction. Are countermeasures against loss of biodiversity under the banner of ecoagriculture feasible? Sufficient? Cost-effective? Sustainable? These are questions that need to be addressed with solid data and rigorous analysis. The following chapter and chapters as well as materials in the annexes seek to provide a systematic foundation for thinking such questions through. Ecoagriculture is not a single technology or system but rather, as stated in the introduction, a collection of practices and farming systems, some old, some new, that have the multiple objectives of conserving and even enhancing biodiversity at the same time that agronomic, economic and social objectives of the agricultural sector are met.

2.2 Contemporary Agriculture: Accomplishments and Challenges

Nobody can know for certain what the structure, technologies and performance of the world's agricultural sector will be very far into the future. The global population is expected to grow to around 9.3 billion persons by 2050, by which date it may begin stabilizing (FAO 2003). Food production will have to be increased significantly not just in order to feed a projected population increase of over 50 percent but also to better meet the needs of an estimated 800+ million people who are presently mal- and undernourished, and to satisfy the greater demand for food that will be created by rising incomes. The World Millennium goal of halving the number of undernourished people by 2015, at the current rate of progress, will not be attained even within 50 years. For ecoagricultural methods to succeed, they will have to help meet these increasing food demands through significant gains in agricultural productivity, while at the same time maintaining natural and biotic resources and satisfactory environmental conditions. There are also other goals that many would argue the agricultural sector needs to meet, ranging from basic livelihood generation to helping assure the continuity of traditional cultures.

Modern agriculture is probably the most successful combination of technologies ever assembled to address any major human need, in this case, the food necessary to sustain life itself.

- It built on a series of technical innovations that started in the 18th century, and in some cases well before, such as animal power-based farm implements and steam and internal-combustion engines to make labor more productive and expand the scale of agricultural production.
- It applied advances in knowledge about soil chemistry and plant nutrition starting in the 19th century to overcome soil fertility constraints by the provision of inorganic fertilizers.
- In the 20th century, the protection of crops and animals from pests and parasites was enhanced by a succession of agrochemical products.
- Perhaps most dramatically, scientific breeding efforts in the past century improved the genetic potential of crops and livestock beyond what farmers had accomplished over centuries. Advances in biotechnology have accelerated these efforts in recent years.
- Supporting these changes were technical and organizational innovations for surface and groundwater irrigation that overcame the limitations of insufficient or irregular natural water supplies where these were a constraint for production.

These innovations have progressively enabled farmers to raise both the productivity of their land, labor and capital and the absolute amounts of food and fiber produced. The Green Revolution from the mid-1960s to the mid-1990s represented a convergence of these developments. The remarkable success and methods of modern agriculture are summarized in Table 1 and Figure 1, with the specific data given in Annex 2. Be-

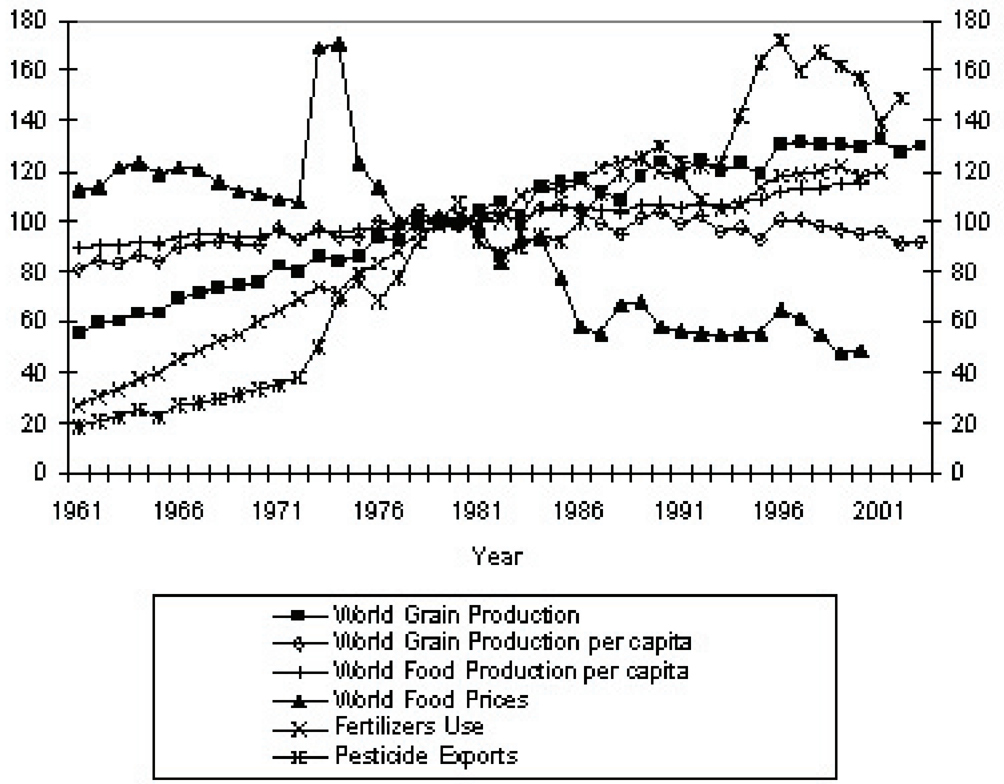
Table 1 Changes in Production Indicators by Decade, 1961-2001, in percent

Decade	World Grain Production *(mmt)*	World Grain Production p/c *(kg)*	Fertilizer Use *(mmt)*	Pesticide Exports *(value)*
1961-71	48.3%	20.6%	135.5%	93.9%
1971-81	25.3%	4.8%	57.5%	163.7%
1981-91	14.8%	-3.0%	17.4%	34.7%
1991-2001	11.1%	-3.1%	2.2%	15.5%

Source: Calculated from Worldwatch Institute data archive, same as in Figure 1, data given in Annex 2.

Figure 1: World Grain and Food Production and Prices, Fertilizer Use, and Pesticide Exports, 1961-2003

(1979-81=100)

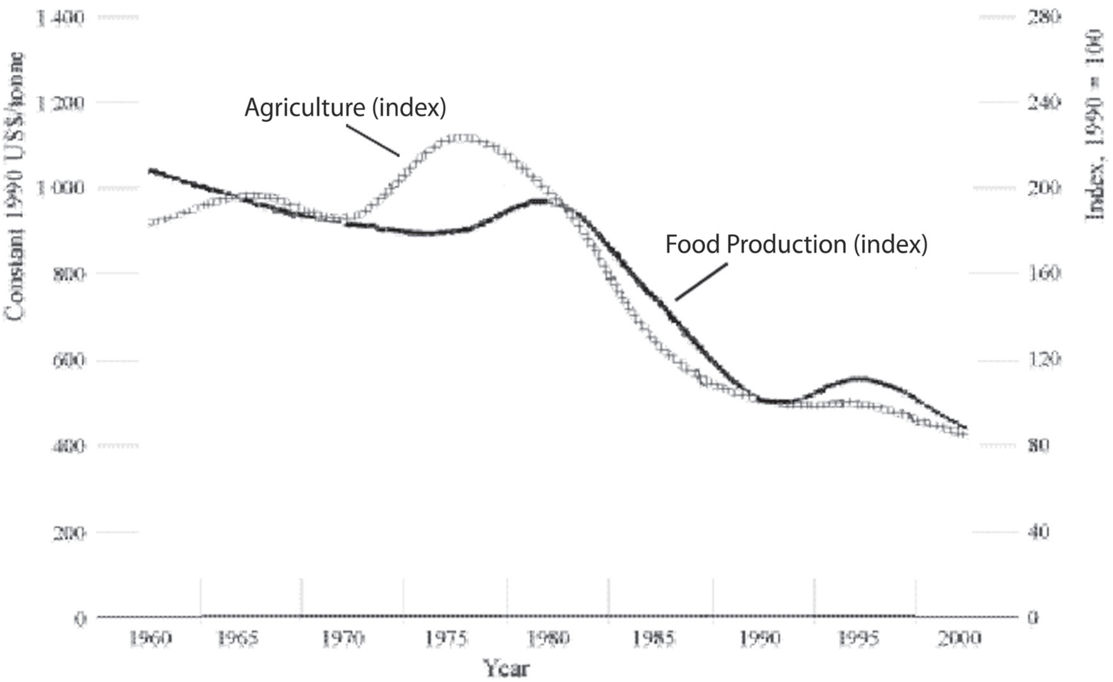


tween 1961 and 2000, global per capita food production went up almost 30 percent, despite a doubling in world population, with a 60 percent decline in the index of world food prices (FAO, USDA and other sources, cited by Worldwatch Institute). Global food production has stayed ahead of population growth over recent decades, however, this masks wide disparities around the world. Some regions—sub-Saharan African and many transition economies, for example—face significant threats to their food security, and in other areas, the displacement of rural smallholders is a major contributor to the problems associated with rapid urbanization.

What does the future hold? Recent studies by IFPRI and FAO have projected future food needs, both globally and for developing countries, out to the year 2020 and beyond (Rosegrant et al., 2001). The increase in global cereal demand is projected to be at least 35 percent, or 654 million tons. Developing countries, where the greatest challenges to food security will continue to exist, account for the greatest share of this increase, with total demand there projected to increase by 49 percent, or 557 million tons, between 1997 and 2020. Cereal production in developing countries is not expected to keep pace with such growth in demand. The net cereal deficit of these countries, which amounted to 103 million tons, or 9 percent of consumption in 1997-99, is expected to rise to 265 million tons, or 14 percent of consumption, by 2030. This shortfall will have to be met by increasing imports, mostly from industrialized country and other food exporters (Pinstrup-Andersen et al. 1999).

In considering the present and future context for ecoagriculture, it is instructive to consider trends in agricultural and food prices. Figure 2 shows long-term price trends from 1960-2000.[1] While real price declines are somewhat different for different products and product

Figure 2: World Market Prices for Agricultural Commodities, 1960-2000



Source: World Bank 2001a, as cited in World Agriculture: Towards 2015/2030: Summary Report (FAO) (http://www.fao.org/docrep/004/y3557e/y3557e06.htm#f)

classes, the overall trend has been for long-term real price declines. The World Bank's index of real agricultural prices decreased by 47 percent between 1980 and 2002 (World Bank, 2004). These price declines reflect the fact that world productive capacity in agriculture continues to exceed total effective demand—what consumers are willing and able to pay for—notwithstanding the food security problems faced by many people in developing and other nations.

Declining real prices reflect in part the distorting market impacts of industrialized-country agricultural protectionism, which generates higher production than would otherwise occur, with resulting dampening effects on global prices. Most observers expect real commodity prices to continue their decline, although some predict that this will occur at a slower rate, due to a continued slowdown in crop yield increases and strong growth in demand for meat (Pinstrup-Andersen et al. 1999). The extent to which future trade liberalization initiatives will lead to less extreme rates of price declines (or even price increases) will be influenced by the outcome of the current Doha Round of international trade negotiations as well as progress in regional trade agreements.

Continuation of these real price trends will have at least three important implications for the challenges facing ecoagricultural approaches. First, the adoption of more environmentally-friendly systems of agricultural production will probably have to occur within a context of declining global agricultural prices. Continued price pressures will reduce farmers' incentives to innovate and aggregate growth rates of crop yields may continue to decline. There will be continued pressure on farmers in many areas of the world to consolidate and expand their farming operations, as they seek to attain an economically viable scale of production while facing reduced price-cost margins. This has specific implications for ecoagriculture, since to be broadly effective, ecoagricultural strategies will have to be successful not only among small-scale producers farming on less-favored lands, but among larger-scale producers farming in high-productivity regions. Overall, then, these factors will create substantial economic challenges for taking up ecoagricultural practices.

Second, for individual farmers to surmount declining agricultural terms of trade they will have to achieve productivity increases through improved technologies, systems of production and management strategies. These strategies must include more effective diversification, particularly into value-added production, as well as diversification into off-farm and non-farm income-producing opportunities (which already account for a sizeable share of farm household income in many rural areas). To the extent that ecoagricultural strategies may have to sacrifice some productivity growth in order to realize biodiversity preservation and other environmental benefits, farmers will find it harder to surmount negative price effects, and the adoption of ecoagricultural strategies will be accordingly constrained.

Finally, declining prices will continue to depress private and public returns for making investments in Green Revolution-type agriculture. Past declines in prices for food are one, but not the only, reason why investments in irrigation and drainage have declined steeply in recent years. Continued low investments in irrigation systems will make it more difficult to concentrate agricultural productivity increases on favored lands, and is likely to lead to pressure for food production increases from less-favored, marginal lands.

At the same time however, there are other counteracting forces that should favor the adoption and diffusion of ecoagriculture strategies. To the extent that these systems and strategies can capitalize on biological potentials and processes not yet fully exploited, there could be some productivity bonuses to be realized. Where synergies can be identified and utilized, the issue becomes one more of complementarities than of tradeoffs. Also, in instances where the continuing price-cost squeeze faced by farmers is due primarily to the increasing costs of external inputs (fertilizers, pesticides, etc.), there may be additional economic incentives to adopt ecoagriculture management strategies. This has been a key impetus, for example, behind the rapid diffusion of zero- and minimum-tillage practices in many countries. Increased recognition of the impacts of agricultural externalities and acceptance of mechanisms to address them—including regulation, private incentive-compatible strategies, and innovative funding strategies—should also continue to favor ecoagriculture. There are many empirical and policy questions that need to be examined. Given how few resources and how little attention have been devoted to these new approaches so far, their prospects cannot be fully evaluated with present information.

2.3 Trends and Problems Bearing on Current Agricultural Practices

While trying to meet global food demand and provide food security, it will be necessary to address many social, environmental, biodiversity and related externalities facing the agricultural sector in the 21st century. The expansion of agriculture, after all, has served as the main driver behind huge changes to the Earth’s vegetation. At the end of the twentieth century approximately one-third of the world’s area under vegetation supported domestic plants (i.e. approximately 40 million square-kilometers under crops and pasture grasses) and between 35 percent and 40 percent of the Earth’s terrestrial biological production was used for human needs (Bakkes and van Woerden 1997; Loh 2002). The impact of human development has greatest on aquatic ecosystems, in part due to infrastructure changes that have accompanied the Green Revolution (dam construction, irrigation, etc.). Estimates indicate that over last 30 years freshwater biodiversity has declined more rapidly than either terrestrial or marine biodiversity; see Loh 2002.

Assuring global food security will continue to depend to an unknown degree on achieving further gains from energy-intensive, fossil-fuel-dependent agriculture. Modern agriculture will continue to be successful and needed in many places. But a number of undesirable externalities, diminishing returns to certain external inputs, and other challenges will demand attention in the years ahead. Present methods and technologies for agriculture should be expected to evolve in response to both foreseeable and unanticipated changes in resource availability, governmental regulations, social needs, and scientific knowledge (Ruttan 2002).

The present and future probable situations of the agricultural sector need to be looked at with an unsentimental eye. This is true for current practices and any proposed alternatives. We review here in brief some emerging issues for modern agriculture as background for considering ecoagricultural opportunities: whether, or to what extent, it offers some solutions to existing and foreseeable challenges facing the sector.

2.3.1 Rising Costs of Production

While the cost of petroleum, the main raw material for most chemical fertilizers and crop protection materials, has fluctuated rather than rising as some critics of modern agriculture had predicted, the prices of these agricultural inputs have risen for farmers. This is partly because governments have been withdrawing the input subsidies they established in the 1960s and 1970s. This trend is due partly to fiscal constraints and partly to a commitment urged by donors to let resource allocation be governed by market mechanisms.

Although petroleum price increases will continue to fluctuate, sometimes wildly, global supplies of petroleum are unlikely to become exhausted. However, the favorable price regime for agricultural inputs that fueled the Green Revolution in the 1960s and 1970s seems unlikely to be restored in the decades ahead. This means that the real prices of many external inputs are more likely to rise than to fall. The decline in fertilizer and chemical use reflected in Table 1 is probably indicative of future trends, driven partly by diminishing returns, discussed below. The costs of water, discussed below, are also likely to rise in the future in many regions as water supplies dwindle. It is expected that the “price-cost squeeze” facing farmers throughout much of the world will continue to be a major problem, as they are caught between falling real output prices and increasing real input costs.

2.3.2 Land Area

Although the overall rate of population growth is slowing, the world’s population will continue to expand through the middle of this century, causing further declines in the per capita availability of arable land. The grain production area per person, which was 0.23 hectares in 1950 and 0.13 hectares in 2000, is projected to decline to 0.08 hectares by 2050, a drop of almost 75 percent within a century (Brown 1999). FAO suggests that there will be demand for an additional 120 million hectares of crop land over the next 30 years, an increase of 12.5 percent. Its assessment of the soil, terrain and climate requirements for major crops suggests that as many as 2.8 billion hectares now uncultivated could be suitable to varying degrees for rainfed production of arable and permanent crops. However, estimates of potentially cultivable land are often overly optimistic, and many factors make it improbable that any more than a fraction of this land could ever be brought into intensive production (Young 1999).

First, most of the world’s *productive agricultural land* is already being used, so additional area must be expected to have lower, and in some cases much lower inherent fertility. Second, not all of this land is really available because of the *tradeoffs* that would be involved in its conversion: the loss of forest cover (on 45 percent of potential cultivable land), loss of protected areas (12 percent), and increasing demand for human habitation and settlement (3 percent). Third, *land degradation* resulting from current agricultural practices and their effects – reduced fertility, soil erosion, salinization – are leading to a loss of vast areas of arable land each year, and this will continue to subtract many thousands of hectares of agricultural land each year from available supply. Fourth, net gains will be diminished by the fact that some current agricultural area, including some of the best quality, will continue to be lost to *urban expansion*. Finally, potential cultivable land is *not distributed evenly*; more than half of the land in question is in just seven tropical Latin American and sub-Saharan African nations. In other regions, South Asia, the Near East and North Africa, for example, close to 90 percent or more of land suitable for agriculture is already being farmed (FAO 2002). So land will become relatively and sometimes absolutely more scarce.

2.3.3 Growing Water Limitations

These are likely to constrain current production technologies in the new century more quickly and surely than land scarcity. Modern agriculture has very high water requirements. With current irrigation practices, it takes 16 tons of water to produce a ton of harvested rice; for maize, a rainfed crop, 10 tons of water are required to produce a ton of grain. The exploitation of groundwater sources for irrigated agriculture in the U.S., India, China and other countries, which was necessary to accelerate the Green Revolution, is now lowering water tables, by a meter or more per annum in some areas, raising costs of production and jeopardizing the long-term prospects for millions of producers.

Water-economizing technologies and even such forgotten methods as water harvesting can alleviate the squeeze that water scarcity is placing on modern agriculture. But competing demands for water, from industries and urban agglomerations, will cut into the agricultural sector's share of freshwater supplies in the future. The most cost-effective opportunities for *water acquisition and distribution* have already been developed, so even if water supply can be expanded, it will be at higher cost. In 2001-2002, investment in major irrigation and drainage schemes were less than $1 billion, compared with about $4 billion in the latter 1990s and $11.5 billion 20 years before (constant price comparisons). There may be some breakthroughs in *desalinization* or some other new technologies, but this is likely only to enhance supply, not lower the cost of water.

More water-efficient production systems will be more essential in the future. The absorption and retention of water in the soil, due to good soil structure associated with abundant soil life and organic matter, will probably offer some of the most cost-effective approaches to mitigating water shortages for agriculture. Reliance on plowing and agrochemical use has diminished soil capacities rather than augmenting them. Better (different) water management of soil and water resources is thus essential if the benefits of crop genetic improvements are to be realized and sustained, directing attention toward ecosystem maintenance rather just than single-species enhancement.[2]

2.3.4 **Natural Resource Degradation**

Modern agriculture faces soil and water constraints in qualitative as well as quantitative terms. Deep plowing and over-irrigation, with monocropped soil surfaces unprotected by vegetative cover, are contributing to soil erosion and salinization on a major scale. Fortunately, many farmers in the U.S., Europe, Latin America and South Asia have started revising their tillage practices, with over 72 million hectares in 2002 under various forms of "conservation tillage" that seek to protect soil resources by physical and biological means, as discussed in the next chapter. The incentives and practices of modern agriculture nevertheless continue to expose millions of other hectares to ongoing threats of degradation.

Water quality is becoming a major concern in many parts of the world, and should be a concern in even larger areas, as the use of chemical fertilizers as well as agrochemical applications is making some groundwater supplies hazardous to health and even directly toxic in certain areas. There are means and dosages that can minimize such harm, but they are not known widely enough or regulated effectively. The widespread use of wood fuels also represents a source of environmental degradation in many regions. Integrated pest management (IPM), one of the strategies associated with ecoagriculture that has grown out of experience with modern agriculture, has demonstrated that reliance on chemical means can be reduced without production losses and that there is economic value in conserving biodiversity within agriculture, discussed in the next chapter and Chapter 6.

2.3.5 **Diminishing Returns or Efficacy of Inputs**

The leading input to modern agriculture has been nitrogen fertilization. In the past 50 years, there has been a seven-fold increase in nitrogen applications, while agricultural production has increased 2.5 times (Tillman et al. 2002). If further increases in production are to be achieved by applying additional fertilizer, how much will be needed to get another doubling? In the U.S. "Cornbelt," the amount of increased output resulting from an additional ton of fertilizer has declined over the past 20 years from 15-20 tons of corn to 5-10 tons (P. Muir, web paper). Cassman et al. (1998) report that with

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[2] *Matthew McCartney (IWMI) notes that changes in water use and quality are having the greatest impact on aquatic ecosystems as freshwater biodiversity has declined more rapidly over the past 30 years than either terrestrial or marine biodiversity (Loh et al., 2002). To a large extent this is attributable to modern agricultural technologies, with increased offtakes for irrigation, dam construction, and eutrophication due to fertilizer applications (pers. comm.:)*

the current efficiency of nitrogen fertilizer use in rice production, if we are to achieve the 60 percent increase in output that everyone expects will be needed in the decades ahead, there will need to be a *tripling* of nitrogen fertilizer application. The article did not discuss how such an increase could be justified economically or acceptable environmentally. Such an increase defies the imagination. And, of course, nitrogen fertilizers are very energy intensive in production and contribute to the direct release of carbon dioxide into the atmosphere, exacerbating global greenhouse gas production.

The trends in global fertilizer use deserve some elaboration. World fertilizer use peaked in 1989 (see Figure 1 and Annex 2). This was partly because of fertilizer price increases and declines in the prices farmers receive for their products, but it also reflects diminishing marginal productivity. Farmers have been learning to use chemical fertilizers more efficiently in response to cost, productivity and environmental concerns, and surely millions of farmers can continue to get net benefits from fertilizer use. But globally, the picture is quite different from 30 years ago, when fertilizer use appeared to be the quickest and surest way to raise production. How the incremental response ratio for fertilizer has changed for grain production on a global scale is seen in Table 2. Increases in production, as with IPM, are now becoming associated with *reduced* fertilizer use.

The use of crop-protective agrochemicals was a kind of second wave for the Green Revolution as seen from Table 1, with growth in their use highest during the 1970s. The marginal productivity and use of these inputs is now also declining on a global scale, like fertilizer. It is fortunate that the prospects of crop protection through biotechnology investments are looking brighter now as the chemical strategy is showing declining benefits and rising costs, particularly in terms of adverse health and environmental externalities. In the U.S., the total use of pesticides increased about 14 times between 1950 and 2000, while the percent of crop loss due to insects increased from 7 percent to 13 percent (Pimentel 1997). While it is true that individual farmers can get benefits from specific applications, the advantages on a wider scale and over time are less clear. A "treadmill" effect is observed where more applications are needed to keep further crop losses from occurring as natural checks on pests and pathogens get eliminated or suppressed by chemical applications.

Some of the decline in crop response to fertilizer inputs is attributable to declining soil organic matter, which is necessary for getting the most productivity out of inorganic nutrients. Remedying low soil organic matter is a necessary but not sufficient condition for better crop performance. Monocropping with heavy tillage, the central strategy of modern agriculture, has had some dramatic successes in raising yield, but its profitability is often marginal because of input costs, and it has contributed to crop losses from increased pest populations and to increased resistance to chemical controls. These affect soil biota in ways that make plants more vulnerable to pest and disease attacks. Increasing application

Table 2: World Grain Production, Fertilizer Use, and Grain:Fertilizer Response, 1950-2001

	World Grain Production *(mmt)*	Increase in Decade	Fertilizer Use *(mmt)*	Increase in Decade	Incremental Response Ratio
1950	631	--	14	--	--
1961	805	+174	31	+17	10.2 : 1
1969-71 (ave.)	1,116	+311	68	+37	8.4 : 1
1979-81 (ave.)	1,442	+326	116	+48	6.8 : 1
1989-91 (ave.)	1,732	+290	140	+24	12.1 : 1
1999-01 (ave.)	1,885	+153	138	-2	*[Not calculable]*

Source: Worldwatch Institute, State of the World 1994, p. 185, with data from UNFAO, International Fertilizer Industry Association, and USDA; updated with data from WI archive.

of fertilizers and agrochemicals within monocropped, high-external-input systems has become part of the problem rather than the ideal solution to biotic constraints on production. This conclusion may not be a very gratifying one because so much has been invested in the chemical control strategies. But the evidence of counterproductive use of external inputs is mounting.

2.3.6 **Environmental Considerations**

Public and policy-makers' concerns about environmental quality and climate change gave impetus to a series of international agreements, culminating in the Kyoto Accord. Momentum for curbing the emission of greenhouse gases and making other changes in policy and behavior was lost when that accord went into limbo. However, pressure to avert the negative consequences of environmental change may well resume. A recent high-level report to the U.S. President has linked such disturbances to national security concerns, e.g., the effects of rising ocean levels resulting from global warming would submerge large adjacent areas and populations. In agriculture, we have seen in recent years how increases in "extreme events" can disrupt production and threaten food security. Health hazards, including endocrine disruption from certain chemical exposures, are also becoming more of a concern (Colburn et al. 1996).

Accordingly, agricultural research and development will need to attend more to their impacts on natural ecosystems and on human health. Agricultural activities such as irrigated rice and cattle production that raise the concentration of methane in the atmosphere will come under more scrutiny. How chemical fertilizers contribute to nitrous oxide emissions and the build-up of nitrates in groundwater needs also to be considered, along with the economic and environmental costs of the energy required to product them. In the future, agriculturalists in all roles and positions will need to think more about reducing negative environmental impacts and enhancing positive results like increasing carbon sequestration. Whenever the full net benefits and costs of agricultural practices are assessed, environmental impacts will get increasing attention.

A continuing challenge in assessing these net benefits and costs—and one of direct relevance to ecoagriculture—is the ability of the market to capture the impacts of externalities associated with environmental degradation resulting from agricultural production and its attendant resource use. The valuation of these impacts and of the contributions of environmental services more generally is an important methodological and policy issue that is currently receiving great attention (Pagiola et al. 2002).

2.3.7 **Genetic Limitations?**

Since the initial success of the Green Revolution, based on breeding semi-dwarf varieties of rice and wheat that could utilize higher applications of chemical fertilizer more effectively, the gains from additional genetic improvement have come mostly from breeding pest and disease resistance into new varieties. This adds to net production by reducing crop losses, but the expansion of production possibilities through breeding has slowed. On-station yields at the International Rice Research Institute in the Philippines, for example, have stagnated (Pingali et al. 1997). This could be due at least in part to declines in soil health and quality after decades of monocropping and high chemical applications. In any case, the genetically-driven part of the Green Revolution is not delivering gains as great as before. We saw in Table 1 that the most rapid production increases came during the 1960s when there was not yet much effect from genetic improvements made by the Green Revolution.[3]

The Green Revolution's gains came from increased use of inputs applied to varieties that were bred to be more responsive to fertilizer, agrochemicals, and irrigation. As seen above, the use of these inputs is becoming more expensive, less productive at the margin, less attractive because of negative externalities, or simply less possible because of limited new opportunities.

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[3] *Determining the exact area under high-yielding varieties is difficult because of different criteria, but starting in 1965, the area under modern varieties in Asia reached about 12 million ha by 1971. This expanded to over 40 million by 1981, to over 70 million by 1991, and to over 80 million by 2001 (calculated from data in Table 34 of http://www.irri.org/science/ricestat ricestat). As can be seen from Table 1, the most rapid gains in grain production came during the first decade of the Green Revolution, a period when field impact began only in mid-decade.*

The long-term viability of agricultural development strategies based primarily on varietal improvement is becoming less certain.

There are substantial expectations that *biotechnology* with new techniques for genetic modification will reinvigorate crop and animal breeding programs. Field-applicable results hold great promise in many cases, but are only beginning to be realized. While some increase in regulation and scrutiny may be justified, across-the-board attempts to close the door on genetic modification work could foreclose opportunities that are beneficial for the poor and/or the environment. Ecoagriculture is not a substitute for efforts to improve the genetic potentials of crops and animals. When managing plants and livestock under what are thought to be optimal conditions, one always wants to have the best available genetic base to get the best return from other inputs.

Biotechnology has potential to contribute to biodiversity conservation, environmental enhancement, ensuring food security and reducing poverty, but there are offsetting concerns at all levels. The scope of biotechnology to increase food production, lower food prices, and decrease hunger and malnutrition is great, but the large costs associated with biotechnological innovation and its possible risks and hazards need to be reckoned with. We also need to consider how widely cost-intensive technologies can be made available to poor agriculturalists, who may be late adopters and suffer from price declines. There is growing evidence of environmental benefits from such technologies as Bt cotton (see, for example, Pray et al. 2001). But these benefits must be weighed against other environmental concerns such as crop-weed hybridization and unanticipated transfer of genetic traits. Agricultural biotechnology methods for overcoming limitations to conventional genetic improvement efforts are certainly worth pursuing, but most agree that biotechnology is not a panacea, and its time frame for results is uncertain. Where there are methods for raising production that are lower-cost and more environmentally friendly these should be considered. These could come within the small-farm sector or the commercial sector. In either situation, productivity gains are crucial, particularly as the pressures and opportunities of global markets make competition for low-cost production greater.

Various concepts and practices that can contribute to what is being called “ecoagriculture” are emerging. No assumption or argument is made that ecoagriculture will replace what is presently understood as modern agriculture. Rather, we consider in this paper how an expansion of opportunities and diversification of methods that are becoming more evident could serve multiple objectives. As discussed in the next section, we assume that optimization among these several objectives is the goal rather than maximizing any single criterion such as yield or profit or employment or number of species.

2.4 Tradeoffs and Synergies with Ecoagriculture

Whether at local, national or global levels, much is expected of the world’s existing agricultural and food systems. We ask that they feed us and feed the world, that they reduce hunger and solve malnutrition, that they generate sustainable incomes and livelihoods for millions of households. In some countries, we ask that these systems contribute to export growth strategies. In many countries, we ask that they reduce poverty and contribute to economic and social equity. Finally, we increasingly ask that they do all these things in ways that are environmentally friendly and do not threaten biodiversity.

An obvious question is: are we asking too much? Are any systems of agricultural production capable to meeting all of these social goals simultaneously? Surely some tradeoffs are necessarily involved. To what extent, then, can the goals of food security, economic growth, poverty alleviation, biodiversity preservation, and environmental enhancement be achieved synergistically, or are tradeoffs unavaoidable in pursuing these objectives?

In assessing ecoagriculture, one needs answers to these questions because the success of many ecoagricultural strategies relies on being able to achieve multiple economic and social goals with synergistic effect. By definition, ecoagriculture requires systems of sustainable agricultural and natural resource management that “simultaneously enhance productivity, rural livelihoods, ecosystem services and biodiversity” (http://www.ecoagriculturepartners.org/whatis.htm). One must ask: what is the record regarding the simultaneous accomplishment of these joint goals?

One need not search far to identify a large relevant literature. Since the 1970s, a number of international conferences, white papers, and reports have addressed these issues, including UNESCO's Man and the Biosphere Program (1987), the World Commission on Environment and Development (the Brundtland Report, 1987), various prominent reports by international environmental organizations (e.g., IUCN/UNEP/WWF 1980), and the World Bank's 1992 review of the status of the global economy and environment.

The actual empirical evidence from these and more recent sources that can demonstrate the complementarity of economic and environmental outcomes is mixed. A recent volume reviewing major global initatives addressing poverty/production/environment linkages concluded that:

> Often…the existence of synergies appears accepted on faith, rather than concluded as a result of careful analysis, research and observation… [T]radeoffs often, although not always, characterize the simultaneous pursuit of development goals....Simple assertions of complementarities in the realization of multiple goals have, in many instances, been shown to be unrealistic and overly simplistic or, at best, to pertain to mostly long-run and aggregate relationships (Lee et al. 2001).

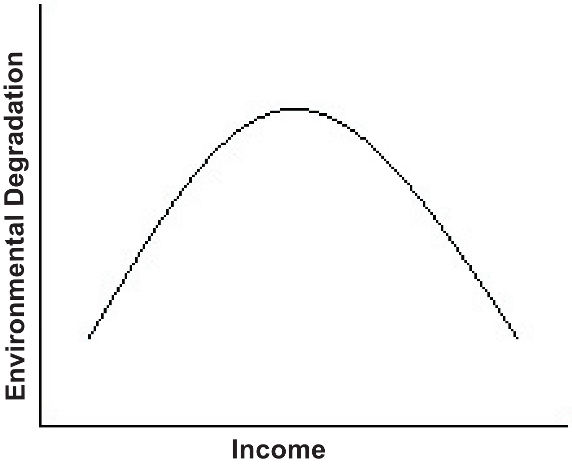
Does the strategy of ecoagriculture hold promise of addressing these multiple goals meaningfully and at a large scale, or is it a strategy that is only applicable in isolated instances, under special circumstances, and with limited generalizability?

The literature on tradeoffs versus complementarities in natural resource management is a large one and draws from many distinct sources. We have provided a detailed review of this literature elsewhere (Lee, et al. 2001). It is possible to discern at least two distinct schools of thought that are relevant here, one focused at the aggregate level, and the second at the micro (farm and household) level.

At the aggregate level, much of the debate regarding whether the pursuit of economic and environmental objectives can be synergistic or not is incorporated in the evidence on what is referred to as the Environmental Kuznets Curve (EKC). The EKC relates economic and environmental outcomes in a way similar to the original Kuznets curve that related income inequality with per capita income levels. It posits an "inverted-U" shape relating environmental degradation on the Y-axis with income levels on the X-axis (Figure 3). At relatively low levels of national income, it is said that environmental degradation (e.g., deforestation, air pollution, destruction of biodiversity) will be relatively low but will begin to *increase* as incomes rise, until at some higher income level, environmental degradation reaches a peak for that country and levels off and then declines (Panayotou 1995). The proposed reasons for this inverted-U relationship are many, including structural economic change first toward manufacturing, and then away from manufacturing toward cleaner service and information industries; the development of cleaner technologies in richer, industrialized economies; increasing consumer demands (with increasing income) for environmental goods and embodied services; enforcement of environmental regulations that results in a cleaner environment; and other factors.

The EKC is an attractive, even seductive, notion because it implies that societies can "have their cake and eat it too." If, at some level of national income, environmental degradation can be expected to decline with further increases in income, the challenge is to get beyond that threshold level as quickly as possible, assuming that economic growth will (eventually) produce a cleaner environment. That has led to various studies designed to identify the level of income at which such

Figure 3. Environmental Kuznets Curve



an 'environmental transition' will occur. By implication, policies to control or minimize degradation along the way become unnecessary or a distraction, according to such an analysis.

Empirical results regarding the extent to which an inverted-U relationship explains the observed patterns in environmental pollution and degradation are decidedly mixed. In general, EKC relationships appear to be most consistent with the data for explaining the concentration of urban air pollutants, where effects are localized, pollution measures are standardized, and the complications introduced by confounding factors are minimized. EKC relationships have been unsupported when trying to explain measures that increase or decrease monotonically, e.g., solid waste generation or the percent of population without access to public sanitation facilities or potable water. Much research has been conducted looking at EKC relationships for deforestation, and these results are quite disparate, with little empirical support overall for the hypothesized inverted-U (Koop and Tole 1999). In summary, at the aggregate level, empirical support for economic-environmental synergies as represented by the Environmental Kuznets Curve are not conclusive or persuasive.

At the micro level, there is a broad and growing literature that addresses the question of synergies vs. tradeoffs in economic and environmental relationships at farm and household levels. This body of research is reviewed in Chapter 5 and will be only broadly characterized here. Much of this literature has emanated from extensive, multi-year and multi-site applied research projects with the goal of analyzing the linkages and tradeoffs among food production, economic returns, and varying measures of environmental outcomes. A recent comprehensive synthesis of this literature as of the late 1990's concluded that,

> …the common assumption of inherent complementarity between agricultural intensification, economic development and environmental goals does not appear to stand up well to empirical scrutiny. Whatever synergies may exist across space and in the long run can be complicated by many factors at the micro level and in the short run (Lee et al. 2001).

The same study suggested that "There do exist many important examples demonstrating the potential synergies between pursuit of household food security, economic growth and environmental sustainability objectives through agricultural intensification… [However,] under most circumstances, agricultural intensification is necessary but not sufficient to achieving food security, poverty alleviation and environmental goals." Thus, it appears that, at the micro level as well, the generalizability of the synergy hypothesis which is relevant to ecoagriculture is limited.

However, in searching for factors and patterns that can lead to synergistic solutions like ecoagriculture, the same study identified a number of *conditioning factors*, the outcomes of which may increase the likelihood that a given strategy may achieve results consistent with hoped for synergies (see also Vosti and Reardon 1997). These conditioning factors include:

- *Population pressure* which may induce intensification and land use changes in either a productive, sustainable fashion (via "Boserupian intensification") or in an environmentally degrading manner;
- *Technological change*, particularly to the extent that it is labor-intensive and not labor-saving;
- *Agroecological conditions* that capitalize on biological processes and interactions such as nutrient cycling, soil water retention, or reduced costs of production, e.g., no-till;
- *Labor-market conditions*, especially as they influence seasonal labor demand, off-farm employment opportunities, and through these factors, help provide capital for households to invest in technologies and management practices that make their agriculture more sustainable;
- *Infrastructure, roads and market access* that help farm households diversify production patterns, increase incomes, and reduce risk, increasing access to input and product markets; and
- *Policy, land tenure and property rights changes* that enable producers to make the most of market-based reforms.

Depending on the joint outcomes of these (and other) factors, a specific strategy for agricultural intensification may prove successful or unsuccessful. The "good news" is that synergistic outcomes are possible; the "bad news" is that this is often difficult and dependent upon positive interactions (feedback) and outcomes among multiple criteria.

For assessing whether synergistic outcomes are achieved or achievable, it is important to identify several cross-cutting criteria that arise from the assessment of specific strategies. These criteria are important to consider when assessing specific ecoagricultural technologies and systems. The first requires identifying whether specific systems take into account all relevant *externalities*, i.e., benefits and costs accruing to individuals, enterprises, communities, and society beyond the private farming operation. These are important for making overall assessments on behalf of society, yet they are generally ignored in the private assessments that individual decision-makers make concerning resource use. In developing countries, it is often the case that economic development priorities are more strongly felt and weighed than broader environmental and sustainability perspectives to which outsiders, government agencies, and NGOs, give more precedence. Reconciling these different objectives complicates any summative evaluation.

To the extent that externalities exist—e.g., downstream sedimentation and water quality deterioration that may accompany erosive upstream tillage and farming practices—it may be necessary to develop innovative mechanisms for those who gain from such practices to compensate those who lose from environmentally-detrimental practices so that societally (and environmentally) desirable practices can be promoted. Part of this assessment may involve developing full and comprehensive accounting of environmental damages generated by private resource practices and/or altering policy mechanisms such as agricultural subsidies that exacerbate the effects of these practices.

Some externalities have an intrinsic *time lag*, with the incidence of costs and/or benefits delayed, which leads to current resource allocation decisions being suboptimal. For example, switching from chemical to organic methods of fertilization may give some loss of yield for three to five years while the soil with more organic matter recovers previously suppressed microbial populations. In strictly economic terms, one should apply discounting to comparably evaluate streams of benefit and costs. However, even if greater net benefit over time are calculated for organic methods, for example, farmers need to be able to cover their costs for any transition period involving short-term losses. From a societal perspective, since there are positive externalities from making this transition, for example, in terms of groundwater quality, discounting of future benefits could undervalue the true future value of improved environmental and human health.

Another issue relates to *scale*. Benefits and externalities may differ between those experienced by small, individual farming operations and the aggregated operations of large numbers of small producers. Aggregation and scale effects are clearly demonstrated at the market level, where the productivity gains achieved by an individual producer may give rewards in the marketplace. But if an entire community or region shares in these, the increased production may move output prices downward, mitigating the aggregate benefits to individuals from productivity-enhancing farming practices, even if they and others in society are better off as a result of the changes in production technology. Scale is important in other ways as well. Biodiversity preservation, for example, is unlikely to be assured by more benign practices just at the farm scale; it is only likely to result if the scale of these practices is large enough to protect distinct animal and plant populations and the ecosystems they are part of in a sustainable fashion.

Scale—often discussed in terms of "*scaling up*"—is important at political and project levels. Much of the scholarly and action-oriented research on sustainable agricultural systems has been conducted at the farm and community level. But increasingly, donors, policymakers and international organizations want to know if the results achieved at a micro level are generalizable to regional or national levels. The interest of such organizations is typically in achieving significant impact, and this must be demonstrated by the application and success of technologies, livelihood and development strategies beyond the individual farm, household or community level. This necessitates attention from the onset of research and development projects to the scalability of results and to the broader impacts of micro-oriented applied research.

All of these elements—both the conditioning factors and the cross-cutting elements identified above—are important to the consideration of ecoagricultural innovations and strategies in this report. As indicated in Chapter 1, this report is not attempting to evaluate ecoagriculture *per se.* Rather, we are considering what are the necessary conditions under which ecoagriculture can succeed? What would have to occur if the strategies reviewed in the following chapters are to address satisfactorily an integrated set of food production, biodiversity and related goals? In addressing these questions, we will show the importance of conditioning factors and related concerns like scalability and externalities when evaluating the costs and benefits of these strategies. These analytical focuses provide a framework within which to identify the relevant criteria for success of ecoagriculture and the concerns which ecoagriculture strategies must satisfy if they are to become widely accepted, adopted and adapted as part of the inventory of techniques, systems and management strategies that farmers will employ.

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ANNEX 2: Time Series Data on World Grain Production total and per capita, World Food Production per capita, Food Prices, Fertilizer Use, and Pesticide Exports, 1961-2003, with comparisons indexed to time series midpoint, 1979-81 average

Year	World Grain (mmt)	*Index*	World Grain p/c (kg)	*Index*	World Food Prices (1960=100)	*Index*	World Food Production p/c (1979-81= 100)	*Index*	Fertilizer Use (mmt)	*Index*	Pesticide Exports ($mill)	*Index*
1961	**805**	*55.8*	**261**	*80.6*	**100.1**	*112.7*	**84.1**	*89.5*	**31**	*27*	**1.32**	*18*
1962	**858**	*59.5*	**273**	*84.3*	**100.5**	*113.2*	**84.9**	*90.3*	**34**	*30*	**1.51**	*21*
1963	**867**	*60.6*	**270**	*83.3*	**107.6**	*121.2*	**85.3**	*90.7*	**38**	*33*	**1.64**	*22*
1964	**914**	*63.4*	**279**	*86.1*	**109.2**	*123.0*	**86.3**	*91.8*	**42**	*37*	**1.81**	*25*
1965	**914**	*63.4*	**273**	*84.3*	**105.4**	*118.7*	**85.7**	*91.2*	**47**	*40*	**1.63**	*22*
1966	**992**	*68.8*	**290**	*89.5*	**108.1**	*121.7*	**87.6**	*93.2*	**52**	*45*	**1.95**	*27*
1967	**1032**	*71.6*	**296**	*91.4*	**107.1**	*120.6*	**89.1**	*94.8*	**56**	*48*	**2.04**	*28*
1968	**1065**	*73.9*	**299**	*92.3*	**103.0**	*116.0*	**89.7**	*95.4*	**60**	*52*	**2.14**	*29*
1969	**1068**	*74.1*	**296**	*91.4*	**99.6**	*112.2*	**88.1**	*93.7*	**63**	*55*	**2.30**	*31*
1970	**1087**	*75.4*	**293**	*90.4*	**98.5**	*110.9*	**89.0**	*94.7*	**69**	*60*	**2.42**	*33*
1971	**1194**	*82.8*	**315**	*97.2*	**96.7**	*108.9*	**90.0**	*95.7*	**73**	*64*	**2.56**	*35*
1972	**1156**	*80.2*	**300**	*92.6*	**95.7**	*107.8*	**87.4**	*93.0*	**79**	*69*	**2.80**	*38*
1973	**1246**	*86.4*	**316**	*97.5*	**148.8**	*169.0*	**90.5**	*96.3*	**85**	*74*	**3.67**	*50*
1974	**1216**	*84.3*	**303**	*93.5*	**151.2**	*170.3*	**90.1**	*95.6*	**82**	*71*	**5.05**	*69*
1975	**1241**	*86.1*	**303**	*93.5*	**109.2**	*123.0*	**90.8**	*96.6*	**91**	*79*	**5.60**	*76*
1976	**1348**	*93.5*	**324**	*100.0*	**101.0**	*113.7*	**91.8**	*97.7*	**95**	*83*	**5.01**	*68*
1977	**1333**	*92.4*	**315**	*97.2*	**89.1**	*100.3*	**91.9**	*97.8*	**101**	*88*	**5.70**	*78*
1978	**1454**	*100.8*	**338**	*104.3*	**87.9**	*99.0*	**94.7**	*100.7*	**109**	*95*	**6.76**	*92*
1979	**1413**	*98.0*	**323**	*99.7*	**90.5**	*101.9*	**94.2**	*100.2*	**112**	*98*	**7.36**	*100*
1980	**1418**	*98.3*	**319**	*98.4*	**89.5**	*100.8*	**93.2**	*99.1*	**117**	*102*	**7.88**	*108*
1981	**1496**	*103.7*	**330**	*101.9*	**86.3**	*97.2*	**94.7**	*100.7*	**115**	*100*	**6.75**	*92*
1982	**1552**	*107.6*	**337**	*104.0*	**74.4**	*83.8*	**96.2**	*102.3*	**115**	*100*	**6.39**	*67*
1983	**1478**	*102.5*	**315**	*97.2*	**82.2**	*92.6*	**95.0**	*101.1*	**126**	*110*	**6.59**	*90*
1984	**1632**	*113.2*	**342**	*105.6*	**83.3**	*93.8*	**98.1**	*104.6*	**131**	*114*	**6.89**	*94*
1985	**1665**	*115.5*	**343**	*105.9*	**69.0**	*77.7*	**98.5**	*104.8*	**129**	*112*	**6.74**	*92*
1986	**1678**	*116.4*	**340**	*104.9*	**51.4**	*57.9*	**99.1**	*105.4*	**133**	*116*	**7.35**	*100*
1987	**1618**	*112.2*	**322**	*99.4*	**49.1**	*55.3*	**98.0**	*104.3*	**139**	*121*	**8.17**	*111*
1988	**1565**	*108.5*	**307**	*94.8*	**58.9**	*66.3*	**97.9**	*104.1*	**145**	*126*	**8.69**	*119*
1989	**1700**	*117.9*	**328**	*101.2*	**60.3**	*67.9*	**99.9**	*106.3*	**143**	*125*	**9.14**	*125*
1990	**1779**	*123.4*	**337**	*104.0*	**51.7**	*58.2*	**100.8**	*107.2*	**138**	*120*	**9.51**	*130*
1991	**1717**	*119.1*	**320**	*98.8*	**50.1**	*56.4*	**99.4**	*105.7*	**135**	*118*	**9.09**	*124*
1992	**1797**	*124.6*	**330**	*101.9*	**49.1**	*55.3*	**100.6**	*107.0*	**125**	*109*	**8.96**	*122*
1993	**1727**	*119.8*	**312**	*96.3*	**48.6**	*54.7*	**100.0**	*106.4*	**120**	*105*	**9.02**	*123*
1994	**1777**	*123.2*	**317**	*97.8*	**49.3**	*55.5*	**101.6**	*108.1*	**112**	*106*	**10.39**	*142*
1995	**1715**	*118.9*	**301**	*92.9*	**49.4**	*55.6*	**102.3**	*108.8*	**130**	*113*	**11.92**	*163*
1996	**1882**	*130.5*	**326**	*100.6*	**58.1**	*65.4*	**105.1**	*111.8*	**135**	*118*	**12.61**	*172*
1997	**1902**	*131.9*	**326**	*100.6*	**54.5**	*61.4*	**106.3**	*113.1*	**137**	*119*	**11.68**	*159*
1998	**1891**	*131.1*	**319**	*98.5*	**48.5**	*54.6*	**106.8**	*113.6*	**138**	*120*	**12.27**	*167*
1999	**1882**	*130.5*	**314**	*96.9*	**42.1**	*47.4*	**108.3**	*115.2*	**140**	*122*	**11.87**	*162*
2000	**1864**	*129.3*	**307**	*94.8*	**43.0**	*48.4*	**108.2**	*115.1*	**135**	*118*	**11.52**	*157*
2001	**1908**	*132.3*	**310**	*95.7*					**138**	*120*	**10.50**	*139*
2002	**1837**	*127.4*	**295**	*91.0*							**10.91**	*149*
2003	**1874**	*130.0*	**298**	*92.0*								

Sources: Indexes are calculated from Worldwatch Institute's data archive collected from FAO, USDA and other international sources (same as for Figure 1). There are no figures worldwide on pesticide use, so pesticide exports are tracked as a proxy. This may understate use since domestic production has increased in a number of countries.

Chapter 3

Meeting Agricultural Productivity Objectives

3.1 Considerations for Assessing Ecoagricultural Alternatives

Because ecoagriculture has multiple objectives and they are not necessarily closely correlated, the challenge is to find some optimization among them. Where there are conflicts or contradictions among the goals, one should focus on what tradeoffs can give the best joint outcome. To the extent that there are compatibilities and even synergies among the objectives, or these can be created, it will be possible to attain more satisfactory outcomes since the objectives can then be met better respectively by approaching them in a collective manner.

The task of achieving an optimum in this case dictates a kind of *minimax strategy*, where one tries to satisfy each goal as fully as possible but subject to the attainment and maintenance of certain minimum levels for the others. Of course, the acceptable minimum can be quite high, e.g., the food production that is needed to meet the nutritional requirements of a still-growing world population, especially since there are at least 800 million persons who are seriously undernourished at present. Estimates of the increase needed vary, but most agree that in the next three to four decades, at least a 50 percent increase in production should be attained.

Failure to accomplish this particular objective will put uncontrollable pressures on natural and biological resources that are already under threat of loss. Moreover, stagnating or decelerating food production will undermine efforts to create livelihoods and improve people's well-being, particularly for the poor, inflating food prices and directing resources away from investments that could help create employment. So there are strong reasons why continuing improvement in agricultural output is not just a variable. A substantial increase is a *sine qua non* for meeting the other two goals.

However, this does not justify a "production first" or a "production only" strategy. Food consumption shortages are most directly a consequence not of inadequate supplies but of poverty and a lack of purchasing power. Nobody should think that production by itself will satisfy human needs. Rather, it is a necessary but not sufficient condition for dealing with these. It can be argued, however, that there is a certain primacy as well as urgency for raising agricultural productivity, albeit in environmentally-friendly ways and with linkages and conditions that ensure that enough of the food produced gets to those who need it most.[1]

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[1] *We are not addressing here the issues raised both pointedly and persuasively by Smil (2004), that part of the challenge of satisfying both food production and environmental objectives turns on dealing with the problem of overconsumption, no longer just in richer countries but also within the middle-income and some lower income countries. The shift to a, "Western" diet as household incomes increase, with more consumption of meats, fats, sugars and salt, not only contributes to growing and serious health problems associated with obesity (heart disease, diabetes, etc.), but it places unnecessary burdens on the world's land and water resources. This is a more serious problem to the extent that the food consumed comes from high-intensity animal production operations that very inefficiently convert vegetable foods into high-quality protein. Smil's arguments about the irrationality of policies that subsidize such patterns of production and consumption are compelling, but rectifying these involves both altering dietary preferences and political reforms that are beyond the scope of this paper.*

The world's capacity to produce more food to meet higher levels of demand is not in question. The economic and environmental costs of doing so can be quite substantial, however, and need to be reckoned with. The situation of the poor will not be improved by producing more food at higher cost, higher because the new technologies require more capital investment or because more marginal, less accessible land and water resources are utilized. Moreover, in terms of economic growth and livelihood expansion, if food production becomes more costly, this will direct resources away from investment in creating jobs and wealth and meeting other needs. So, as suggested in the previous chapter, finding ways to raise *productivity* in the agricultural sector is essential to be able to meet all three objectives in positive-sum ways.

There are two general directions in which agricultural production can develop in the 21st century, although the overall pattern of investment and activity will, of course, be some combination. This mix will respond to the relationships among factors of production determined by their relative availability, cost and productivity (Hayami and Ruttan 1985), responding also to changes in technology and to certain political, social and cultural considerations.

The approach of the Green Revolution, which greatly increased food availability and lowered food costs, was (a) to make improvements in the genetic potentials of plants and animals, and then (b) to increase inputs—of fertilizers, feeds, water, chemical treatments, etc. The genetic improvements made were ones that in particular increased plants' and animals' efficiency of converting inputs into outputs. Within such a paradigm, increasing outputs is typically a function of investing in more inputs. This implies that lower external input strategies must generally give lower output, as contended by the most outspoken advocates of "modern agriculture." Avery (1995) even contends that the environment will benefit from the use of *more* rather than fewer chemical inputs for agricultural production.

Quite a different view of how agriculture is best and most productively practiced has emerged over the past several decades, loosely termed agroecology. This differs from modern agriculture by focusing on *combinations and communities* of plants, animals and soil organisms, rather than on one particular species (crop or animal) at a time. It seeks to form synergies among them that can be captured in production processes. Also, agroecology explicitly embraces *multiple objectives*, including benign impacts on ecosystems and contributions to social and cultural values, rather than direct all efforts toward single goals such as yield or profitability (Altieri 1987).

Proponents of agroecology claim that higher outputs can be achieved by reducing rather than by increasing certain inputs, such as inorganic fertilizers and agrochemical biocides, as well as with less use of fossil-fuel energy. By capitalizing on synergistic biological processes that can be nurtured within agroecosystems, fostering beneficial interactions among species, especially in the soil, they seek to reduce the "environmental footprint" of agricultural production. This, to be sure, makes little sense from an input-centered perspective on agriculture that gives little thought or credit to what plants and animals, in conjunction with their growth environment, can do for themselves. The GxE effect (genetics times environment), which stresses interaction and interdependence, is downplayed in more linear models that regard genes as directly causal.

For agroecological approaches to be feasible underpinnings for ecoagriculture, they will have to demonstrate that they can achieve *higher agricultural productivity* with constant or often lower external input methods. A substitution of one approach by the other is not the issue. On theoretical grounds, optimization reasoning suggests some compromise and combination of approaches. Pragmatically, it never happens that whole systems of production get replaced by other systems, except perhaps over many years, partly because there are powerful factors that inhibit change. What is relevant to consider is to what extent, and where, and how quickly, ecoagricultural systems will become accepted and utilized. Possibly, ecoagriculture will be limited to areas that have presently relatively low productivity, where modern agriculture (plowing, chemical amendments, etc.) has not been performing very well anyway, leaving the bulk of food production to higher-input methods in other, more-favored areas. Or over time, ecoagricultural elements may be integrated into existing modes of production, much as integrated pest management (IPM) and conservation tillage have become part of modern agriculture over the last two decades after earlier skepticism.

Evaluation of alternative practices, though they are formulated in terms of kind, needs to become one of degree. To what extent can lower external input agriculture meet agricultural production needs? This will vary according to physical environments, crops, and marketing and other infrastructure. That ecoagriculture may not be a superior or acceptable strategy in all cases does not invalidate it for some or many areas where the alternative of high-external-input agriculture may be less suitable, for various reasons. And possibly over time, as resistance based on present interests and thinking diminishes, these practices will become "mainstreamed."

In making comparisons, it is important that the high external input agricultural alternative be assessed fully and fairly, including, importantly, a consideration of externalities. Decision-making by individual households typically deals with prevailing market prices for inputs and outputs, calculating private net benefits, or costs, without regard to externalities and the "social costs" resulting from production. From a societal point of view, however, when deciding about policies, subsidies, infrastructure investments, etc., it will be very important to take all externalities, positive and negative, into account. Where the interests and conclusions of private as distinguishable from public actors diverge, the latter need to accommodate the former, at least in the short run. However, any disparities between the two sets of conclusions should be addressed as a matter of public policy, with efforts made to reshape public policy and redirect private choices so that through incentives, regulations, etc., there is a convergence of private (individual) and public (societal) net benefits.

When we refer to inputs as being high or low, all kinds of inputs need to be assessed. What are referred to as "low-input" agricultural production strategies usually refer to purchased or external inputs, ones exogenous to the farming system, not generated within it. What is often meant is "low external-input production strategies" which often have *higher* inputs in terms of labor and management intensity, employing more "imported" inputs to get higher productivity from household resources or to reduce the need for them. There has been a centuries-old trend for farmers to avail themselves of external inputs, particularly to enhance the energy resources they can invest in their production, thereby reducing or making more efficient the labor and land resources at their disposal.

Some argue that this trend is inexorable and that any agricultural system that requires more labor inputs therefore cannot become widely used. However, more important than labor-*intensity* for decision-making, at least by households that depend particularly upon their labor power for income and well-being, are considerations of labor *productivity*. What are the returns to labor? Anything that earns them more output per hour or day of labor has an attractive logic, especially if it reduces their cash costs, as financial resources are typically a binding constraint.

Also, where land is relatively scarce, what are the returns to land? More intensive management of agricultural production generally increases the returns to land, although some of the gains from increases in land productivity may be offset by reductions in labor productivity, unless there are new technologies available to offset these. Throughout much of the world, smaller farming operations have higher output per hectare, as larger operations optimize income by more "extensive" strategies, which means less investment of resources per hectare.

A further consideration that will weigh ever more heavily in 21st century agricultural decision-making is *returns to water*, which will often become a more limiting resource than land, labor or capital. Agricultural practices and systems that conserve water and use it more productively, such as mulching or permanent ground cover, will be more and more attractive. Nobody can know for certain what will be the effects of anticipated climate change, but higher temperatures and shifting rainfall patterns are likely to put stress on both irrigated and rainfed systems of production. This will make different crops, and land and water management practices more attractive in the future as modern agriculture is "thirstier" than many alternatives.

There is also a *time dimension* that needs to be incorporated in any evaluations. When agriculture has been conducted with heavy tillage and/or with applications of fertilizers and agrochemicals, the soil systems on which agriculture is based have diminished nutrient resources such as nitrogen and reduced populations of soil biota that support and protect plant growth as discussed in Chapter 6. Modern agricultural practices create a kind of dependence on continuing tillage and chemical applications because intensively-exploited soil systems become diminished in their capacities to sustain crop yields without continuing manipulation of or substitution for biological processes.

Switching to production systems that are less intensive with respect to external inputs usually requires some period of "transition" to restore more favorable biotic conditions in the soil. Yields may decline at first when external inputs are reduced. The question for farmers is how deep and how long such reductions are, and can they be reduced in their severity and duration? Further, can farmers manage such transitions within their own resource base, or do they need external financial support to make the transition to a lower-external-input mode of production? Such support is a kind of subsidization to put production onto a lower-cost track in the future. It is not very different in form but quite different in function from previous public sector subsidization of agricultural inputs such as fertilizers or pesticides to get farmers to switch onto higher-cost tracks. However, the benefit-cost ratios and sustainability can be much more favorable because costs and vulnerabilities are lowered.

These are difficult, multifaceted issues, often requiring more information than decision-makers, private and public, presently have in hand. With regard to ecoagricultural land use, which is our concern here, it is important to stress that any evaluations should be undertaken with a commitment to rely on empirical knowledge, fitted into defensible models or other kinds of systematic analysis, that are explicit about any value assumptions being made and not driven by preconceptions that either favor or dismiss certain modes of agriculture. Both modern agriculture and any ecoagricultural alternatives should be even-handedly evaluated, looking at all external as well as internalized costs and benefits of production. Analysis of any and all production systems should weigh their respective contributions to agricultural productivity, to biodiversity preservation and other environmental conservations, and to household livelihood and well-being, since agricultural sectors around the world in this 21st century will increasingly be challenged to justify themselves in terms of how they contribute to these three objectives, not just to outright production.

3.2 Addressing Tradeoffs and Complementarities

3.2.1 Biodiversity

Gains in the productivity of agricultural lands that Green Revolution and related technologies made in the latter part of the 20th century probably slowed the conversion of forest and other uncultivated areas to arable use, thereby making a contribution to the conservation of biodiversity (Dowswell and Borlaug 1995). There are, however, some analysts who object that the methods used had many unintended or uncounted consequences, particularly with regard to soil and water quality, so that the total effect was not as benign as Green Revolution proponents suggest (e.g., Altieri 1987).

We leave to others the task of sorting out how much debit should be placed against the credits attributable to the Green Revolution in this regard. There are debates over how much benefit was actually created since one should not attribute all gains in production since 1965 to the Green Revolution. The proper comparison is with any incremental productivity gains attributable to its new technologies over and above some baseline rate of improvement that might have been expected to continue. Sorting this out is complex. Probably the new technologies made some positive contributions to the maintenance of vulnerable ecosystems and to the species richness associated with them. But our task is to look ahead, rather than back, considering what are the most promising options now in this new century.

The most obvious way in which some if not all ecoagriculture practices can benefit from conservation of biodiversity, so that agricultural productivity and also livelihoods are improved, is through preservation of a more diverse gene pool for the species of crops and animals being grown and of their near-relatives. Some biotechnology visionaries envision a time when genes can be engineered rather than just relocated, but for some time to come, plant and animal breeders will probably have to rely on the genetic material that nature has provided in both variety and abundance, recognizing that some or much of this is in danger of becoming lost. Biotechnology opens up opportunities to utilize genes from a wide variety of species for any particular crop or animal improvement effort. But the natural pool remains the base for innovation. Practices and benefits associated with this are considered in Chapter 6, Section 6.2.1.

One facet of biodiversity that is given too little attention is the importance of this within soil systems that directly support plant life and, indirectly, all animal life including human beings. Modern analytical methods such as terminal restriction fragment length polymorphism (T-RLFP) are enabling microbiologists to gain more precise knowledge about the populations of microorganisms living and functioning in the soil.[2] The soil has been a kind of "black box" about which we have had only limited knowledge based on those organisms that are culturable, a small fraction of the total. Indeed, a large part of our soil research has been conducted under axenic conditions, i.e., after sterilization or fumigation has eliminated all living organisms, so that resulting explanations are framed in physico-chemical terms, minimizing or ignoring the biological dimensions of soil functioning. This gives a truncated understanding of how soil systems actually perform. It is like trying to understand the functioning of the human body through anatomy only, without studying its physiology, since studying sterilized soil samples is more like dissecting a cadaver than appraising the ways in which living organisms function.

What is widely known though still incompletely understood is that the fertility and sustainability of soil systems depend on a complex and intricate food chain/food web underground, well described by Wardle (2002). This differs from the common implicit view of soil as an inert medium for anchoring plants and a repository for (our) nutrients and water that are taken up by plant roots. That plants exude into the soil through their roots a substantial portion of the photosynthate produced in their canopies is not widely appreciated, though well documented in the scientific literature.[3] The carbohydrates, amino acids and other organic compounds put into the rhizosphere provide energy and other substances for the bacteria and fungi living in, on and around the roots. These microbes in turn are food for larger organisms like protozoa and nematodes, which in turn get preyed upon by collembola, mites and various other arthropods. All of these, as well as plant roots, benefit from the activities of earthworms and other fauna that make the soil better aerated, better aggregated, more water-retentive, suppressive of pathogens, etc. Plants are thus more active than passive, intricately interdependent with their environment. The disciplinary designation of "plant pathology" has focused scientific attention on the negative roles of microorganisms even though pathogens are a minority of soil biota, for the most part held in check by other organisms in the subterranean domain. As seen in Chapter 6, this understanding of soil and crop disease and health is gaining wider appreciation and acceptance.

No matter how much effort is made to "industrialize" agriculture through engineering and chemical interventions, it remains a thoroughly biological enterprise. Chemical and mechanical inputs can make agriculture more productive and predictable to a degree, but it will always be vulnerable to "extreme events," i.e., droughts, floods, heat waves, cold spells, as well as pest or disease attacks. The things that are included under the heading of "biotic and abiotic stresses" underscore how dependent food production systems are on a multifaceted environment that needs to stay within certain ranges of temperature, moisture, etc. if agriculture is to be successful. These affect not only the plants and

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[2] *This kind of analysis has showed, for example, that when nitrogen fertilizer is added to the soil, the expression of the nifH gene supporting biological nitrogen fixation by endophytic bacteria living the plant roots is inhibited and reduced (Tan et al. 2003). This general effect of inorganic fertilizer inhibiting soil microbial processes including biological nitrogen fixation has been reported in the literature for some time.*

[3] *See, for example, the encyclopedic treatments of this subject in Pinton et al. (2001) and Waisel et al. (2002). In general, about 40-60 percent of photosynthate goes into the roots, much of it used for metabolism; but a similar proportion gets exuded into the rhizosphere around the roots, where soil biota are orders of magnitude more than in bulk soil. Good examples of this literature on the symbiotic relationships between soil organisms and plant roots are Bonkowski (2004), Brimecomb et al.(2001), Dakota and Phillips (2002), Frankenberger and Arshad (1995), and Gyaneshwar et al. (2002).*

animals of immediate concern but the other organisms that have major effects, positive and/or negative, on productive outcomes.

With enough expenditure of energy and other external inputs, agricultural operations can withstand the effects of severe environmental fluctuations, but these are high-cost solutions except where the environment is naturally benign and reliable. Unfortunately, we appear to be entering a period when "extreme events" are becoming more common. Agriculture is sustainable only where, for the most part, "normal" environmental processes prevail or production systems are very resilient. Agroecosystems are better able to withstand the effects of biotic or abiotic "shocks" when they are more diverse, both in the crops that compose the farming system and in the total ensemble of species, plant, animal and microbial, that constitute the agroecosystem, and when soil systems are able to withstand various stresses. Much of modern agriculture has been premised on the economies of scale that can come with monoculture. But this has its own vulnerabilities which diversity within and among species, above- and below-ground, can mitigate.

3.2.2 **Ecosystem Services**

There is a more obvious convergence of interests between agriculturalists and environmentalists with regard to the functions that ecosystems perform in terms of the hydrological cycle and purifying water, land and air through biological processes (Section 6.2.8 in Chapter 6). Intact ecosystems within watersheds help to capture and store water in the ground, vegetation and microbial populations, at the same time filtering and detoxifying it so that more and better-quality water is available for agricultural, domestic and other uses throughout the year. Solid and fluid wastes get decomposed and can be made less objectionable (and often beneficial) through microbial activity. The maintenance of vegetative ground cover reduces soil erosion and loss from water runoff and wind, keeping land more productive and preserving water source quality. This also minimizes the costs of waterway, canal and reservoir siltation.

Both agricultural productivity and livelihood creation and maintenance are enhanced by having intact and functioning ecosystems. Agricultural production systems based on diversity from intercropping or rotation can be made more productive than monocropped ones, especially if full-cost accounting is done, calculating the costs of soil loss through erosion and of desiltation, for example. A small change in rice cropping systems in China showed that just by interplanting two different varieties of rice, one high-yielding but susceptible to blast infection with the other a local variety resistant to blast, production could be increased by 89 percent, with reduced costs of crop protection (Zhu et al. 2000). The benefits of reduced chemical applications for the biodiversity and health of the soil were not included in these calculations.

Agricultural practices and cropping systems commonly reduce the diversity of plant and/or soil biota, but they can enhance or sustain ecological services that contribute to biodiversity beyond the cultivated areas at least indirectly. Ecosystem services depend on a high degree of biodiversity if not necessarily on maximum biodiversity. Many farmers and even decision-makers who may place no particular value on biodiversity per se can be motivated to protect this for the sake of the ecosystem services that maintain the quantity and quality of natural resources—water, soil, air.

It is easier—though still often quite difficult—to put a value on these services than on the biodiversity that supports them, by estimating the value of soil lost through erosion and of crops foregone for lack of water, the costs of desilting rivers and reservoirs and of health problems resulting from impure air or water, etc. Economists and others have attempted to attach monetary values to such benefits, comparing them with the costs or other forgone benefits of achieving them. This effort has had some success and is the subject of considerable current interest, though it remains still inadequate for a fully satisfactory assessment as discussed in Chapter 5.

3.3 **Considering Ecoagricultural Approaches**

It is appropriate to think of ecoagriculture in terms of a *variety* of approaches rather than as a single thing or even single characterization. In Chapter 1, we reviewed the ecoagricultural strategies that McNealy and Scherr (2003) proposed as exemplifying this emergent approach. All can contribute to agricultural productivity while enhancing biodiversity either directly or indirectly. Although the term "agroecology" already has widespread use, the concept of ecoagriculture has merit by focusing on various kinds of agriculture, rather than on what appears to be a certain kind of ecology.

As suggested in Chapter 2, the approaches that come under this rubric should not be regarded as some kind of primitive or backward agriculture because they are not "modern," i.e., not do not rely on engineering, chemical or genetic improvements. What comes under the heading of ecoagriculture can be considered as "post-modern" agriculture in that it builds upon the science and experience of "modern" agriculture as it reorients agricultural development efforts in directions that are more suited to the requirements of the 21st century in terms of factor productivity. In this sense, it may be seen as the most modern kind of agriculture, drawing heavily on recent advances in the biological sciences about how soil systems function as the foundation for all agriculture (Chapter 6).

The reservoir of practices that can be drawn on for ecoagricultural development is based on knowledge that has been developed in the past 10-20 years or more by researchers in many countries. These innovations often have come from working closely with farmers and NGOs involved in innovations to resolve problems or constraints that they encountered when using what are regarded as modern agricultural methods under various circumstances. The innovations are responsive to variations in types of soil, topography of landscape, size of holding, labor, cash or other limitations, pest and disease problems, market failures, etc. They are thus as a rule more adaptive strategies, formulated inductively, rather than universal solutions based on general scientific principles deductively applied and validated on a few (small) locations operating under near-ideal conditions, as much of contemporary research-driven innovation in agriculture.

One common characteristic of ecoagricultural approaches is that these farming practices and cropping systems have a *plurality of objectives*, not just aiming to achieve the highest yield possible or the greatest net earnings per crop or highest present-year profit margins. Ensuring food security, maintaining stable as well as increased income over time, enhancing the natural resource base to assure productivity for this and the next generation, resilience in the face of shocks, and robustness on response to the vagaries of climate—these are all valid objectives.

Producing a surplus for market sales is always desirable for farm households, and this is important for countries as a whole, which need to assure the food supply for urban populations. But for many countries, the agricultural sector currently is not self-supporting, with hundreds of thousands or even millions of food-deficit households. This slows overall national growth because they are not yet productive enough to add much to net national output. Larger-scale, currently more productive farming operations may be very successful for themselves and for the national agricultural sector, but to the extent that their smaller-scale sector counterparts lack productive alternative opportunities for their underemployed labor, this subtracts from rather than adds to national wealth. Poverty reduction would thus benefit the whole nation, not just those identified as poor. This is why a concern with livelihoods ranks alongside the other two criteria for successful agricultural development.

There have been many advances in knowledge and practice in the last decade or two in a number of areas that can contribute to effective ecoagriculture initiatives, building on an accumulating scientific base but that warrant much more research both for evaluation and for improvement. As a foundation for this report, we undertook a review of component elements for ecoagriculture, surveying literature that has appeared just in the last five years in the main relevant scientific journals and discussing with faculty who are most knowledgeable about these areas of research and application to get their insights. The results of this effort to summarize the state-of-the-art are presented in Chapter 6. Here we summarize some of the key findings of this review, having already referred to current thinking on agrobiodiversity conservation and utilization above.

3.3.1 **Organic Systems of Production with Improved Soil Health and Biodiversity**

One of the factors driving modern agriculture with its dependence on engineering and chemical inputs has been the achievement of higher returns to capital and labor by displacing and reducing labor. One of the arguments against "organic" agriculture has been that it is too labor-intensive and thus is not competitive with mechanized agriculture relying on fertilizers for nutrients, rather than mobilizing them from soil processes, and on chemicals for pest and disease control. Organic farming methods find that chemical inputs can be reduced and eventually eliminated. While there may be some yield loss initially as the biotic systems below- and above-ground adjust (recuperate), cash outlays are reduced, so profitability may suffer little or not at all. As labor productivity increases with mastery of techniques and development of labor-saving practices and implements, costs of production are further reduced.[4]

The question from a food-production standpoint is whether aggregate output from such systems can compare with modern production methods. In the domain of horticulture, it is found that once soil systems have been enriched by various organic practices, yields can certainly be higher. A feature article in *Nature* (April 22, 2004) discussed the growing acceptance of "organic" methods and principles by conventional science and commercial agriculture, not to mention large-scale food companies. One factor that draws them together is a growing appreciation of the contribution of soil biology to agricultural production, discussed in numerous places throughout this report.

The further question is whether organic methods can satisfy the much larger basic demand for the staple crops that supply most of the calories in our diet, particularly for the poor. Conservation (no-till) agriculture (Section 6.2.9 in Chapter 6) is not necessarily organic, but it is evolving in that direction, reducing the need for chemical fertilizers and crop protection as soil quality is improved. In the U.S., over 30 percent of arable land is now under some form of conservation tillage, most of this for staple crops. Moreover, the System of Rice Intensification (SRI) (Section 6.2.10 in Chapter 6), though not necessarily an "organic" methodology, has been shown able, in some contexts, of doubling rice yields or more without requiring any chemical inputs, and saving water at the same time. It has been shown that in hilly areas of Central America, maize and bean production can be doubled or more with simple methods, not using mechanization or chemical fertilizers. The latter can add to yield, but chicken manure with green manure and cover crops can give better results (Bunch 2002). In these and other cases, greater labor-intensity frequently substitutes for external-input use, creating an additional set of challenges that may offset the gains achieved from lower external-input use.

There is one branch of organic agriculture that is based on philosophical principles, while another branch is more based on scientific understanding of soil processes and capacities. Both use similar practices that mobilize ecosystem services, so their results are quite similar. There are other branches that use organic practices for more mundane reasons, either because environmental protection regulations restrict their use of chemicals, because of adverse effects on groundwater and/or wildlife, or because given rising costs of purchased inputs (fuel, fertilizer, etc.) and premium prices received for chemical-free produce these alternative production methods are becoming more profitable.

Nature (April 22, 2004) reports that worldwide the demand for organic products is rising about 20 percent per annum. It concludes that the evidence on whether organic food products are healthier for consumption is too mixed to draw any firm conclusion (although the evaluations are mixed between showing health benefits and not, so probably there will ultimately be agreement on some benefits but maybe not as great as proponents suggest). In terms of impact on the environment, there are probable benefits from improved water, air and soil quality, though some studies do not show any significant improvement. The durability of benefits cannot be known because there are few long-term studies. On productivity effects, a 21-year Swiss study concluded that organic fields produce, on average, 20 percent less than conventional fields, though another long-term study in the U.S. found no difference, with a 20-40 percent advantage for organic fields in drought years, probably because root systems are more developed and soil systems more robust.

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[4] *One concern is that labor-intensity can be a disincentive for adoption of these practices. We discuss this important constraint further in the final section of this chapter. On the other hand, labor intensive production creates employment for the poor, who are most in need of livelihood enhancement. A reduction in labor-intensity which is a good thing for agricultural production considerations has negative consequences for livelihoods.*

A continuing point of controversy, noted in the *Nature* review, is whether organic farming can acquire sufficient nitrogen, without using fertilizers, to achieve and sustain the yields needed to feed large populations. If one compares organic matter inputs with chemical fertilizer, the former do not contain equivalent nitrogen. However, proponents of organic agriculture see this comparison as spurious, because the function of compost and other organic inputs is to serve as a *substrate* for soil biota more than to nourish plants directly. They advise: *instead of feeding the plant, feed the soil, and the soil will feed the plant*. This thinking is supported by what is being learned about "soil health" and belowground biodiversity (see Sections 6.3.6 and 6.3.7 in Chapter 6). To understand and evaluate organic methods thus invites a paradigm shift in thinking, though proper evaluation needs then to be as empirical and systematic as any other made in agricultural science.

There is still more unknown than known about the interactions among plants, soil, nutrients and microorganisms. But enough scientifically-respectable research is accumulating, documenting the contributions of microorganisms to soil fertility and sustainability as well as to plant performance, that previous dismissals of organic agriculture as outside the realm of science are no longer sustainable. This does not mean that all conventional agriculture can, should or will ever be given up. The adverse effects of chemical-based crop production and protection are often not very serious, or there may be little alternative to them for meeting immediate food needs. As said before, ecoagriculture is not intended to be a monolithic replacement for present agricultural systems and practices. The conclusion from our review of scientific understandings is that there are good justifications for more of agricultural production to be moving in this direction. In doing so, it can have beneficial effects for biodiversity and for livelihoods.

3.3.2 **Agroforestry**

The field of agroforestry arose in the late 1970s to make explicit the socioeconomic roles and biophysical functions of trees within tropical farming systems. Prior to this perceptual reorientation, trees and shrubs on farms and in farmscapes were not "seen" by mainstream agronomists and other scientists and professionals who had instrumental roles in shaping international agriculture technology and policy, because trees were the province of another discipline—forestry—and usually a different government department.

Since then, the science of agroforestry has explored the advantages of combined production systems involving trees, crops and animals and has generated a host of insights into how woody perennials interact with other elements of agricultural systems to affect their productivity and sustainability. A focus of research has been to determine the agroecological conditions under which particular agroforestry practices will generate multiple private and public benefits, and to understand the constraints in realizing this potential.

It is now well established that the key to effective practice is to design and manage systems that optimize complementary interactions and limit competitive ones. The initial promise of agroforestry stemmed from the realization that many early successional tree species were fast-growing and could deliver a variety of products and services that small farms needed, quickly and often simultaneously. Food, fodder, firewood and building materials could be produced by the same or a complementary selection of trees that also improved soil fertility and moisture retention. Over time research has produced a better understanding of the ecological, climatic and management conditions under which various combinations of trees, annual crops, and animals can or cannot generate multiple benefits on a sustained basis. In 1999 a publication series on "Advances in Agroecology" released a state-of-the-art volume, *Agroforestry in Sustainable Agricultural Systems*, edited by L. Buck, J. Lassoie, and E. C. M. Fernandes. The material in this compendium showed how agroforestry can contribute to sustainable agricultural productivity. We have drawn upon selected information from this volume to characterize the conceptual foundations of agroforestry that are particularly relevant to the assessment of ecoagriculture. In Chapter 6 we amplify how knowledge of agroforestry contributes to an understanding of the potential for ecoagriculture.

A conceptual foundation upon which tropical agroforestry research was initiated is that trees help maintain soil fertility and support the growth of associated crops (Rao et al., 1997). Today a substantial body of knowledge is available on the role of nutrient cycling in the maintenance of soil fertility in agroforestry systems. Nair et al. (1999) reviewed four major categories of agroforestry systems that occur across the four major agroecological/geographical zones of the tropics and demonstrated that agroforestry systems can provide nitrogen for crop production in all of them (hedgerow intercropping, parklands, improved fallows, and shaded perennial crop systems) under specified conditions. The review revealed that agroforestry systems are not capable, however, of providing sufficient amounts of phosphorus to maintain crop yields. The authors concluded that while the basic tree-mediated processes of nitrogen fixation, production and decomposition of tree biomass, and nutrient uptake from deep soil horizons are measurable, a lack of appropriate research methodologies prevents adequate determination of the dynamics of these processes under field conditions, thus making it difficult to predict the success of management strategies applying these processes.

Another cornerstone of the field of agroforestry research is that there are numerous wild species of trees and shrubs that have potential for being domesticated in agroforestry systems, to exponentially expand the timber and non-timber benefits of trees to farmers. The domestication and commercialization of trees is viewed by Sanchez and Leakey (1997) as essential to achieving agroforestry's potential to balance food security with the utilization of natural resources within an ecological framework "akin to the normal dynamics of natural ecosystems." Pointing to important tree-domestication successes worldwide, and with explicit attention to the nutritional value of new or improved tree products, Leakey and Tomich (1999) project high returns on research investment in domestication. They lay out a carefully reasoned agenda for expanding the efforts of public research institutions to domesticate more tree species in order to promote economic growth with enhanced food security and reduced poverty, while preserving the possible environmental services of wild species.

A third defining principle of agroforestry, in addition to roles of trees in soil and crop improvement and the direct benefits of tree products to households, concerns its relationship to the conservation of biodiversity. Pimentel and Wightman (1999) provide evidence of wild biodiversity conservation in multispecies gardens and in hedgerows/shelterbelts maintained along the edges of cropland and pastureland, while simultaneously reducing soil erosion and moisture loss. They point out also the roles of riparian tree buffers in reducing the negative effects of sediment and chemical run-off on aquatic life systems. Their conclusions, like those of many other researchers, are that agroforestry can provide the means to increase biomass, and in turn, improve food crops and livestock productivity, while simultaneously upgrading the productivity of degraded soils. They provide evidence of a doubling of grain crop yields in some agroforestry systems and of a 60 percent increase of animal products while protecting the soil from erosion.

3.3.3 Conservation Agriculture

The concept and practice of Conservation Agriculture has evolved out of a variety of zero-till, no-till and low-till practices over the past 30 years, as noted in Section 6.2.9 of Chapter 6. Three decades ago, the idea that one could grow field crops more productively and more profitably *without plowing* was for most farmers and scientists an absurdity—about as sensible as proposing that rice could produce better in unflooded paddies than in continuously flooded paddies, discussed in the following section. Yet, experience and scientific evaluations have shown that conservation tillage—ceasing tillage and maintaining continuous vegetative cover on fields—has many advantages for enhancing production with lower inputs and sustainable yield, also making agricultural domains more hospitable to biodiversity above and below-ground (Calegari 2002).

Agronomists have long known the negative consequences of plowing for many years: increased wind and water erosion, soil compaction, oxidation of soil organic matter, loss of nitrogen, adverse impacts on both aerobic and anaerobic soil organisms and loss of biodiversity among microorganisms, and loss of aggregation and desirable structural properties affecting, among other things, water infiltration rates (Brady and Weil 2002). However, the pragmatic need to control weeds made plowing an accepted practice, discouraging consideration of alternatives, particularly investigation of other means for weed control that could overall enhance desirable forms of biological activity in and on the soil. Avoiding plowing can cut erosion dramatically and encourages great soil microbial diversity and activity. It also avoids the destruction of biologically-induced soil aggregation and the ripping up of vast but unseen networks in the soil of the hyphae of mycorrhizal fungi which assist plant roots in acquiring water and nutrients from a greater volume of soil.

The initial experimentation with no-till has evolved into more complex systems for managing plants, soil, water and nutrients, including particularly permanent vegetative cover as CIRAD researchers working with colleagues in Brazil, Vietnam, Madagascar, Tunisia and other countries have done. It can sometimes take a few years to build up the fertility that has been lost through tillage practices, but higher levels of production are attainable with these methods and at lower cost (P. Hobbs, pers. comm.).

The CIRAD experimentation in Brazil has led to farming systems where yields of maize and soybeans can be raised by 50 percent with a 50 percent reduction in the use of external inputs, mobilizing nutrients already in the soil but unavailable with current practices and then recycling them. These methods adapted to the production of unirrigated (rainfed) rice have led to average yields over 8 tons per hectare, more than obtained in most irrigated rice production systems (Seguy et al. 2003). Some soil amendments can be used with conservation agriculture as it is not an "organic" production system. However, it evolves in that direction as soil biodiversity is enhanced with these alternative practices.

3.3.4 **Integrated Resource Management**

conservation agriculture is an example of a broader set of agricultural production systems that can be characterized as "integrated resource management," which includes what is called integrated nutrient management. Basically, integrated resource management refers to changes in the direct management of plants, soil, water and nutrients, which indirectly affect the abundance and diversity of soil organisms to obtain higher yields and greater production efficiency through synergistic effects among these resources. Where animals are part of the farming system, they are additional resources to be managed in complementary ways.

In Chapter 6 (Section 6.2.10), we report briefly on the most demonstrative examples of integrated resource management, achieving agricultural objectives more efficiently and beneficially as well as making the agricultural environment more hospitable to biodiversity, also improving livelihoods and well-being. We go into one example at some length here because it shows how more ecologically-grounded crop management can achieve greater outputs by using less external inputs, a strategy that will make ecoagriculture a more feasible proposition because the benefits of positive-sum complementarities can be enlisted to serve multiple objectives rather than have to wrestle with zero-sum tradeoffs.

The System of Rice Intensification (SRI) developed in Madagascar some 20 years ago and now is spreading around the world, with positive results demonstrated in about 20 countries. SRI often can double the yields of irrigated rice when SRI methods are used as recommended. This increase can be achieved at lower cost because:

- Farmers do not need to purchase and use any new seeds; the methods have worked with any and all varieties so far, eliciting a more productive *phenotype* from any rice genotype.
- Farmers do not have to apply chemical fertilizer; although this gives positive results, home-made compost usually gives better results at lower cost.
- Neither are agrochemicals usually needed, since as a rule, SRI rice is enough healthier and resistant to pest and disease attacks that chemical protection is not economic.
- Irrigation water can usually be reduced by about 40-60 percent; fields are not kept continuously flooded during the vegetative growth phase.

With costs of production being reduced while yield goes up, profitability is enhanced at the same time that adverse environmental impacts are diminished. SRI permits less water to be withdrawn from surface or groundwater supplies, and soil and water quality are improved when fertilizers and agrochemicals can be reduced.

This all sounds too good to be true, and there are objections from within the scientific community, as noted in

Chapter 6. But the objections are for the most part based on limited or incorrect information and on questionable assumptions. Once the methods applying SRI insights and principles have been adapted to local conditions and are popularized, many farmers appreciate their advantages, even if some scientists hold back. Examples from two countries show the scope for achieving agricultural improvements with SRI. Additional country experiences are summarized in Chapter 6.

- In Cambodia, where only 28 farmers could be persuaded (by the NGO known as CEDAC) to try SRI methods in 2000, by 2003 this number had reached 9,100, and this year, the number is expected to be between 40,000 and 50,000. Farmers who have tried the methods for three years have seen their yields go from 1.34 tons per hectare to 2.75 tons per hectare; their costs of production fall from 231,300 riels per hectare to 113,140 riels per hectare, and their net household income from rice go from 499,900 riels to 879,800 (Tech, 2004).
- The International Water Management Institute (IWMI) evaluated SRI methods in Sri Lanka with a survey of 60 SRI farmers randomly selected in two districts and 60 non-SRI farmers. The first group were not using all the recommended practices, or using them fully, but still averaged a 50 percent increase in yield. There was a 90 percent increase in the productivity of water used as applications could be reduced. Labor productivity went up 50 percent in the dry season and 62 percent in the dry season. Profitability of rice production (riels per hectare) went up 83 percent figuring labor costs at the prevailing off-farm wage rate and 206 percent if family labor inputs were not costed (Namara et al. 2003).[5]

SRI principles can probably be extrapolated or adapted for other crops, but rice may be more responsive to its methods because of this crop's genetic potential for profuse tillering. We have seen that SRI ideas applied to upland (rainfed) rice in the Philippines could give yields averaging over 7 tons per hectare, three to four times more than usually obtained without irrigation. SRI challenges standard thinking because its methods produce *more output with less total inputs*. In fact, initially SRI requires more labor input, while farmers are learning its methods, but once these have been mastered, many farmers find that SRI can even become labor-saving for them.[6]

How is this possible? The SRI experience suggests that it is possible to have the kind of complementarity and synergy in farming systems that can obviate the need for tradeoffs, having both more agricultural output and conservation of biodiversity:

- With SRI, by transplanting very young seedlings (8-12 days old instead of 3-4 weeks old), the plants' potential for greater tillering and root growth is preserved. This can be explained in physiological terms by an understanding of phyllochrons (see Section 6.2.10 in Chapter 6). SRI plants have 30-50 tillers, sometimes even 80 to 100 or more, with correspondingly larger root system—when other conducive SRI practices are also used.[7]
- With SRI, rice is planted much more sparsely, leaving wide spacing between plants. Instead of having 3-6 plants in a hill, single plants are set out in the field, not in a row but in a grid pattern with spacing of

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[5] *Of particular interest was that rice farmers using conventional methods were experiencing net economic losses from their production in 28 percent of seasons; SRI farmers only in 4 percent, so given the lower cost requirements and higher yields, SRI was also less risky. Contrary to the conclusion from some research in Madagascar (Moser and Barnett 2003), the IWMI evaluation found that poorer farmers were as likely to adopt SRI as richer ones, and were more likely to continue using it.*

[6] *In the first year, labor requirements can be 20-50 percent more. But in a Cambodia evaluation, 55 percent of the farmers who had three years of experience with SRI reported that it is easier to practice than their conventional methods; only 18 percent considered it more difficult, and 27 percent said there was no real difference (sample size N = 120) (Tech, 2004). In an evaluation done with Madagascar farmers (N = 108), it was found that SRI methods were labor-saving by the fourth year (Barrett et al. 2003).*

[7] *Farmers are beginning to experiment with direct seeding to save the labor required for nursery-making and transplanting, and this is also producing good results. Transplanting is not necessary with SRI; what is necessary is to avoid trauma to rice plant roots after they have begun their vegetative growth, i.e., beyond about the 15th day (the start of the 4th phyllochron of growth).*

25x25 cm or wider. This gives plants more exposure to solar radiation and helps achieve "the border effect" for the whole field, not just along the edges.[8]

- With SRI, rice paddies are not kept continuously flooded during the period of vegetative growth, only kept moist, and intermittently dried to induce deeper root growth. When roots are continuously hypoxic, they begin degenerating, so that by the time of flowering, when grain production begins, as many as 3/4 of the roots can have degenerated. This impairs plants' capacity for accessing soil nutrients, and makes the addition of chemical fertilizer all the more necessary. With SRI methods, it takes five to six times more force (kilogram per plant) to uproot rice plants because of their larger and healthier root systems.
- With SRI, it is recommended that compost be added to the field to support larger and more diverse populations of soil biota, in the idiom of organic farming, feeding the soil rather than the plants. Chemical fertilizer enhances yield with SRI, but not as much as will organic fertilization, because the latter serves as a better substrate for microbial populations. Further, the application of inorganic nitrogen suppresses the expression of biological nitrogen-fixing genes in endophytic bacteria that live in rice roots (Tan et al. 2003)

Thus, one can show with scientific explanations and validation why "less" can produce "more."

- Transplanting small, younger plants can preserve greater plant potential for tiller and root growth for physiological reasons that are documented in the literature.[9]
- Fewer plants per hill and per m^2 can produce more rice because the close spacing of typical rice production can reduce radiation in the lower part of the canopy even below the threshold for photosynthesis, which means upper leaves are "subsidizing" lower leaves.
- Less irrigation water means that plant roots do not degenerate, preserving their ability to take up nutrients throughout the growth cycle rather than begin senescing after panicle initiation. Alternating wet and dry soil conditions also contributes to soil biodiversity by getting both aerobic and anaerobic biota and giving plants the support of a wider range of organisms.
- Less or no application of chemical fertilizer and agrochemicals contributes to more abundant and diverse soil biotic communities which perform a variety of services for plants. These include besides biological nitrogen fixation, also phosphorus solubilization, greater nutrient uptake, suppression of soil pathogens, inducing systemic resistance, producing phytohormones to stimulate root growth and other services listed in Sections 6.2.6 and 6.2.7 in Chapter 6.

The case of SRI has been elaborated at length here because it shows new possibilities for developing agricultural production systems that are less dependent on external inputs and better able to match and benefit from the processes that occur in natural systems. This has been the guiding principle of CIRAD's research to establish more productive and sustainable farming systems in a wide variety of countries, mimicking as much as possible the ground cover and nutrient cycling of forest ecosystems.

This has been thought to be not productive enough to meet world food needs. But there is mounting evidence that these agroecological or ecoagricultural systems are often competitive in terms of sheer output, and more

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[8] *Scientists have recognized for years that rice plants on the edges of fields grow stronger and produce more. When taking samples to estimate yield, these must be taken from the center of the field "to avoid the border effect." However, this effect is only undesirable if it biases estimates; agronomically, it is something to be desired.*

[9] *Phyllochrons, similar to degree-days but better grounded in physiology, were first documented in research by T. Katayama in the 1920s and 1930s. He did not publish his results, however, until 1951, after World War II, and his book was never translated into English. Phyllochrons are still not much known among rice scientists, but they are studied by wheat scientists (see special issue of* Crop Science*, 35:1, 1995) and many forage scientists since this analysis applies for all gramineae species. It is well-known by rice scientists in Japan (Matsuo et al. 1997).*

beneficial in terms of profitability because costs of production are lowered. There is not enough length or depth of experience to make any firm judgments about the sustainability of such systems, but we need to remember that the modern, high-external inputs systems are not themselves prime candidates for sustainability.

It would be a mistaken and dubious enterprise to construct agricultural systems that cannot utilize any external inputs, and ecoagriculture does not take a doctrinaire position on this. It is not intrinsically "organic," even though it benefits from the insights and practices that have come from organic agricultural production. SRI is pragmatically rather than necessarily organic. If any nutrients become limiting, such as phosphorus, they can be added, probably with little adverse effect on soil biota if genuine deficits are being remedied. It is amendments in excess of plant and other biotic needs that create problems of soil and water pollution and of inhibiting microorganisms.

3.4 The Scientific Basis for Ecoagricultural Approaches

More detailed information and discussion of the body of experience and literature that informs the consideration of ecoagricultural alternatives presented here is given in Chapter 6. Unfortunately, there is very little literature that provides any specifics on the linkages and effects between agricultural practices and conservation of biodiversity, discussed in the next chapter. This is difficult to offer any overarching conclusions on the issue of tradeoffs vs. complementarities with regard to agroecological options. In general, the practices and systems associated with ecoagriculture should be more favorable for livelihood generation from the standpoint of reducing external-input-dependent modes of production that often are favored. The latter have typically tended to be labor-replacing or -displacing, through the mechanization of operations or the substitution of chemicals for manual labor. We have not found evidence that agroecological approaches have adverse impacts on livelihood creation, and they should, in general, be supportive of more and more diverse income streams for households most in need of income.

Agricultural practices such as those reviewed in Chapter 6—which reduce water extraction and/or chemical use, embrace polycropping in preference to monocropping, reduce soil disturbance and erosion, and so forth—are likely to reduce the impairment of soil biodiversity and to provide more hospitable habitats for a wide range of species. Thus, while no studies that we could find have calibrated biodiversity effects of these alternatives, general knowledge of ecological principles and dynamics suggests that the effects of these farming practices and systems should be benign or even positive.

There are a number of different kinds of biodiversity to be evaluated and supported, as discussed in the next chapter. Few if any kinds of agriculture are going to be solutions for protecting a particular endangered species of any genus. Conversion of wild lands to cultivation or grazing invariably will reduce the biodiversity that existed before agriculture was introduced. But if the agriculture itself has some degree of diversity, and fields have borders, hedgerows, windbreaks, etc. the level of conservation can be reasonably high, and certainly more favorable than conventional practices.

Even an agricultural sector as modern and bountiful as California's depends for its productivity and sustainability on the vast array of organisms of myriad species that live in, on and around the fields and pastures that produce crops and animals (Qualset, 1995). While it has been thought most efficient to focus research and resources on one species at a time, agriculture remains a thoroughly biological enterprise, where interactions and symbioses among species are basic to each species' success.

Ecoagriculture seeks to capitalize on such dynamics, which give it the chance, even with low inputs, to achieve high levels of productivity and be economically profitable. What is not known, given the limited experience with ecoagricultural approaches and even less evaluation research done on them, is how far they can be developed as an alternative to conventional agriculture, and in what and how many places. The scientific basis for pursuing ecoagriculture in many if not all places appears quite sound, even if it still needs and warrants further elaboration.

One important constraint to the broad applicability and dissemination of agroecological and ecoagricultural approaches, as previously mentioned, relates to labor demands and labor use. Very often, it is the substitution of labor inputs for externally-purchased inputs in these systems that makes comparable, or even increased, productivity levels achievable. These strategies yield significant benefits in economizing on the use of often unaffordable external inputs and achieving higher labor use among household members, as well as by increasing local and regional demand for labor. However there are numerous disadvantages that must be kept in mind. Family labor resources and local labor markets may be incapable of supplying the required labor demands, especially on a seasonal basis. Labor may have higher opportunity costs especially in peri-urban areas and other areas of relatively good infrastructure, and may thus be unavailable at the lower levels of remuneration common to agricultural employment. Finally, agricultural labor is typically hard and arduous work, and the prospect of doing more of it may be unappealing to many farm households. These and other limitations of agroecological approaches (documented in Lee and Ruben 2001), are important to keep in mind when evaluating the offsetting benefits of low external-input systems. Empirical evidence on the adoption and subsequent disadoption of agroecological approaches has confirmed that higher labor demands and related labor market issues are among the primary causes of disadoption where it has occurred (Neill and Lee 2001; Moser and Barrett 2003).

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Chapter 4

Meeting Biodiversity Conservation Objectives

> In 1981, as I emerged from a Ph.D. program in ecology, I sought real-world applications of the principles of ecosystem functions and ecological interactions I had been studying. Two areas of particular interest emerged: conserving biodiversity and enhancing sustainability of agriculture. I spent the next twenty years bouncing back and forth between them, often wondering why it seemed so hard to bring the two together, despite a common dependence on ecological processes for long-term success. *(Soule 2002:169)*

4.1. Considerations for Assessing Conservation of Biodiversity in Agriculture

Assessments regarding biodiversity are fraught with emotional pitfalls, misunderstandings of goals, terms, and concepts and a dichotomy of perspectives that sets "nature first" against "people first." We believe that much of this controversy is a confusion more often based on a mistrust of the perceived philosophy of the "other" camp than on real disagreements over issues. Over the past 20 years we have been involved in numerous discussions and graduate seminars at Cornell where the policy debate quickly polarized into one where proponents for biodiversity (usually biologists) argued with persons focusing on the plight of poor people trying to make a living off of the land (most often agronomists or sociologists). To conclude that biologists do not care about poor rural people or that social scientists studying agriculture do not care about the world's natural biota is too simply stated, and certainly wrong.

The interdisciplinary team preparing this report considers the conservation of wild biodiversity extremely important. We also consider the situation of poor people trying to make a living from agriculture dire. And we believe that the demands for an adequate supply of healthy, safe food for the increasing world population are critical. However, this is a statement of who we *are.* The question to be addressed in this report is: what are we going to *do?* Chapter 4 highlights what is known and what is not known about the varied relationships between agricultural practices and wild biodiversity. We build upon a selection of studies that have examined exactly these relationships. But before starting, a number of issues should be clarified with regard to assessing the conservation of biodiversity within agricultural settings: spatial scale; ecosystem health; domesticated varieties; and the overlap between wild biodiversity and agrobiodiversity.

4.1.1. Spatial Scale

We are trying to evaluate/assess agricultural systems/practices that maintain as much of existing biodiversity locally, regionally, or globally as possible. But clarification is needed regarding quantity vs. quality of wild biodiversity. The hierarchy of local to global diversity is important. For example, it is possible to increase aggregate biodiversity locally through various land-use practices, and the introduction of non-native species, while simultaneously making it impossible for certain "sensitive" species to survive there (Sax and Gaines 2003). If these sensitive species are the ones that tend to be lost in nearly every local situation, they become rare regionally, e.g., gray wolves (*Canis lupus*) or globally (Spix's macaws, *Cyanopsitta spixii*). Therefore, if one takes a larger spatial perspective, more biodiversity may be conserved globally if certain local practices encourage the conservation of certain sensitive species even at the expense of more common species (Lennon et al. 2004). The claim that certain agricultural practices actually increase local biodiversity may be true, but in some cases, the biota that they benefit may not be the biota that need aggrandizement. This point has been made in an agroforestry context by Schroth et al. (2004a). So claims that particular agricultural practices "increase biodiversity" need to be made clear: enhancing local biodiversity that may augment local agricultural productivity is quite different from conserving particular species as part of local biodiversity that actually contributes to global or regional biodiversity in need of protection.

For a very concrete example, we probably have more American robins (*Turdus migratorius*) and northern cardinals (*Cardinalis cardinalis*) in the northeastern U.S. than we did 300 years ago, because most "local" land-use practices inadvertently favor these species, but we probably have far fewer hermit thrushes (*Catharus guttatus*) and scarlet tanagers (*Piranga olivacea*), which require large areas of moderately old, contiguous forest. The global conservation status of a species should inform any assessment of a local practice that can affect a globally rare species or process *if one wants to claim that a particular local agricultural practice benefits biodiversity*. The term "biodiversity" includes millions of species; some of these species are in great need of help, while many are not.

On the other hand, the conservation of biodiversity that is locally, regionally, or globally rare may not be what is being claimed. Maybe the claim is simply that one local practice or system maintains more biodiversity than an alternative practice *on that site*. This claim is also relevant and important because when the conservation of rare species is not at stake, it is usually preferable to have more biodiversity, even if common, than less. It is generally believed that, all else being equal, having more biodiversity contributes to greater agricultural productivity than an alternative system that sustains less biodiversity on the same site.

There are many studies associating biodiversity *in toto* with agricultural systems' productivity and resilience, but the question is not easily resolved because of the complexity and multidimensionality of ecosystems and the fact that biodiversity even in undisturbed ecosystems is optimized rather than maximized. Multidimensional optima are devilishly difficult to identify. The relationships need not be symmetrical, as loss of biodiversity appears more disruptive than its enhancement from a stable system. A high research priority is to resolve uncertainties regarding such relationships, particularly between the diversity of soil biota and agricultural productivity (Johnson et al. 1996; Schlapfer and Schmid 1999; Loreau 2000; Griffiths et al. 2001; Bardgett 2002; Catovsky et al. 2002; Anderson and Weigel 2003).

4.1.2. **Ecosystem Health**

The quantity of biodiversity is often not the most relevant concept (Callicott and Mumford 1997). A more or less complete assemblage of the native biota, interacting and functioning normally, represents *ecological integrity*, and this in turn contributes to *ecosystem integrity*. As species are lost from a system, that ecosystem's integrity is increasingly compromised. True *ecosystem integrity* is likely only to be found in protected areas free of most kinds of human use and, therefore, it is not a realistic goal for agricultural systems. On the other hand, *ecosystem health*, which is determined primarily by whether ecological sustainability is possible, is a reasonable goal for any biological system, including those that are agricultural.

Ecosystem health focuses more on the thermodynamic properties of the system, on "multiscaled interacting processes, such as photosynthesis, energy transfer from one trophic level to the next, and nutrient cycling" (Callicott and Mumford 1997: 37). There are a myriad of human-created biological systems, e.g., tree farms, hayfields, and rubber plantations, that may exhibit *ecosystem health* even if not *ecosystem integrity* because they are missing most of the species native to that ecosystem type that were originally present there. Stated logically, *ecosystem health* is a necessary, but insufficient condition for *ecological integrity*, while *ecological integrity* is a sufficient, but not necessary condition for *ecosystem health*.

4.1.3. Domesticated Varieties

Domesticated varieties are undoubtedly important for agricultural productivity now and in the future. Support for this view is now legion (e.g., Thrupp 1998; Collins and Qualset 1999; Srivastava et al. 1999; Wood and Lenné 1999; Brush 2000; Kaihura and Stocking 2003). The genetic and morphological diversity present in the various breeds and varieties of domesticated plants and animals, although perhaps no more than a few thousand years old, should be conserved whenever possible. In fact, farmers in tropical countries often require, even demand, that they have access to certain varieties of plant forms that increase their options for dealing with future uncertainty (S. Padulosi, pers. comm.).

It is fairly common to find statements of the following sort: “Traditional agriculture conserves agrobiodiversity and safeguards reservoirs of genetic diversity” (Altieri 2004: 35). But Altieri is referring here to *agrobiodiversity*, not to wild biodiversity, and he is presumably referring to the genetic diversity found in crop varieties that farmers *have chosen* to cultivate in their fields. Those concerned with conserving agrobiodiversity see their goal challenged by the influence of seed producers and “modern agriculture” that encourage farmers to plant still fewer varieties with the promise of higher yields, thus narrowing the genetic pool for domesticated crops. However, the protection of wild biodiversity on agricultural lands seems an even more difficult and precarious task.

4.1.4. Overlap between Wild Biodiversity and Agrobiodiversity

The emphasis on biodiversity that is important to agricultural production, i.e., agrobiodiversity, is different from the focus on wild biodiversity as defined for ecoagriculture (McNeely and Scherr 2003). However, an area where these two categories of biodiversity converge is in the soil, which on some farms may contain as much wild biodiversity as a tropical rain forest.

Soil organisms are known to create a healthy soil environment conducive to better crop productivity (Brussaard et al. 2004), so below-ground biodiversity is likely to be encouraged by farmers and land managers through compatible agricultural practices whenever possible. If this link were well and widely understood—that the adoption of practices that contribute to below-ground diversity creates healthier populations of below-ground wild biodiversity, which leads to increased crop production and a diversity of above-ground wild biodiversity—there would be evident incentives for devising production strategies that benefit farmers and at the same time conserve wild biodiversity in agricultural landscapes. However, such a relationship is very complex and apparently equivocal, and some links are difficult to measure, let alone see (Adams and Wall 2000; Hooper et al. 2000). Research that makes these links clearer will have many benefits.

4.2. A Survey of Studies on Agricultural Practices and Conservation of Biodiversity

Expanding agriculture is often cited as one of the greatest threats to wild biodiversity. The ecoagriculture approach derives from the proposition that some agricultural practices, at least in some contexts, can maintain wild biodiversity within an area or landscape. We sampled the literature for studies that would provide evidence supporting ecoagricultural claims about the potential of agriculture to conserve wild biodiversity.

4.2.1. Loss of Biodiversity due to Monocropping of Large Areas

It is abundantly clear that agricultural practices have been instrumental in reducing the amount of high-quality habitat for wild biodiversity. This is especially true of certain crops, e.g., bananas, palm oil, and pineapple, grown on large acreages in tropical lowlands, where wild biodiversity would have been plentiful. Some of these areas would almost certainly be considered biodiversity hotspots today if millions of hectares had not already been cleared for this type of monoculture agriculture. A review of major crops and their impact on native fauna and flora has been undertaken by Clay (2004:166), who suggests, for example, that “It is quite likely that the production of sugarcane has caused a greater loss of biodiversity on the planet than any other single agricultural crop.”

Why is it that wildlife hate monocropping? An oblique but meaningful answer goes something like this: “If you build it, they will come.” The vast majority of herbivores are insects, and in fact, the number of species of insects on earth probably exceeds that of all other life forms combined (Erwin 1982). If a field or a landscape is comprised of one species of plant, there is a limit to the number of species of herbivores that will be attracted to feed or oviposit eggs on those plants, even assuming that no chemical control by humans is involved.

Herbivorous insects have evolved the ability to process the chemical compounds in the plants on which they feed, and especially in the tropics, each plant species represents a different suite of compounds to which insects must adapt. For each plant species, there is some finite number of herbivores capable of feeding on that plant. As the number of plant species in an area increases, the number of herbivores likely to be found among them also increases. With an increase in herbivores comes an increase in predators and parasites, each adapted to feeding on or parasitizing a subset of the herbivores found in this system.

It is really simple arithmetic. More species of plants results in more species of herbivores, which attracts more species of predators, parasites, and parasitoids, etc. As the number of invertebrate species increases, the area becomes more attractive to vertebrates that feed on them, e.g., birds, bats, frogs, and a variety of mammals. So as the number of plant species increases, so does the number and variety of vertebrates that feed directly or indirectly on plants.

This considers only feeding behavior. The physical structure of the vegetative community is also important. If you have many layers of vegetation reaching from the ground to many meters high, including herbaceous ground cover, shrubs, small trees, and canopy trees, there are diverse assemblages of organisms that have adapted to each of these strata. With these vegetative strata come many more nooks and crannies, e.g., hollow trees, decaying logs, and leaf masses on tree branches, that attract and support animals to breed and nest there. As the arithmetic continues, biodiversity increases. It is expected in wildlife biology that if the appropriate habitat is available for any organisms that are adapted to using it, they will appear in time, assuming they still exist somewhere in that landscape.

Most of the world's agriculture is not comprised of large acreages of a single crop. Millions of small landholders around the world farm relatively small parcels of land for their subsistence. And because of the need to hedge the risks of crop failure and assure household survivability, farming systems are often quite diverse. This means that the potential to improve productivity, economic viability, *and* conserve wild biodiversity on these parcels is high.

4.2.2. **Quantitative Studies of the Effects of Agricultural Practices on Wild Biodiversity**

We examined the agricultural and biological literature for studies that document a correlation between the implementation of a particular agricultural strategy, or suite of practices, with some measure of wild biodiversity. We surveyed peer-reviewed journals, government reports, in-house documents on experiments or field trials, and other sources of written information from studies that provide evidence—or an absence of evidence—for a claim that a particular agricultural method conserves biodiversity. Results were included only where the investigators actually quantified the amount or kinds of biodiversity. We organized these studies within a matrix depicting the range of both agricultural techniques and measures of biodiversity, e.g., taxa or habitat conserved.

We also interviewed numerous individuals responsible for, or knowledgeable about, agricultural practices and their effects on biodiversity. We received many e-mails containing suggestions, references, people to contact, philosophical concerns, and other factors to consider. This section summarizes the results of our literature review, drawing also on any other sources of information that would temper or bolster our statements based on this literature.

Our sample includes 79 studies that met these criteria, although this set of studies is by no means exhaustive (Annex 4). It should be viewed as a representative sample of the kinds of results being produced by those who study agriculture and its effects on wild biodiversity. The table is organized by the single variables examined by these experimental studies, which is the approach generally used in field studies, i.e., all other variables are isolated in an attempt to get an answer about the effect of perennial crops vs. annual crops on birds, for example. The number of column headings (n = 18) suggests the complexity of this issue for the real world, where several of these variables may be extant and interacting in complex ways on the same site. To make matters more complicated, the calculus of a particular set of interacting variables is likely to have different effects on different taxonomic or functional groups of wild biodiversity.

Nevertheless, there are quantifiable results. We found that 9 of the 18 ecoagricultural strategies that we surveyed were found by at least three authors to affect diversity of at least three taxa. The strategy most often correlated with the conservation of wild biodiversity was the maintenance of adjacent hedgerows or woodlots. Eighteen of the 24 studies addressing that strategy documented positive correlations with eight taxa plus the conservation of natural habitat. Organic agriculture was correlated with increased diversity of seven taxa plus habitat in eight studies. Shaded tropical agriculture, especially coffee and cacao, were found to have higher species richness of three taxa by eight different studies. Most importantly, this literature matrix points out some patterns in the research and reveals some important gaps. It should therefore be useful for strengthening the call for more research and focusing it on the direct conservation benefits of sustainable agriculture practices. For example, many proscriptions are likely to be criticized as site-specific, taxon-specific, or agronomic-specific, and some of those that measured biodiversity across taxa found inconsistent or even inverse correlations. Few studies included economic or productivity data, or linked directly to parallel studies with such data. And most studies relied on local species richness without any direct measure of impacts on or implications for regional biodiversity.

More broadly, a few high priority knowledge gaps merit mention. First, the current debate over the linkage between diversity and ecosystem functioning or ecosystem stability is not likely to be settled soon, and yet important advances are being made. One of the most important aspects of this debate, regarding the nexus between agriculture and conservation, is the agricultural value of below-ground biodiversity. Several studies have demonstrated that application of agricultural chemicals, especially pesticides, herbicides, etc., significantly reduces soil biodiversity, while the reduction or elimination of those chemicals results in higher below-ground biodiversity.

Insofar as soil biodiversity is associated with agricultural productivity, studies should be done that directly assess net costs or benefits of alternative production practices using chemical fertilizers. What increased production costs result from chemically-intensive farming, or lower value of production when soil is degraded biologically? Once soil is being chemically fertilized, continued applications are usually needed to sustain or raise production. (More inorganic nutrients are needed to compensate for loss of organically-mobilized nutrients.) Is the increased production from fertilizers worth more than the possibly foregone income (higher cost of production with eventually lower yield)? We need reliable knowledge comparing “with” and “without” systems of production, and not just in a single year (when the effects of previous chemical applications are still strong) but over some number of years. This is a controversial subject because modern agriculture is wedded to the use of fertilizers, but a biological and an ecological perspective raise questions about both profitability and productivity over time, seeing a financial value in soil biodiversity.

4.2.3. **Issues of Measurement**

To aid in the discussion of biodiversity conservation, further work needs to be done to refine methodologies for measuring biodiversity. Standard indices for biodiversity should be developed that allow for on-site measurements that are relevant to regional and global biodiversity. These could include: 1) weighted analyses that incorporate the conservation value of endemic, rare, or threatened species; 2) measurements of reproductive success, rather than simple presence vs. absence counts; or 3) assessment of the impact of any local species assemblage on regional or global biodiversity. Better assessments of biodiversity will be a vast improvement over the current common practice of simply counting the number of species present.

Further, creating an index or other methodology is only the first step. Improved measurements will be valuable only if they are widely adopted. For example, conservation biologists have developed sophisticated means to classify habitats. They quantify characteristics such as vegetation type, spatial components (size, configuration, location within the broader matrix), and the importance to wildlife to assess the value of a particular area to conservation. Some conservationists already incorporate these factors into their projects. Conservation International (CI) is working with soybean farmers in the Brazilian *Cerrado* to protect the rapidly disappearing forests there. Farmers are legally required to set aside a certain percentage of their land for conservation. CI attempts to classify and prioritize remaining forest areas and encourages farmers to set aside those parcels that are most threatened or most valuable for regional conservation of wild biodiversity (Conservation International 2003; B. Semroc, pers. comm.). Too many projects at present claim a conservation benefit when any "habitat" is protected, with little mention of what that habitat actually represents, or what species it supports.

4.3. Principles of Habitat Management for Maintaining Biodiversity

Habitat fragmentation is the most serious threat to biological diversity and is the primary cause of the present extinction crisis (Wilcox and Murphy 1985).

It is impossible to study every agricultural practice and to evaluate all of their effects on biodiversity. Fortunately, enough work has been done to produce some biological generalizations that seem to be true over most geographical areas (e.g., Hansson et al. 1995). Biologists always end up concluding that it is the quantity and quality of habitat that is the limiting factor for biodiversity. The following principles of reserve design (Meffe and Carroll 1997) can be adapted to thinking about agricultural landscapes, by replacing the word "reserve" with the word "habitat patch." It is our belief that if you asked a representative sample of ecologists or conservation biologists about the following statements, most would agree, for example, that larger habitat patches are better at protecting wild biodiversity than smaller habitat patches.

4.3.1. Landscape-Level Recommendations

The following propositions are reasonable ones to guide recommendations for the management of any agricultural landscape.

1) SIZE: A larger habitat patch is better than a smaller habitat patch. Assuming that the two patches are the same shape, the smaller patch will have a greater proportion of its area affected by any "edge effects."

2) HETEROGENEITY: Habitat patches that are spatially and temporally heterogeneous, i.e., in terms of soils and abiotic factors, are usually superior to habitat patches that are homogeneous, especially with respect to plant species and morphological types, i.e., herbs, shrubs, and trees. A diversity of edaphic conditions tends to result in a greater diversity of plant species, which should result in turn in a greater diversity of animal species.

3) SETTING: The landscape context within which the habitat patch sits is important; the less "hostile" the landscape is in general, the more effective that habitat patch will be in maintaining biodiversity. For example, a patch of mature forest is more likely to maintain its biodiversity if surrounded by a young secondary woodland than if surrounded by cattle pasture.

4) CONNECTEDNESS: Connection among habitat patches is generally advantageous, so that the issue of *corridors* must be addressed. Habitat connections among patches are almost certainly beneficial for the dispersal of some species, though perhaps negative for others, and neutral for most. However, the weight of critical thinking on this issue still recommends having connections whenever possible. In addition, the connection itself represents habitat to some wild species.

5) PREFERENCE FOR UNDISTURBED AREAS: Natural physical units (e.g., ridges, canyons, drainage basins) and modified landscape elements (e.g., roads, cities, agricultural fields) should be identified. Having a diversity of natural elements in any landscape will enhance its biodiversity value, while modified elements detract from that value. Disturbance of almost any kind encourages the invasion of non-native species and weedy species. This does

not mean that modified landscapes are invariably hostile to biodiversity but rather that having more undisturbed areas confers biodiversity benefit.

6) MODERATION OF SHARP CONTRASTS: Buffer zones that "soften" the ecotone between the habitat patch and modified landscape elements should be encouraged. All natural habitat patches are influenced by the matrix in which they are found; the less difference there is between the patch and its matrix, the better.

4.3.2. **Additional Principles**

In addition, four general principles of good conservation management can be suggested (Meffe and Carroll 1997):

1) Critical ecological processes and biodiversity composition must be maintained. Of course, these have to be identified before they can be maintained, and determining what process is critical is not usually simple.
2) External threats must be minimized and external benefits maximized. The greatest external threat to a patch of natural habitat, aside from destroying it outright, is the invasion of non-native species or some form of pollution. Indigenous people often represent an external threat to the remaining habitat patch, but their knowledge of the local fauna and flora also represents a benefit.
3) Evolutionary processes must be preserved. This is a difficult principle to implement, because of the long time horizon that must be adopted. It is always a worthy goal, however, and can be approached by maintaining as many of the biological elements of the system as possible. Refer to the goal statement for conservation biology in section 1.6.1.
4) Management must be adaptive and minimally intrusive. This really applies particularly to natural areas that are actively managed for wild biodiversity, but the general advice is wise. Tread softly, proceed slowly, and evaluate what you do as you go.

These various propositions and principles provide some theoretical foundations for assessing different agricultural systems/practices with regard to their contribution to, or compatibility with, biodiversity conservation. Because biodiversity is multi-dimensional (4.1.2), evaluating its extent and status, as well as changes in these, is challenging. If the processes and dynamics that produce these outcomes are regarded as a kind of "black box," making assessments becomes that much more difficult. Accordingly, it is important for environmentalists and agriculturalists to have some agreement on the "intermediate" factors so that these can inform evaluations, knowing something about mechanisms and causal influences for what are admittedly very complicated and inexact outcomes.

4.4. **Intensification of Agriculture and the Conservation of Biodiversity**

The primary question here is whether intensification of agriculture in some locations saves natural habitat elsewhere from being converted to food production, an argument put forth by Pagiola and Kellenberg (1997) and Borlaug (1998). This issue was a major concern at the DIVERSITAS workshop/scoping meeting held in Alexandria, Egypt in May 2004. However, there was no agreement on a definition of the term "intensification." Some believed it should be defined by the level of inputs per hectare and others by the yield per hectare. The term can be and is used differently by different disciplines and individuals. We presented the three main uses of the term at the end of Chapter 1. A World Bank publication states: "A basic principle of biodiversity-friendly policy reforms is to *discourage agricultural extensification* and *encourage agricultural intensification*." (Pagiola and Kellenberg 1997: viii, emphasis in original).

If by intensification, one means that the agricultural fields are so heavily manipulated physically and chemically to increase yields at the expense of nearly all wild biodiversity on that site, then the entire justification in biodiversity terms must rest on this increase in yield saving natural habitat elsewhere since the production process in this manner reduces or degrades habitat in and near the site of production. There may be many reasons why natural habitats are still being converted besides the need to produce more food, so modern, energy- and chemical-intensive agriculture should not be blamed for all habitat loss. However, because so much of the world's land area is employed in agricultural production, it seems unnecessary and unwise to "write off" wild biodiversity on the 40 percent of the world's surface in agriculture with the hopes that the remaining natural habitats will become repositories for all the remaining fauna and flora on earth not exploited for agricultural purposes.[1] If nothing else, agricultural lands are potential connections among the remaining natural habitats (see item 4 in 4.3.1). Therefore one can argue that this function, at a minimum, should be encouraged (Kreuss and Tscharntke 1994).

On the other hand, if intensification means increasing yields by some means other than the high-input, monoculture approach, e.g., by crop diversification, then there is potential for on-site conservation of wild biodiversity as well as agrobiodiversity. A recent study in northern Greece found yet again that the species richness of woody plants was the best overall bioindicator for several groups of plant and animal biodiversity (Kati et al. 2004). This was compatible with the diversified agriculture practiced in that region. One can say that if intensification involves diversifying crop varieties, with encouragement of a diversity of native woody plants, then there can be overall increase in species diversity. Again, the exact approach to "intensification" makes a difference in biodiversity outcomes. On this, Edwards et al. (1999) offer useful insights.

4.4.1. **Ecosystem Services**

But are there stronger reasons for agriculture to foster populations of wild biodiversity on agricultural lands? That nature can provide benefits to humans simply by allowing ecosystems to function naturally is now commonly accepted (Costanza et al. 1997; Daily et al. 1997; Daily and Ellison 2002). Ecosystem services are "ecological processes that benefit people" (Luck 2003). These include maintaining hydrologic and nutrient cycles, providing beneficial interspecific relationships (pollination, pest control), and sequestering, filtering or degrading contaminants, to name a few. For these services to be available, viable populations of native biota need to be present and fulfilling their role in that system (Ostfeld 2003). For example, wetlands are known to remove excess nitrate deposited from the atmosphere or moving from agricultural fields before it reaches streams and lakes. However, without the presence of denitrifying bacteria, the removal does not occur (Toet et al. 2003). Simply looking at two wetlands, one with and one without these important bacteria, would not reveal which wetland contains these essential organisms. Simply observing some habitat or agricultural system does not reveal the critical evidence on whether that system has the health or integrity to provide ecosystem services other than the most basic, i.e., all plants remove carbon dioxide from the air. Rigorous measurements or studies need to be conducted. Although Annex 4 lists examples where agricultural practices are compatible with or even conserve various forms of wild biodiversity, it would be extremely valuable to produce a comparable table showing documented examples of how wild biodiversity specifically aids crop production.

Although much is still to be learned about this, many are sure that the ecosystem services provided by wild biodiversity are advantageous to those trying to produce food (Paoletti and Pimentel 1992; Letourneau 1997; FAO 2003). However, the debate continues over how much and what kinds of biodiversity are necessary to enable ecosystems to function properly. As land use intensifies, Loreau et al. (2001) believe that a larger pool of species is required for proper assembly and functioning of ecosystems. The hypothesis cannot be rejected however that a few dominant species can provide sufficient functional diversity to explain primary production in grassland ecosystems.

Again, much of the purported value of biodiversity in this regard is below-ground. In addition to the usual suspects that are known to be important to soil health (e.g., bacteria, fungi, earthworms, etc.), ants, which spend time below and above ground are also important. Ants score second in animal turbation only to earthworms, but ants have a wider geographical distribution (Folgarait 1998). In Argentina, for example, *Camponotus punctulatus* move 2100 kilograms per hectare per year of soil in sown pastures to construct their mounds. On the negative side of the ledger, most forms of agriculture or other disturbances examined (except fire in Australia) have resulted in a decrease in ant species richness (Folgarait 1998, Table 2).

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[1] *This discussion of agriculture is, obviously, focused on field-crop production, where the issue of intensification and monoculture is most evident; there are also some intensive uses of aquatic and marine ecosystems. The same issues apply in those exploited areas.*

4.5. Conserving Wild Biodiversity in Agricultural Landscapes

The results of studies listed in Annex 4 show that some agricultural approaches are more benign than others with respect to conserving wild biodiversity. For example, the most studies that we found actually documenting conservation benefits were studies on the value of maintaining hedgerows, windbreaks, or natural habitat adjacent to agricultural fields (also see Schroth et al. 2004b). Similarly, organic agriculture, and shaded tropical agriculture have been well-documented to maintain more species at all or nearly all taxonomic levels than the standard modern practices that these ecoagriculture strategies replace. However, those are simply the practices that have been best studied. Therefore we conclude that there should be increased research on other practices, rather than endorse the practices we know most about. Further, most of these studies have relied on simple on-site species counts, and therefore are missing a key facet of biodiversity conservation: impacts on regional or global diversity. More studies are needed to provide this link to determine whether agricultural systems implementing these strategies reduce or encourage the conversion of more natural habitat.

This should be no surprise that different agricultural practices should result in different effects on native flora and fauna in localities, given that those practices foster different sets of ecological interactions. Determining such results is demanding in terms of data and better methodologies, but even doing so is a long way from demonstrating that introducing "better" agricultural practices on farms will have significant consequences for local or regional biodiversity. In The Netherlands, for example, agri-environment schemes have been established, but overall landscapes are so affected by intensive agricultural uses in general that the on-farm schemes have had little positive effect thus far on wild biodiversity relative to nearby fields not under the conservation schemes (Kleijn et al. 2004).

There is a danger in concentrating too intently on individual fields, or plots or crops. The context within which those units exist is extremely important. The principles governing these relations have been well articulated in recent reviews sanctioned by the Ecological Society of America (Christensen et al. 1996; Dale et al. 2000). Understanding what needs to be done to conserve wild biodiversity in agricultural landscapes is difficult, but enacting the appropriate changes on the ground without compromising economic and productivity gains will be even more difficult. Any gain in conserving wild biodiversity without significant losses in the other two spheres should be reason to cheer, and how to accomplish that constitutes the greatest information gap in ecoagriculture. As seen in Chapter 3, there are promising areas of research and practice, but selecting, adapting, and welding them into large-scale application remains a challenge to scientists, policy-makers, and agriculturalists alike.

Perhaps we need to think even further out of the box. Would it not be possible to create entirely new habitats on agricultural land, which encompass both cultivated and wild plants, herbaceous and woody plants in edible, medicinal, and structural forms, highly cultivated areas and those that are much less so, with a diversity of domesticated livestock along with wild vertebrates and invertebrates? It would mean thinking about landscapes anew, almost as if they were devoid of life, like many degraded agricultural environments, and intentionally designing landscapes that purposefully include wild and agrobiodiversity, with humans who live off the products of this design?

Such an Edenesque result would require community and population ecologists, agronomists, landscape ecologists, and even landscape architects, horticulturists, city and regional planners, working closely with local residents who have indigenous and practical knowledge. The novel result might protect more biodiversity than the present piecemeal, "hold onto what you can afford to" approach espoused now. Many people spend their lives trying to design towns and cities that are physically and psychologically healthy for their inhabitants, and that function efficiently. Why should a diversity of scientists and farmers not attempt to design agricultural landscapes from the ground up with the same kind of goals? Actually, this idea is decades old. It was proposed by Wilson and Willis (1975) as a way to at least think about designing future nature reserves in a degraded world. They termed this approach "applied biogeography." To initiate such a process would require a great deal of knowledge about species interactions, the compatibility of domestic and wild species of plants and animals, the appropriate spatial configuration of land uses for maintaining viable populations of wild species in an agricultural matrix, etc. The questions that need to be answered are not entirely new, but the novel context within which these questions would be asked might lead in unexpected directions.

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ANNEX 4: Examples of Studies that Examine the Quantitative Relationship Between Various Agricultural Practices and Wild Biodiversity

Taxa or surrogate of diversity measured	Ecoagricultural strategy: agricultural practice claimed to conserve biodiversity								
	Shaded tropical ag.	Trees in pastures	Other agroforestry	Other mixed cropping	Perennial crops	Low-tillage	No-tillage	Increased fallow	Other grassland mgt
Mammals									
Birds	76, 75, 34, 58, 54, 46	28, 39		11	72				57
Ants	52, 53, 54, 3	24							
Other vert.species									
Soil invert.species			44	63				43	
Other invert.species	54, but no 60	24	65, 1	68, 42			68		20, 45, 56
Soil microbes				68		27	68		
Soil biomass						27		74	74
Soil organic matter	64				72, 32			74	74
Trees	64		8						
Other plants	64	39							10, 7

Taxa or surrogate of diversity measured	Ecoagricultural strategy: agricultural practice claimed to conserve biodiversity								
	Reduced chemicals	Organic	Other Euro innovation	Post-harvest treatment	Managed flooding	Eco-certification	Lower intensity ag.	Adjacent hedgerow, forest.	Landscape level practice
Mammals								67, 16; but no 13	
Birds	57, 69	9, 10, 29		10, 15	6, 26, 25, 71		48, 57	37, 19, 48, 13	59, 66, 48, 57
Ants		53		17, 26				24, 3	
Other verts.	36							31	
Soil inverts.	50	49			6		50		
Other inverts.	4	but no 73						24, 13, 2, 4, 56, 60, 70, 22, 41	66, 18, 32, 73, 41, but mixed 44, no 42
Soil microbes	50, 14, 18	49					50		
Soil biomass		55					74		
Soil organic matter		61					74	62	
Trees						but no 35		38, 8, 30; but no 13	30
Other plants	10	5, 73	10				77, 12	37, 78, 30, 12; but no 13	77, 66, 30, 73

Literature Matrix Index

Code	Citatio
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Chapter 5

Meeting Livelihood Objectives

5.1 Introduction

Enhancing ecosystem and environmental outcomes together with improved food security and rural livelihoods is one of the central tenets of sustainable development in rural areas. Specifically, ecoagriculture strategies seek to conserve wild biodiversity in agricultural landscapes while enhancing agricultural and food production and rural welfare (McNeely and Scherr 2003). To be sustainable, conservation of wild biodiversity in productive landscapes should not compromise the enhancement of economic well-being, locally or globally. The challenge facing ecoagriculture strategies, therefore, is that of generating complementary outcomes among three goals: (i) improving household livelihood objectives such as food security and income generation; (ii) achieving productive land uses (agriculture, forestry, etc.) that contribute to household economic (and other) objectives; and (iii) achieving biodiversity conservation that generates environmental benefits.

The simultaneous achievement of these outcomes is a challenge, conceptually and in practice. To date, empirical analyses of alternative land use practices have tended to reveal an inconclusive relationship among achieving livelihood enhancement, biodiversity conservation, and productive land uses. In one prototypical example, household level research in two settlements in the western Brazilian Amazon found that among alternative crop, livestock, and extractive activities, improved pasture-livestock systems involved low labor requirements and were the most profitable for households in terms of returns to labor, but ranked low in terms of carbon sequestration (Vosti et al. 2002). The authors also concluded in this case that “agricultural intensification appears to be at odds…with plant biodiversity” (p. 258). Elsewhere, improved nutrient management and soil-health related practices are being advocated, yet the economic viability of these systems remains uncertain (Gobbi 2000; Lyngbaek, et al. 2001). Research that directly evaluates alternative livelihood strategies which simultaneously conserve wild biodiversity is in its infancy (Carpentier et al. 2000; Williams et al. 2001; Stolton 2002). Syntheses of research on agricultural intensification have identified conditions under which synergies, rather than tradeoffs, may emerge that simultaneously achieve diverse social objectives, consistent with ecoagriculture strategies (Vosti and Reardon 1997; Lee et al. 2001; Margolius et al. 2001; Jagger and Pender 2003).

These and related outcomes raise numerous policy questions. In general, are ecoagriculture strategies best characterized by tradeoffs or synergies among multiple goals? More broadly, is it more efficient to spatially segregate or to integrate biodiversity conservation, food production and local economic development? In integrative conservation and development efforts, how are the costs and benefits distributed with respect to economic growth, employment, and the livelihood concerns of small landowners? Such questions raise the issue, more generally, as to how tradeoffs or complementarities between objectives may be identified and assessed.

Economic analysis can contribute in multiple ways to a framework for assessing possible tradeoffs and complementarities among the objectives of different ecoagriculture strategies. An ideal livelihood-oriented framework would employ multiple measures of household welfare, including cash income, health, food security, and risk minimization, and would recognize that non-monetary factors (e.g., social capital and norms) also influence decision-making (Ashley 2000). Because ecoagriculture strategies involve landscape level changes and multiple objectives, economic analysis should reveal the distribution of monetary (and non-monetary) costs and benefits associated with different practices among different stakeholders. In addition, analysis should ideally assess the contribution of different market and non-market mechanisms in equitably redistributing costs and benefits (e.g., compensating farmers for conserving biodiversity). At a macro level, economic analysis can bring considerations regarding trade policies, local, regional and national market arrangements, and incentives, subsidies and technology adoption measures into the analytical framework. Achieving all, or even most, of these diverse objectives in a single study however is a tall order.

In this chapter we examine how economic analyses centered on achieving livelihood objectives can assist in determining whether ecoagriculture is a suitable option for a particular landscape, what factors influence the viability of ecoagriculture at the local and regional level, and what policy conditions enable and obstruct ecoagricultural approaches to land use. We begin by discussing some key livelihood and policy considerations that pertain when assessing complementarities versus tradeoffs among the three objectives of ecoagriculture. We also describe, on a selective basis, the characteristics of existing and emergent models and methods that would enhance an ecoagriculture analytical framework. We review quantitative and mixed models for examining and understanding key relationships. We conclude this chapter by discussing the strengths and limitations of existing models and identify areas requiring additional research to strengthen the economic knowledge base underlying ecoagricultural strategies.

5.2 Considerations in Assessing the Livelihood Impacts of Ecoagriculture

The potential contributions of economic analysis to a framework for examining ecoagriculture approaches will vary depending on the objective of the research project or development program. Some generalizations are possible, however. At the household level, economic analysis can identify and incorporate financial, demographic, biological, management and institutional factors that inform decision-making. It can also reveal the economic implications of alternative land use and technological practices given a household's orientation toward alternative welfare-maximizing objectives (i.e., achieving food security, minimizing risk, or generating income). And it can simulate the farm and household-level effects of policy changes that may modify output and input prices, input availability and costs, or new legislation that may influence resource management decisions.

At regional and national levels, the concerns of policymakers are often somewhat different. Regional adoption profiles, aggregate market impacts, and regional environmental effects resulting from the introduction of new technologies or systems are often of central interest. National sector-level effects of domestic and international policy changes are of great concern since these effects define the policy environment within which households operate. Ideally, policymakers will need to assess how ecoagriculture approaches perform against other management alternatives in terms of diverse measures of economic growth, employment generation, equity concerns, and poverty alleviation. Economic analysis is also useful in estimating the net present value of different activities at different geographic scales, time periods, and under varying price regimes. Alternative enterprises can be evaluated at social versus private prices, leading to an assessment of the social opportunity costs of different management decisions. The effects of management decisions on national poverty alleviation and equity goals can also be assessed. Biodiversity concerns can be addressed by better understanding the externalities of resource management decisions and their internalized effects in household or government decision-making. Similarly, economic models may contribute to understanding how macroeconomic, trade and sector policies affect the viability of ecoagriculture strategies.

Few individual studies can make progress using all, or even most, of these criteria. Yet, ecoagriculture strategies inherently have multi-dimensional objectives, and thus need to be evaluated by multiple criteria. Criteria that are central will differ by type and scale of technology, production system, ecoregion, national policy objectives, and dominant household concerns.

5.2.1 **Economic Viability and Related Concerns**

The economic viability of land management practices is a necessary but not sufficient condition for adoption in most cases. As Cary and Wilkenson (1997) conclude, "…the best way to increase the use of conservation practices to overcome land degradation …will be to ensure the practices are economically profitable." Perhaps the most widely used conservation agriculture practice, zero (and minimum) tillage, has been widely shown to be economically profitable and has spread to millions of hectares of North and South America and elsewhere, with increased yields of maize and soybeans, while fertilizer and herbicide applications have been sharply reduced (FAO, 2001). However, other characteristics of management practices, farm households, and the land itself can also influence adoption and implementation. Yield, uncertainty, and health effects of proposed practices, and decision-makers' objectives regarding food security, minimizing risks, and discount rates (e.g., preference for short- versus long-term benefits) will influence land management decisions. Practices that require upfront investments and that may involve a transition period during which returns are low (for example, tree-based systems) may be unattractive and have to surmount additional impediments to achieve widespread adoption.

Empirical research has shown that a wide set of household characteristics, land and agroecosystem factors, and external policy factors will also influence the adoption of land management practices (for example, see Neill and Lee 2001). For a subsistence household, production and consumption decisions are non-separable and will result in different optimal input choices than would occur if only production or consumption objectives were present. Similarly, a risk-averse household with limited access to credit will respond to biophysical factors differently than a risk neutral household. Labor shortages or varying opportunity costs of labor will also alter the appeal of certain land use practices (see Chapter 3). Adoption of conservation practices is different from the adoption of conventional technology because these practices often result in externalities (positive and negative), can involve high transaction costs if cooperative action is required across a large area, and the benefits may only accrue after a long period of time (Marsh and Pannell, 1998).

5.2.2 **Equity and Poverty**

Equity and poverty concerns are central to ecoagriculture strategies for many reasons. Perhaps most centrally, rural poverty is centered in many of the same regions where wild biodiversity is richest and also under threat (Nelson, et al. 1997, cited in McNeely and Scherr 2003). Thus if one is to simultaneously address biodiversity and livelihood needs, one must necessarily deal with poverty and equity issues. Alternatively, one can contrast the Green Revolution, in which benefits were focused in highly productive areas, and ecoagriculture strategies, which are often explicitly aimed at addressing the needs of marginal farmers and rural households living in less-favored lands. In the latter context, the distinction between "welfare poverty"—measured by income, consumption or nutrition indicators—and "investment poverty" is relevant (Reardon and Vosti, 1995). As Reardon and Vosti suggest, the latter should reflect the ability of the household to invest in resource improvements that "maintain or enhance the quantity and quality of the resource base—to forestall or reverse resource degradation." This is an important distinction, because investment-poor households will lack the resources and ability to "invest their way out of" poverty, even though in some cases they may not be poor by conventional income-based standards. Production strategies that entail significant fixed costs and a minimum efficient scale of investment can be beyond the reach of poor households. Risk and subsistence constraints may further discourage these households from accumulating assets and increasing productivity. These concerns hold particular importance for conservation agriculture and ecoagriculture strategies that require investment of householders' time, marketed surplus, or other household resources in order to reap benefits that may primarily accrue over the long run.

Equity concerns are important for other reasons as well. Biodiversity conservation efforts are unlikely to prove sustainable if the net benefits accruing from projects and programs are distributed inequitably. Increased equity is likely to reduce the number and severity of resource conflicts. The net benefits resulting from biodiversity conservation may indeed differ across stakeholder groups, particularly those that are heterogeneous. In some cases, sharp inequities in the incidence of benefits may lead to technological failure. In semi-arid India, for example, Kerr and Sanghi (1992) found that soil and water conservation technologies such as contour or graded bunds that resulted in unevenly distributed benefits and costs and that required group action were not undertaken. In this case, “equity becomes a prerequisite to efficiency”, the authors concluded.

5.2.3 **Markets**

Markets profoundly influence the economic viability of ecoagriculture, as with all types of agricultural systems. Product market characteristics dictate the prices received by farmers, the variability of those prices, and the levels of marketing margins that influence profitability levels. Factor market characteristics dictate the cost of inputs and thus the viability of land management practices. Transaction costs associated with marketing will depend on market characteristics, including market proximity, scale economies in marketing and distribution, and the availability of market information (Omamo 1998). Current and anticipated output and input prices are crucially important in influencing production decisions, land allocation patterns, and investments in new technologies. To cite just one of many such examples, Baltas and Korka (2002), in a study of land use practices in 76 villages in northwestern Greece, show that land is more likely to be allocated to the land use practice with the higher level and lower variability of expected returns.

To the extent that ecoagriculture strategies are practiced in less-favored areas distant from central city markets and without good infrastructure, they may be particularly susceptible to market imperfections. Effective product diversification, for example, is a particularly important strategy in areas where crop monocultures are not competitive. Ecoagriculture strategies such as agroforestry-based systems and agrosilvopastoral systems are inherently multi-product systems, necessitating efficiently functioning markets for multiple commodities. If these markets are present, this may encourage strategies such as the domestication of high-value non-timber forest products within either enriched forest fallows or other forms of multistrata agroforestry (Leakey 2001). Without access to competitive markets and the availability of storage, transport, and communication infrastructure, farmers and traders cannot market their products effectively, limiting the effectiveness of diversification efforts and accompanying land use practices.

Effective marketing services are particularly important when the diversification is into high-value cash crop production (Kherallah and Gruhn 2001). Effective marketing strategies may seek to take advantage of market premiums for agricultural products grown in specific conditions or for “niche” markets. Examples include shade-grown coffee, organic produce, and genetically-modified organism-free products. But successfully pursuing these options and obtaining premium prices may require special management expertise, marketing services or market information. Niche markets often suffer, for example, from the lack of a “critical mass” of marketable production at the regional level to achieve an efficiently functioning market. Inadequate storage facilities and scale of production in input markets such as those for mechanical services may further limit production capabilities. Another market dimension, product certification, is particularly important for niche markets, and can be costly (Gobbi 2000). Certification is done on a crop or product basis, and is usually granted for one or two products grown within complex systems (e.g., coffee or cocoa, within a shade grown coffee or cocoa system). And certification or ecolabeling policies alone may be inadequate for stimulating demand. They may benefit from being associated with efforts to educate consumers regarding relevant production processes (Nunes and Riyanto 2004). But not all producers have the management abilities or particular expertise to be successful in pursuing high-value production strategies.

5.2.4 **Internalization of Externalities**

A significant component of ecoagriculture is the conservation of biodiversity. Achieving this goal results in positive externalities: pollination services, soil health and fertility, maintaining genetic potential, controlling pest populations, etc. To achieve biological conservation, households bearing the costs of preservation may need to be compensated, especially in situations in which they are producing a public good for which compensation through standard market channels may be impossible. There are different possible arrangements for market- and payment-based compensation for ecosystem services. These mechanisms can generate incentives to conserve biodiversity and maintain ecosystem services in productive landscapes; the mechanisms can be spatially explicit and have landscape-level effects.

The mechanisms for paying for ecosystem services range widely. They include government programs such as the Conservation Reserve Program in the United States (Feather et al., 1999) and the Environmental Quality Incentives Program in the U.S., similar programs in the European Union, and other direct payments programs supporting conservation practices (Ferraro and Kiss 2002). Among developing countries, Costa Rica's payments for environmental services (PSA) programs are perhaps the most elaborate, compensating farmers and landowners for environmental services including carbon sequestration, watershed protection, biodiversity conservation, and the provision of scenic beauty (Zbinden and Lee 2005). Other mechanisms are market-based such as certification (e.g., for shade grown coffee) and tradeable permits (Greenhalgh and Sauer 2003; Chomitz et al. 2004). Payments can be made for a wide set of ecosystem services such as water quality, water flow, water retention, soil erosion mitigation, and habitat creation. A recent review identified roughly 300 examples of such mechanisms worldwide (Landell-Mills and Porras 2002, cited in Pagiola et al. 2002b). Currently, there are 20 countries that engage in some form of payments (primarily direct payments and some subsidy program) for conservation (Ferraro 2004).

Payments for ecosystem services have the potential for significantly advancing conservation efforts. The popularity of these mechanisms is based on the premise that they can directly and cost effectively address environmental goals and use economic instruments, such as taxes or incentive payments, to stimulate voluntary landholder compliance (Stoms et al. 2004). These approaches avoid far more complicated and management-intensive options, such as integrated conservation and development programs, which often seek to advance conservation goals indirectly. What is lacking in ecosystem service payments programs is the scientific basis to substantiate the contribution of improved practices on biodiversity conservation or ecosystem health (personal communications with Pagiola 2004 and Chomitz 2004). Operational issues such as program design and financing, assuring sustainability, and balancing equity and environmental goals also present challenges. The key challenge in this field, then, is that of identifying, quantifying, and valuing the actual services provided by the ecosystem, and then determining how to structure a sustainably effective incentive-based payment system around those services. A similar difficulty arises with performance-based payments, where it is necessary to identify performance measures that are measurable at a reasonable cost and clearly linked with management decisions.

5.2.5 **Property Rights**

Property rights assign rights to individuals to streams of benefits. Benefits can be generated from agricultural land, but include all land-based natural resources (Place and Swallow 2002). There is widespread evidence in the literature of causal linkages between effective property rights and the adoption of technology (Feder et al. 1985). Property rights are especially important in situations employing technologies with long-term cost and benefit streams, such as the adoption of agroforestry systems, soil conservation structures, and managed fallows systems. In these and similar cases, assured access to future benefits is necessary to induce current period investments. Gebremedhin and Swinton (2003), for example, found that secure land tenure arrangements were among the most important determinants of soil conservation investments in the Tigray region of Ethiopia. Property rights can thus positively influence incentives to adopt new land management strategies, especially in areas with an existing high degree of insecure rights (Place and Swallow 2002).[1] Property rights affect access to information, wealth, risk management and credit, which also in turn influence technology adoption. Property regimes can also buffer environmental risks and price fluctuations.

Indigenous tenure systems and property rights institutions in Asian and African societies often provide sufficient incentives to adopt technology (Knox McCulloch et al. 1998). Common property regimes accommodate multiple users beyond the household level, and therefore are better able to distribute benefits equitably (Knox and Meinzen-Dick 1999). However, in many

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[1] *The exception is when the costs of investments are very low or the expected profits are high, in such cases property rights are not as relevant (Place and Swallow 2002).*

locations, these systems are challenged by state ownership and private property tenure. A recent comparative review of land tenure and forest management in seven Asian and African countries found that: 1) state ownership is the most inappropriate land ownership system; 2) common property systems were effective when key forest resources were minor products, and 3) that high-value tree production is less amenable to common property management (Otsuka and Place 2001). The authors concluded that social forestry projects should be redesigned to retain community management of forest production, but strengthen individual incentives for the management of high-value trees. Property rights are also shaped by technology adoption. Tree planting has been widely cited as one investment that confers strong land rights to individuals (Fortmann and Bruce (1988), Suyanto et al. (1999), Snyder (1996) and Baland et al. (1999) as cited in Place and Swallow 2000).

5.2.6 **Social Capital and Collective Action**

Social capital is "the structure of relations between actors and among actors" that encourages productive activities" (Pretty 2002). Social capital is based on relations of trust that reduce the cost of collective action. Reciprocity and exchange among group members generates trust and confidence in collective efforts (Pretty and Ward 2001). Institutions, including common rules, norms and sanctions that elevate group interests above those of individuals, further strengthen obligations among people. This engenders positive environmental outcomes (Pretty 2002). Varughese (1999, as cited in Poteete and Ostrom 2003) found that in Nepal, forest conditions were more closely correlated with collective action than with population pressure. Chakrabarti et al. (2001, cited in Poteete and Ostrom 2003) also found a positive correlation between forest conditions and level of collective action.

Social capital can benefit the implementation of land management practices that enhance agricultural productivity and conserve biodiversity (Pretty 2002). In the Peruvian Altiplano, social and human capital displays a clear association with the choice of sustainable agricultural practices (Swinton and Quiroz 2003). It can engender synergy between productive land uses and ecosystem integrity (Flora 1995; White 1995; Krishna and Uphoff 1999; Dougill 2001) and influence local welfare (Poteete and Ostrom 2003). Increased social capital can thus contribute to improving livelihoods, as evident in 69 villages in Rajasthan, India where local development was positively associated with a combination of social capital and capable government agency (Krishna 2003). The viability of management approaches that require coordination and cooperation among land users also positively benefits from social capital.

5.2.7 **Macro and Trade Policies**

Government policies have distorted agricultural performance worldwide. Subsidies, protectionist trade policies, currency overvaluation, and land reforms are examples of macro-level policies that have strongly shaped resource use and agricultural production (World Bank 2003). For example, agricultural price subsidies and price supports have supported the expansion of large-scale cropping systems in industrialized countries, thereby reducing global commodity prices and making it difficult for developing country producers to compete in these markets. This issue is a central factor in the impasse in the current Doha Round of trade negotiations under the auspices of the World Trade Organization. Were industrialized countries to significantly reduce agricultural subsidies, those countries would likely lose a substantial degree of trade competitiveness. To the extent that marginally productive areas in industrialized countries would go out of production, biodiversity would benefit. Conversely, projected increases in global commodity prices would likely benefit developing countries that have a disproportionate reliance on agriculture. These price increases would likely improve the economic prospects for many rural households in developing countries. It is not clear that environmental and biodiversity objectives would necessarily be realized by a simple shifting of commodity production from industrialized to developing countries, where environmental laws and regulations are typically less stringent and less likely to be enforced. At the same time, the prospect of improved economic returns would create options for developing country producers that could potentially strengthen ecoagriculture strategies.

The global reduction in trade barriers in the past two decades has also had a significant effect in some countries expanding their exports of "non-traditional" commodities, including the high-value products previously mentioned. These products have great potential as part of export diversification in many countries, and promotion of non-traditional, value-added exports is a widely touted economic growth strategy. But taking advantage of increasing global demand for these products is not easy. Success in non-traditional agricultural export industries typically requires superior management expertise, good marketing and transportation infrastructure, close attention to global price and market trends, and pursuing modern business and marketing practices. These requirements are often outside the realm of smallholder agriculturalists. To achieve success, ecoagriculture strategies that seek to serve the international market must not only succeed on the production side, but in marketing and product distribution.

The reduction of trade barriers has the potential to further increase production, trade, and consumers' welfare. However, trade also can negatively affect resource use and lead to environmental degradation if production with negative environmental externalities shifts to countries with relaxed or poorly enforced environmental regulations, and/or if those countries don't enforce the regulations they have. A favorable policy context for ecoagriculture will require measures that internalize negative externalities and reward sustainable resource use.

5.2.8 Investment in Conservation

As we have seen, there is widespread evidence that economic viability is a crucial incentive for the widespread adoption of most agricultural and natural resource management practices. Thus, investments in conservation of wild biodiversity on productive lands must generate greater returns than alternative investments. For a private landowner, ecoagriculture will be economically rational if the current and discounted future expected benefits derived from management practices exceed their costs (including opportunity costs).

Investment in appropriate land management practices across a landscape is important to achieve wildlife conservation. Ecoagriculture strategies require landowners to make financial and capital commitments. Suitability of an investment will depend on private and social costs and benefits. Returns on private investments, however, will need to take into consideration activities and investments in neighboring plots and, where relevant, the broader landscape to fully reap the environmental and biodiversity benefits of alternative land use practices. Similarly, for governments, selection of ecological reserves, environmental enforcement, and research and information exchange all require optimal allocation of limited funds (Polasky et al. 2001). Intangible benefits or indirect costs associated with investments in conservation have to be made explicit and, wherein possible, measured when comparing different investments or policy measures for promoting biodiversity conservation on productive landscapes. Governmental and non-governmental organizations investing in biodiversity conservation and social welfare need to stimulate cost-effective approaches that efficiently achieve the objectives of the initiative.

All of the aforementioned factors are important considerations when designing and promoting land management practices with multiple objectives. The viability of a particular land management strategy under a particular combination of factors cannot be transferred to a different context without research. Model outcomes, therefore, are important for specific conditions. Model interpretation will also depend on which factors are incorporated and how effectively they complement reality.

5.3 Assessing Tradeoffs and Synergies in Ecoagriculture Strategies

Approaches that examine the role of the abovementioned factors on land use and that evaluate tradeoffs and synergies among biodiversity, productivity and livelihood objectives, can improve stakeholders' understanding of ecoagriculture strategies. Ideally, models are able to integrate variables measuring biological diversity, recognize the heterogeneity among and within stakeholder groups, capture the spatial and temporal scale of the activities, incorporate feedback loops, address risk and uncertainty, and model dynamic interactions among alternative land and resource uses. Examination of household decision-making should also be based on theoretically sound frameworks. Moreover, approaches should recognize that the farm household is the main decision-making units regarding land use and technology adoption. However, understanding market outcomes and addressing policymakers' interests often require analysis at a more aggregative level.

Meeting all of these criteria is clearly a major challenge, particularly for ecoagriculture-related research where knowledge generated in terms of multiple dimensions and indicators is required. It is the rare analytical or modeling approach that successfully addresses even a few of these criteria. Typically, this necessitates tradeoffs among modeling criteria depending on what are judged to be the key issues and constraints in specific empirical situations. Model design and application will also vary depending on the ecoagriculture strategy of particular concern. Ideally, modeling approaches should also be comprehensible to a range of stakeholders, including private and public decision-makers.

This section reviews modeling approaches of potential relevance to the analysis of ecoagriculture. The discussion is by necessity selective; no attempt is made to be wholly inclusive. The particular emphasis is on quantitative modeling approaches that are capable of addressing tradeoffs and synergies among the biophysical and economic components of a system. A few examples of mixed approaches are also discussed. Mixed models incorporate both quantitative and qualitative information and examine relationships between biological and social components of land use practices, or they examine synergies and trade-offs between productivity, biological diversity, and welfare. Details regarding the models referenced in this section and other related models are in given in Annex 5.

5.3.1 **Quantitative Modeling Approaches**

Quantitative approaches for assessing the interaction between ecological and economic phenomenon are numerous and often quite sophisticated. Models typically link biophysical and economic factors at varying scales, simulate land use changes at farm or regional landscape scales, or may use spatially explicit information incorporating GIS-based approaches. Bioeconomic models and systems models are among the promising vehicles for analyzing biophysical-economic interactions. These, and other, modeling approaches vary widely—by level of decision-making, level of detail in the data, scale of analysis, and which variables are considered as exogenous versus endogenous (e.g., determined) within the analytical approach. This section briefly describes some of the basic characteristics of major quantitative modeling approaches and illustrates how they are currently being applied.

5.3.1.1 *Bioeconomic Models*

Bioeconomic models link biophysical and decision-making processes at the household, village and regional levels (Kruseman and van Keulen 2001). Biological variables can include soil- related parameters, water quality measures, number of different species per area or variables representing biological diversity. Bioeconomic models often include biophysical information as constraints (Jensen et al. 2001); employ measures of land suitability; make assumptions regarding impacts of practices on biodiversity (Fleming and Milneb 2003); and develop sustainability indicators as measures of environmental impact (Zander and Kachele 1999). Economic and biological components can be defined to best represent the relevant characteristics of the problem at hand. Bioeconomic models are most commonly developed at the farm and household levels. They often have separate modules that specify farm household preferences, technological choice, and sustainability parameters (Heerink et al. 2001). They can be solved through linear programming, dynamic programming, and other related approaches.

Bioeconomic models can reveal tradeoffs and synergistic relationships between the biophysical and economic dimensions of the system, or among the biological elements. Bioeconomic models at the household level often incorporate farm household modeling that accounts for natural resource endowments, inputs and labor allocation decisions, and output choices and consumption preferences under different conditions of market development (Heerink et al. 2001). Biophysical information is linked to the production side of the farm household model. These approaches are also used to understand the impact of international trade on production, marketing, and land conservation decisions (Barbier and Schulz 1997).

Bioeconomic models have been developed to assess the economic impacts of a broad range of technology adoption and policy scenarios (de la Briere 2001; Barbier et al. 2003). Okuma et al. (2002), to cite just one example, used a dynamic utility-maximizing bioeconomic model to assess, *ex ante*, the likely impact of adopting multiple technologies on crop-livestock systems under various policy scenarios in the Ginchi watershed of Ethiopia. They found that under the existing policy conditions, soil conservation measures may not be a profitable venture and that tree planting or conservation measures were not adopted despite their profitability. Instead the need for food self-sufficiency resulted in fallowing in the crop-rotation pattern.

Examination of policy impacts on biophysical parameters, such as soil erosion and carbon sequestration, is also possible (Barbier and Bergeron 1999; Schipper et al. 2001). Schipper et al. (2001), for example, use an elaborate static bioeconomic model (SOLUS) to explore the aggregate effect of policy measures on both efficiency and non-economic and environmental sustainability objectives at a regional level in the Atlantic Zone of Costa Rica. The model incorporated sustainability and environmental parameters relevant to the region in the optimization. The authors found that technological improvements result in increased economic surplus and reduced environmental degradation, more so than restrictions on soil nutrient depletion.

Bioeconomic models are limited in how they represent biophysical parameters. In the case of soil, some approaches incorporate information on erosion, representing changes in soil components at a geographical scale, but do not adequately capture the temporal scale or dynamic changes in soil conditions (Lehman 2004, pers. comm.). Representations of how a specific practice affects biological diversity may be based on inappropriate assumptions. Likewise, the use of available crop growth models does not capture the dynamics of multiple cropping systems (Heerink et al. 2001). Another major challenge for these approaches is aggregating up to the regional or watershed levels which are often of greatest to policymakers. The regional scope of the SOLUS model cited above is unusual. Additional research is needed on these and various other aspects of bioeconomic modeling.

5.3.1.2 *Spatially Explicit Models*

Ignoring the spatial dimension in resource management problems that are inherently spatial in nature can lead to incorrect conclusions about the viability of alternative management strategies (Brown 2003). This is certainly the case for ecoagriculture, as in other applications. In ecoagriculture, the mosaic of land-uses across a landscape affects the viability of integrating agricultural productivity with conservation of habitat for wildlife and improved livelihoods.

Advancement in spatially explicity modeling has mostly occurred in non-economic fields of study. Geographers and biophysical scientists have taken the lead in developing spatially explicit models of land use change. There are three categories of spatially explicit non-economic models – simulation models, estimation models, and hybrid approaches[2] (Irwin and Geoghegan 2001). Change is stimulated using vast amounts of spatially disaggregated land use and land cover data, typically obtained from satellite imagery. These models are not typically behavioral or economic models and generally use an “ad hoc approach to identifying physical variables that represent the outcomes of economic and social processes” (Irwin and Geoghegan 2001). Spatially explicit non-economic simulation models of land use change often build on mathematical models in which the behavior of a system is generated by a set of probabilistic or deterministic rules (Irwin and Geoghegan 2001).[3] Although these models have made a significant contribution to land use/land cover modeling, they have been limited in capturing the causal relationship between individual choice and land use outcomes (*ibid*.).

Work in environmental economics has focused on developing economic models of individual landowners’ decisions within a spatially explicit framework (Irwin

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[2] *Hybrid models involve estimating parameters with simulations.*

[3] *Much of the work in this area identifies transition rules by quantifying the resulting pattern. The explanatory power of these models is demonstrated by showing how the hypothesized interaction effect is similar to the resulting spatial evolution of the land use pattern (Irwin and Geoghegan 2001). Moreover, these models are based on change rules that are based on the cell’s attributes and states of surrounding cells. The use of only these attributes overlooks a host of other factors across a landscape that change land use patterns (Irwin and Geoghegan, 2001).*

and Geoghegan 2001). Spatially explicit economic models have focused largely on deforestation. These models use economic theory and the empirical literature to identify variables to include in land use conversion models and to identify causal relationships (Chomitz and Grey 1996; Pfaff 1999). They estimate the parameter values to help understand the factors influencing land uses rather than predicting micro-level changes in the spatial pattern of the landscape. For example, Chomitz and Grey (1996) found that in Belize roads influence the probability of land being used for commercial agriculture because road access affects market access[4]. Spatially explicit economic models, such as those discussed above, require creative use of spatial data in models and improved empirical methods, including those being developed in spatial econometrics (Irwin and Geoghegan 2001).

More recently, spatially explicit economic models have been developed to improve targeting in the retirement of agricultural lands, such as the U.S. Conservation Reserve Program (Newbold and Weinburg 2003). Newbold and Weinburg developed a theoretical model that uses spatially explicit models of production functions in an optimization framework. The objective is to maximize environmental benefits with a budget constraint. In this model environmental benefits are being considered with different weights added to each. Using information on the environmental benefits, the benefit-cost ratios are calculated for each spatial cell that could be conserved. The cells with highest benefit-cost ratios are conserved and the benefit-cost ratio for neighboring cells are updated. The process is then repeated till the budget is completely expended. Extensions of these models would be useful for examining ecoagriculture initiatives that create additional habitat for wildlife because of the inherently spatial nature of habitat creation.

Bioeconomic models have been extended to incorporate spatial elements that inform resource use decisions. Brown (2003) reviews examples of such models and also provides a detailed description of a spatial-temporally explicit model of shifting cultivation and forest cover dynamics in the Congo Basin. The latter model converts a spatial-temporally explicit resource extraction model into a nonseparable household model applicable to subsistence agriculture. The spatial dimension is made explicit by recognizing that households' decisions regarding which parcel to fallow versus to cultivate varies with spatial factors (e.g., location of plot and spatial variation in soil conditions) (Brown 2003). This type of modeling approach is similar to a systems modeling approach that is spatially explicit. It suffers from the same limitations as the spatially explicit economic models discussed above and those associated with systems approaches.

5.3.1.3 *Systems Analysis Frameworks*

Models that integrate distinct disciplinary frameworks, for purposes of this report, are identified as systems analysis frameworks. Systems analyses are based on theoretical models or operate around posited causal relationships among elements of a system. They often involve hierarchical systems, with separate models for biophysical, socioeconomic, and policy components connected through input-output relationships, tenure arrangements, or markets. The components can be spatially explicit, include macroeconomic components, and employ multiple data sources.

Loosely coupled or open models have distinct disciplinary components executed independently, with outputs from each component feeding directly into other models (Antle and Stoorvogel 2003). A closed model is one in which the processes in distinct submodels interact simultaneously, rather than recursively, as in the case of loosely coupled models. This can involve decomposing each of the models into a sequence of sub-processes that are loosely coupled, with feedback among the submodels. "Another approach is to simulate the two models sequentially, once for each of the shorter time steps, each time using data from one model to initialize the other model up to that point in time" (Antle and Stoorvogel 2003). Antle and Stoorvogel (2003) applied these two different systems models to identify the economic, environmental and human health tradeoffs in Ecuador's potato-pasture production system. With the loosely coupled model they found that farmers shifted towards potato production as the price of potatoes increased relative to milk. This resulted in increased pesticide use and environmental and human health ef-

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[4] *The findings, however, need to be interpreted with caution because there were endogeneity problems.*

fects associated with using pesticides. In contrast, the closed systems approach revealed substantially different estimates of impacts at sites where the feedbacks were strongest.

A systems analytical framework is helpful in examining the interactions among different systems components. Simulations are used to assess how modifications in one component alter other elements. Systems models can be used in various contexts that are relevant to assessing ecoagriculture strategies, such as in analyzing: factors influencing households' decisions across different land use options (Legg and Brown 2003a); alternatives for simulating land use in unobserved situations (Antle and Capalbo 2001); examining tradeoffs between environmental and economic indicators resulting from different policy and technology scenarios (Stoorvogel et al. 2003); assessing potential outcomes from simultaneous changes in land use at a landscape scale (van Noordwijk 2002); and identifying the impact of policies on biological diversity (Stoms et al. 2004). Systems analyses are potentially suitable for examining ecoagriculture strategies that enhance habitat value of farmlands and efforts to increase habitat for wild biodiversity.

Research and development of systems analytical frameworks has furthered the understanding of interactions among the social, economic, and ecosystem service components of systems. The Alternatives to Slash and Burn (ASB) program managed by the International Centre for Agroforestry Research (ICRAF) has supported the development of systems models within the SIMILE environment. SIMILE links systems dynamics modeling with spatially explicit landscapes (Legg and Robiglio, 2001). It is a series of biophysical models of farming systems linked through land tenure relationships to models of villages and households which incorporate kinship and other linkages (*ibid.*). SIMILE models activities and landscapes and evaluates the impacts of a range of interventions and policy options on rates of forest conversion to agriculture. FALLOW (van Noordwijk 2002) extends the above systems framework and includes plant biodiversity. This model was developed to predict changes in food self-sufficiency, soil fertility, carbon stocks, plant species richness and watershed functions at a landscape scale with changes in population and land use, and has been applied in Indonesia.

Systems models that explicitly examine wildlife habitat are limited. An example is TAMARIN, a systems model being pilot tested in the Atlantic Rainforest area of Brazil (Stoms et al. 2004). TAMARIN evaluates and compares different landscape configurations for achieving conservation goals at the regional scale. The model sets general environmental goals and then uses economic instruments to induce voluntary compliance to achieve these goals. TAMARIN simulates a range of programs involving economic instruments with flexible specification of program eligibility, payment rules and budget for the program. The model uses three layers of spatial information in GIS—current land cover, ecologically distinctive sub-areas, and the opportunity cost of conservation expressed as a value which is assigned to each point on the landscape. The main objective of the model is to assist planning conservation of wildlife habitat.

A key challenge in using systems analysis approaches is parameterization of the components of the models. These models are typically highly data intensive. Sensitivity analysis is also important in systems analyses to assess the threshold levels for the different elements of the system. There are different user-friendly interfaces for conducting a sensitivity analysis for a systems approach (e.g., STELLA software).

Systems analytical frameworks that capture the interactions of various systems elements provide a promising framework for examining ecoagriculture. Hierarchical models that link together different disciplinary models either through open or closed loops are suitable for this purpose. These frameworks are flexible and different disciplinary models can be adapted to the local context. Furthermore, they are relatively easy to comprehend and can generate policy recommendations.

5.3.1.4 *Macro-Level and CGE Models*

Macro-level models can be used to assess the effect of policy changes, such as trade liberalization, on land uses and the implications for biodiversity conservation. Much of the recent interest in these approaches has been stimulated by understanding the effects of major trade liberalization initiatives (WTO, NAFTA) on land and resource use. In terms of approaches particularly relevant to analyzing ecoagriculture strategies, one subset of "trade-conservation" models links two-country, two-good trade models with species area curves to examine how trade policies affect the area of land used for agriculture, timber and conservation. These models have production, species assemblages, and consumer preference components. The model is solved for species assemblages and the maximization of consumer utility under different trade regimes (Polasky et al. 2003). To make models tractable, assumptions such as the incompatibility of productive land uses and the conservation of native biological diversity may be necessary (Polasky et al. 2003).

Computable General Equilibrium (CGE) models are useful in capturing the second-round effects of land use changes. CGE models applied at a regional level are useful in the ecoagriculture context for assessing the impact of trade or domestic policies. However, few CGE models addressing questions related to agriculture and land use explicitly integrate biophysical or biodiversity components. CGE models often use different land classes, in which biological/biodiversity properties are implicit rather than explicit. Spatially explicit information can be linked with a CGE model to generate information on how large-scale phenomena, such as climate change, affect the integrity of regionally specific ecosystems (Darwin et al. 1996). Darwin et al. (1996) used land classes in a model that links GIS with a CGE model to assess how global changes in climate, human populations and international trade policies might affect land area under tropical forests at the regional scale. National-level CGE models and multi-market models can be used to analyze the impact of economic policy reforms on prices faced by farm households (Dyer et al. 2001). They can also assess how land use practices affect national-level measures of development (Lewandrowski et al. 1999). These models could be altered to examine issues at scales of interest to ecoagriculture strategies.

5.3.2 **Mixed Models Used to Evaluate Tradeoffs**

Tradeoffs and synergies can be examined using models that analyze ecological and social elements of a land use practice independently and that incorporate theoretically sound assumptions and/or information about related practices (Dougill et al., 2001; Jagger and Pender, 2003). Mixed models are capable of using both qualitative and quantitative information, although the former must sometimes be incorporated in ad hoc fashion. Such models can include a broad range of social variables, such as social capital, property rights, and village-level information. These models can also incorporate spatial information, including climate variables, land uses, and levels of soil erosion (Pender 2003).

Mixed models can generate insights into how policy changes affect land use practices and household welfare, and can provide information on feasible development options and resultant biophysical changes. Pender et al. (2001) identified the major pathways of development that have been occurring in Honduras, their causes and implications for agricultural productivity, natural resource sustainability and poverty. He found that development pathways affected changes in agriculture and resource management but not changes in poverty (also see Pender 2003). The horticulture, coffee, and non-farm employment development pathways resulted in favorable productivity outcomes but their implications for resource conditions are mixed. These models might be modified to include additional pertinent spatial information. For example, spatially explicit information can be incorporated in a dynamic fashion to capture the interactions between the socioeconomic, productivity, and biological elements of the system. Bolwig et al. (2003) applied such a model in Uganda to estimate the potential consumer and producer benefits, and export revenues of simulated changes at the subnational and national levels. The results revealed that increased production in cotton increased benefits but the production was occurring in areas that were not close to the markets (Bolwig et al. 2003).

Mixed models have distinct benefits and disadvantages. For example, they are not constrained by having to link data collected at different temporal and spatial scales. However, these approaches may not capture the full interactions among the various biological and social elements of a system. Moreover, a further key limitation is that these approaches are time- and resource-intensive, and are dependent on the collection and incorporation of extensive empirical data. Despite these limitations, the application of these models may usefully be extended to various ecoagriculture strategies.

5.4 How Economic Evaluation Can Contribute to Making Sound Choices

This brief review has identified some of the analytical approaches that have been used to examine the multidimensional aspects—economic, production, and environmental—of alternative production systems relevant to ecoagriculture. For the purposes of specific production strategies, the strength of these approaches is in their varying potential to: 1) identify specific measurable outcomes that are consistent with the multidimensional indicators of ecoagriculture strategies; and 2) evaluate specific tradeoffs and synergistic relationships between and among these alternative outcomes. Regarding the latter, ecoagriculture has the potential to benefit from achieving synergistic outcomes from many sources, including:

- Increased efficiency of input use;
- Synergies between component inputs;
- Substituting natural capital for financial capital;
- More efficient spatial organization;
- Improved input performance;
- Economies of scale through farmer collaboration;
- Benefits to farming from wild species or revegetation.

Whether it is able to do so will require significant progress in applied research along the lines outlined here. In some limited cases, modeling efforts have prioritized the assessment of tradeoffs from the outset, making these approaches particularly promising (for examples, see numerous chapters in Lee and Barrett 2001). The approaches reviewed here can also provide insights regarding the effectiveness of policies, incentives for adoption, and effects of different land management approaches. Such analyses will assist in designing of mechanisms to compensate individuals for conserving biodiversity in productive landscapes.

It is important not to underestimate the analytical and data-related challenges posed by ecoagriculture research. The explicitly multi-dimensional nature of ecoagriculture strategies means that economic, agronomic, and biodiversity elements should ideally be simultaneously incorporated in analytical and modeling efforts. To do this rigorously requires detailed data of very different types, collected over multiple years, and analyzed using sophisticated methodologies, some examples of which have been reviewed here. These analytical and data requirements do not lend themselves well to "one-off" research efforts, but rather to long-term, well-funded research programs incorporating multiple disciplinary approaches. In the past, such research programs have understandably been mostly focused on micro-level production systems (individual farms or communities, several communities, or the subwatershed level), where conditions are more likely to be homogeneous, and analysis is more tractable. However, this has meant the ability to address the aggregate-level market and policy issues of primary interest to policymakers is often limited. One of the key challenges for ecoagriculture, from an analytical perspective, is to make the most of past and emerging research efforts, recognizing that the ability to rigorously assess the tradeoffs and complementarities among multiple objectives is necessarily limited to relatively few strategies, and that the conditions favoring an "ideal" research environment arise only infrequently.

Formal analysis and modeling of ecoagriculture should build on and extend current efforts to capture various elements at the landscape scale. Efforts to assess the impact of land management on ecosystem services should better capture the spatial and temporal element of these services. Such models could benefit from strengthening their bioeconomic component to incorporate appropriate biophysical and biodiversity variables, such as soil erosion or soil nutrient parameters, species diversity measures (e.g., the Shannon index, or intra- or interspecies diversity), or information on water quality.

Better understanding the tradeoffs and synergies resulting from ecoagriculture strategies given positive ecosystem externalities would provide valuable insights. Moreover, the prospect of designing appropriate payments and compensation schemes around these externalities is likely to be of growing interest to both policy-makers and resource owners and managers. The TAMARIN model (see Annex 5) provides an interesting example of such an effort. TAMARIN is a model that explicitly considers wild biodiversity (mega-fauna) and the economic incentives necessary for creating necessary habitat, and is based on economic and ecological principles. Adjustments to this model, including improvement of its economic sub-module, could extend its relevance to ecoagriculture.

Extending research findings from one scale (e.g., the farm or household) to a larger scale (e.g., the watershed or landscape) must be carefully done since simple aggregation is often not appropriate, either in terms of market outcomes (e.g., price determination) or biophysical effects (e.g., soil erosion impacts). Ultimately, a focus on spatial dimensions should lend insights into the crosscutting issue of "separation versus integration" identified earlier in this chapter. Ecoagriculture strategies are built on the assumption that integrative approaches to simultaneously realizing economic, production, and biodiversity goals are optimal, or at least preferred. But integrative strategies employed at the micro level may not necessarily yield optimal results when considered at a more aggregative level. Future research directed at this issue of the scale and spatial dimensions of ecoagriculture strategies is required to conclusively demonstrate the viability of these strategies under varying biological and market conditions.

Implementation of ecoagriculture strategies would also benefit from linking improved quantitative and mixed models of land use with planning processes. A comprehensive understanding of the tradeoffs and synergies among the livelihoods, biodiversity, and agricultural productivity components of ecoagriculture should inform participatory planning processes and assist decision-making. Economic analysis could forecast the impact of proposed ecoagriculture strategies and/or assess its feasibility. The analyses could identify the distribution of costs and benefits or more accurately assess the viability of specific land use strategies given local conditions and the political context. Such information would assist in effectively targeting ecoagriculture.

5.4.1 **Directions for Future Research**

In addition to the above, there are several areas of additional research that could enhance our understanding of the tradeoffs and synergies resulting from ecoagriculture. Given the focus of ecoagriculture strategies on the conservation of wild biodiversity, perhaps the greatest need is in developing measures and indicators of wild biodiversity that can be easily incorporated in modeling approaches and used in meaningful fashion both for research and policy analysis. Research makes clear that different environmental indicators can respond differently to economic and production decisions. Biodiversity outcomes associated with identical production strategies may be dramatically different for plant biodiversity compared with soil micro-fauna compared with large mammals. And these outcomes may be very different from other environmental outcomes (soil erosion, land deforested, carbon sequestration, etc.). We need better tools, measures, and indicators to incorporate in modeling efforts to identify alternative outcomes *within* the broader objective of biodiversity conservation.

A deeper understanding of factors that inform households' decision-making across multiple objectives and their implications for ecoagriculture would be beneficial. Models used to predict or examine the viability of ecoagriculture need to more adequately represent whether or not the decision-maker is updating their knowledge regarding the system, and how this knowledge changes with spatial aggregation, or dispersion, of habitat. The role of social capital in shaping decision-making, mitigating risks, and ensuring the necessary conditions at the landscape level needs to be better represented in models of ecoagriculture.

Improved representations of the biophysical component of ecoagriculture systems would strengthen ecoagriculture analyses. An ideal approach would use simple yet theoretically sound measures of the biophysical system. Using these measures, the biophysical components could be examined at the appropriate geographic scale and models then capture the temporal scale at which biophysical changes affect land managers. The biophysical component of the model should be dynamic and, therefore, evolve with the land management practices.

Relatively few of the models examining the impacts of land use changes consider the negative externalities faced by land managers. For example, a farmer's selection and planting of perennials on the boundary of his/her property can affect the crop productivity of the neighboring farms (Jagger and Pender 2003). Nutrient leaching can affect soil health in neighboring plots. GIS-based models should be able to capture these effects or internalize this information in measures of land suitability. This will be crucial to comprehend the landscape scale effect of ecoagriculture strategies.

Most of the models reviewed in this chapter are not restricted to a particular scale of agricultural activity. This is important because "large-scale, high-tech agricultural producers have considerable scope for ecoagriculture" (McNeely and Scherr 2003, p. 108). However, the applicability of ecoagriculture will vary in different land management situations, including those defined by scale. Monocropping tends to prevail at the large-scale end of agricultural systems, and we need to better understand how measures of biodiversity change as scale varies. Empirical research should also be conducted for systems with distinct characteristics including land size, risk preference, and knowledge. Such research would assist in classifying what factors affect the suitability of ecoagriculture strategies and improve targeting of ecoagriculture approaches.

Comprehending the impact of land management practices on livelihoods would benefit from multidisciplinary research approaches that can examine the relevant components of the system at multiple scales and integrate this information for decision-making and policy formulation. Examples of approaches include the Alternatives to Slash and Burn program of the CGIAR, and the SCRIPs initiative at the International Food Policy Research Institute.

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ANNEX 5: Sample of Economic Models Incorporating Livelihood, Productivity and Ecosystem Elements

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
BIOECONOMIC MODELS (Static models)					
Barbier and Schulz, 1997 (Bio-economic model of wildlife exploitation and trade)	To determine the optimal wild and natural species exploitation levels factoring in opportunity cost of habitat conservation, and wider social value of biodiversity. Also, to examine the impact of trade on optimal exploitation of species and habitat in the long-term	National scale	The model has a biological component, which examines the change in total species stock based on aggregate biological growth rate across species and expansion in number of species as size of habitat changes. The model assumes habitat conversion occurs because of other economic activities and all output is consumed. The model takes into consideration the social utility function of the country and examines the trade-off between harvesting or utilization of wild species from conserved natural habitat versus conversion of habitat of land to produce other commodities. Examines two scenarios - (i) a closed economy where the objective is to maximize the present value of future welfare, and (ii) an open economy in which the wildlife products can be exported. The latter case has a trade balance equation and a new definition of total domestic consumption. The objective is to maximize open economy welfare. The key output of this model is the optimal long-run levels of wildlife and habitat exploitation.	The population dynamics of the species is incorporated in the biological component of the model	This paper provides a theoretical representation of the models. In solving these models for the closed economy, it is evident that the conventional bioeconomic models that do not factor in the opportunity cost of preserving habitat or the value of biodiversity may over-estimate optimal long-run levels of wildlife species and habitat. In the case of the open economy model it is unclear, when compared to the closed economy, whether the long-run optimal level of species and habitat conversion would be higher. However, comparative statics suggest that trade interventions (made to internalize global values of biodiversity) can be counterproductive whereas an alternative policy of an international transfer of funds would lead to greater long-run conservation of species and habitat.
Barbier et al, 2003 (Trade-off between economic efficiency and contamination)	To identify the optimal location for coffee processing plants along a river by examining transport, variable and fixed	Water shed	Bioeconomic model solved with mathematical programming. Model minimizes annualized costs for a sub-watershed subject to constraints (processing capacity, processing quantity, water availability, effluent concentration, and investment). Uses GIS to situate the different plants and determine which ones would minimize cost for the whole sub-watershed.	Incorporated with consideration of water demand and effluents must be below the pre-	Application to watershed in Honduras: with collective processing and change in location of processing plant - improved efficiency is possible. This will require providing adequate incentive for producers to participate and may require coffee cooperative assistance.

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
	costs		Also tests the effect of different coffee premiums and effluent level restrictions on the location of the processing plant. The key outputs include graphs that show the relationship between quintals of coffee processed and water contamination for each of the different locations of the processing plant. It is also possible to generate outputs for different coffee premiums.	determined maximum effluent concentration	
de la Briere, 2001 (Probit and duration models)	Analyze the determinants of adoption and maintenance of soil conservation	Farm-household level	Intertemporal behavioral model of households' labor allocation to agriculture, soil conservation, and labor market activities in the context of household specific market failures (in this case food market). The household maximizes an additively separable utility function over three periods and over food and income, given a discount rate, the production technologies for food and soil fertility, wage rate, land and household labor availability. Using information from comparative statics, the model estimates adoption of soil conservation for two scenarios (without subsidy and with subsidy but for all households). The model uses duration analyses to assess whether the households continue to practice soil conservation beyond the short-term. The key output of the model can be used to improve targeting of technology transfer.	Soil fertility is incorporated as a constraint	In the application to a watershed in the Dominican Republic: 1. Welfare measures such as food subsidies are effective in promoting conservation, 2. Food self-sufficiency induces soil conservation, 3. Actual land ownership favors maintenance of soil conservation, 4. Large land holdings are associated with lower soil conservation adoption and maintenance, 5. Less education results in earlier abandonment of soil conservation, 6. Soil erosion on farmers' plots is not totally stopped.
Jansen et al., 2001 (UNA-DLV)	To predict the short-term (less than 5 years) effects of agricultural policies on farmers' land	Farm scale and regional scale	Bioeconomic model (Technical Coefficient Generators (TCG), Linear programming (LP), econometrics, GIS). Uses individual farm models for representative farms. TCGs are used to generate coefficients of different crop and livestock production systems and tech-	Incorporated as constraints (e.g., include the expected monetary	Applied to the Atlantic Zone of Costa Rica: Introduction of technological change results in: small and medium farms increase cash crop production; haciendas extend pasture at the expense of frontier forest areas; banana plantations increase

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
	use decisions		nologies. Uses partial model results for the different farm types to determine total regional product supply and factor demand through weighted aggregation. The GIS is used to archive and manipulate geo-referenced data and present the results spatially. The key output includes technological options and farmers' reactions and measures of (partial and aggregate) policy effectiveness.	value of nutrient losses in farm income objective).	use of less suitable soils. For overall region with adoption of alternative technology - expansion of crop and pasture is at the expense of agricultural frontier forests; there is increase in economic surplus and reduced nitrogen depletion.
Jansen et al., 2001; Schipper et al., 2001, (Sustainable Options for Land Use (SOLUS))	To explore the aggregate effect of policy measures on both efficiency and non-economic and environmental sustainability objectives at a regional level.	Regional scale	Bioeconomic model (includes: Technical Coefficient Generators (TCG) for production technologies; linear programming (LP) to select optimal combination of production systems; econometrics; and GIS). It is based on the Regional Economic and Agricultural Land Use Model (REALM) which identifies optimal combination of production systems by maximizing economic surplus generated by the agricultural sector. The latter is formulated as a multi-market structure. It is a single year model. The key outputs include quantification of trade-offs between economic and sustainability objectives which are identified by running the model for different scenarios or by simulating alternative land use systems.	Sustainability and environmental parameters relevant to the region are incorporated in the optimization. The model assesses the effect of these restrictions on economic surplus.	Applied to the Atlantic Zone of Costa Rica. Looked at different scenarios and identified the impact of technology and policy on ecological and environmental measures. Found that the improved technology scenario does increase economic surplus and less environmental degradation. Similarly restrictions on soil nutrient depletion have improved benefits but lower economic benefits than technological progress.
Skonhoft and Armstrong, 2003 (Conservation in reserves)	To understand the effect of habitat conversion and harvesting outside reserves affects conservation within reserve	Regional scale	The model has two components: an ecological and an economic model. The ecological model captures the change in stock of wildlife within and outside the reserve. The model uses one stock of wildlife to represent the whole game population. This stock is divided into two subpopulations that are connected by dispersion. The economic second component of the model looks at a single owner and assumes that	The population dynamics of the species is incorporated in the ecological component of the model.	This is a theoretical model that assumes there is no illegal harvesting occurring within the reserve. It finds that land conversion triggered by improved profitability in agriculture does not necessarily have a negative impact on the wildlife population in the reserve. The model also finds that when harvesting occurs outside the reserve, there is a smaller stock of wildlife

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			maximization of current equilibrium net benefits steers land use and harvesting policy. The benefits include both consumptive and non-consumptive value of wildlife. The key output is an identification of wildlife population levels, given different conditions.		within the reserve. However, when harvesting occurs and harvesting is profitable, the impact on stock population in the reserve is ambiguous because the owner has an incentive to create habitat.
Zander and Kachele, 1999 (Multi-objective decision support tool for agroecosystem management)	To develop sustainable land use options	Farm-level	The model simulates the influence of prices and policy regulations on the farmers' decision-making and the effect of resulting agricultural practices on the indicators of sustainability. The model involves a hierarchical structure of economic and ecological modules. The first level develops technical coefficients, the second level calculates the economic coefficients of site-specific production techniques, the third level evaluates the ecological effects of these techniques, the fourth generates the linear programming model, and the fifth level starts the subprogram that solves the equation system, analyzes the data and transfers it to GIS. There is a feedback between the outputs of the model and the goal setting. The key output is a regional sector model which provides overall economic evaluation, trade-off scenarios, and regional land use patterns which provide an overall evaluation of the ecological condition.	Practical measures on the environment are incorporated using select sustainability indicators. The paper talks about six of them: potential for nitrogen leaching, potential wind, water erosion, protection of wild flora, disturbance index for amphibians and an index for partridges.	This paper provides a theoretical representation of the model.
BIOECONOMIC MODELS (Dynamic models)					

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
Albersen and Sun, 2001 (Social welfare maximization)	To identify and simulate socially desirable and economically efficient trajectories of investment and resource use for the future.	Plot and national	The welfare model is a T-period optimization model in which 1. every consumer maximizes the T-period sum of their own utilities subject to intertemporal budget constraint and discount rate, 2. every producer maximizes his own profit for each time period, subject to technology and natural condition constraints, 3. the commodity markets clear, and 4. resource utilization matches resource availability. The model develops an agent-specific transformation function that describes the set of technologically efficient production functions. A cost of transformation and degradation induced transformation process are also modeled and incorporated into the decision-making process of the economic agent. A key output of this model is a set of investments at the individual and government level.	One of the vectors in the transformation function represents the characteristic of the land (both inherent characteristics and characteristics resulting from the decision makers' behavior.	This study provides a theoretical representation of the model. Mentions that the transformation function (where land is transformed from one state to another) can be incorporated in the profit maximization model of producers, or embedded in an intertemporal welfare optimization framework or other (partial) intertemporal frameworks that use the transformation function in combination with resource management. This approach can also be used to examine multiple inputs and outputs
Barbier and Bergeron, 1999 (Dynamic/ recursive linear programming)	To examine the effects of state policies on farmers' incomes and natural resource conditions	Watershed scale	The model uses linear programming to maximize aggregate utility of a whole micro-watershed over a five year planning horizon. The results of the first year of planning horizon become the initial resources of a new model that is solved for the following five years. The process is moved one year forward and repeated until the full time period of the simulation has been covered. It accounts for the whole watershed, and identifies two social groups (farmers and ranchers). The elements in the model include a population and labor, partitioning the watershed, crop production, product allocation, livestock production, soil erosion, perennial and forests, EPIC model. Different policies are examined. The output includes simulations of land use across watershed, income per person by	A soil erosion equation. Yield and erosion parameters are from bio-physical model - EPIC (Erosion Productivity Impact Calculator). The microwatershed is also divided into different land categories	The model is applied to a microwatershed in Honduras. Finds that changes in microwatershed are due mainly to changes in population rather than changes in policy. Labor is the constraining factor. Areas with low population and high population farmers employ soil conservation measures. Areas with medium population (when expansion to other land areas for agriculture is still feasible) farmers do not invest in soil conservation.

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			group, simulation of crop productivity, and conservation measures. This is done for the different policies.		
Bontkes, 2001 (Regional simulation model)	To provide qualitative insight into the dynamics of agricultural development	Farm and regional	Model is an intertemporal simulation model. The model divides up farms and soils by type and the number of farms and soils in each types is known. The simulation proceeds by determining: 1. the areas per crop and inputs applied per farm type, 2. availability of nutrients for crop uptake, 3. crop production (including pasture), 4. animal production based on available quantity and quality of feed, 5. cereal prices, 6. sale or purchase of animals based on farm income, 7. changes in number of farms per farm type and the soil fertility characteristics per farm and soil type. This new situation (7) is used to as the initial condition for the subsequent year. This information is aggregated to the regional level. Farmers' decision-making is simulated using decision-rules that are derived from interpretations of interviews and literature and some socio-economic research. The model produces continuous input-output relationships.	Incorporated as soil fertility in step two of the simulation.	The model is applied in Mali where the base case involves decreasing soil organic matter content when no additional measures are taken, leading to decreasing millet yields while maize yields increase as a result of application of fertilizer and animal manure. Scenario 1 is a change in prices for cotton and compound fertilizer. The increase in cotton price initially increases area under cotton, but this eventually decreases as soil organic matter decreases. A change in fertilizer price does not have a major impact on cotton area. These changes result in reduced soil organic matter, but benefit large farmers in terms of development.
Fleming and Milneb, 2003 (Dynamic stochastic simulation of production-export marketing)	To capture the lagged effects of government policies, exogenous factors and decisions made by cocoa producers on the industry	Industry (no geographic scale)	This is a dynamic stochastic simulation module composed of eight modules for estimation: economic surplus; area of cocoa trees (with separate modules for each cocoa tree variety); land suitability; input–output relations; break-even values; export volumes and values; export prices; and domestic price formation. (did not use a dynamic optimization model to estimate the area replanted	This is incorporated in the land suitability, but not really considered in the analysis	Applied to PNG: Have runs that are deterministic and stochastic for the various policy options. There is a range of impacts. The most positive impact on profit results from a devaluation of local currency and reduction in opportunity cost of labor input. Neither short-term price support or price stabilization are preferred (from a profit standpoint) to the results of

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			under trees). The economic surplus module measures the welfare changes. The output is discounted economic surplus under different pricing policies for both smallholders and estate owners.		the base-case. A planting subsidy provides a small gain over the base case.
Okumu et al, 2002 (Integrated crop-livestock farming system)	To assess, ex ante, the likely impact of multiple technology adoption on crop-livestock systems under various of policy scenarios	Watershed scale	The model uses a dynamic non-linear mathematical programming framework. The model optimizes an aggregate watershed utility function-comprising production, consumption, profit and leisure. This optimization function is indirectly linked to the biophysical aspects of the watershed through an exponential soil-loss yield-decline equation with single-year time lags. And cumulative soil losses in previous periods determine yields in the next period. For each location in the watershed, the model calculates the optimal fertilizer and dung application rates for every crop activity and selects the most profitable crops for cultivation. Relative prices, costs and yields are adjusted for the effects of erosion in each period. The key output of the model is a quantification of tradeoffs in the achievement of indicators of human and biophysical welfare given the current and simulated policy environment and institutional settings.	Captures the biophysical component via the soil loss yield decline equation.	The model is applied to Ginchi watershed in Ethiopia: Soil conservation measures may not be a profitable venture given existing policy conditions (for both long and short term) instead crop rotation is preferred. Under policy of adoption of technology find that tree planting or conservation measures are not adopted despite their profitability. Instead the need for food self-sufficiency results in fallowing in the crop-rotation pattern. Also improved human-nutrition goals could be achieved simultaneously by improving land user rights that facilitate the multiple-adoption of commercial trees, new high-yielding crop varieties and increased fertilizer application.
Romano, 2001 (Dynamic control model of farm production)	To analyze how lack of access to labor markets affects soil management decisions	Farm household	This dynamic farm profit maximization model analyzes the importance of different factors on the use of soil conservation practices. The farm production is determined only by family labor and soil quality. A farmer maximizes present value of production with the following	Soil quality is the index of soil characteristics and is incorporated as a con-	Application in El Salvador: For households without access to markets, the off-farm employment is negatively related to soil conservation and significant. It is not significant for those with access to labor. Rural market conditions, therefore, affect

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			constraints: soil quality, labor availability and initial soil quality. In the empirical model production is a function of farm capital owned, land size operated, labor used in productive activities on farm, soil quality index, and index of total factor productivity. The model separates farmers that have access to labor markets and those that do not. The model uses logit regression. The output provides information on the relationship between off-farm employment and use of soil conservation measure.	straint.	behavioral responses of farm households with respect to soil conservation.
Shiferaw et al., 2001 (Endogenous soil degradation)	To examine the inter-linkages between population pressure and poverty, their impact on household welfare and land management, and the consequent pathways of development in a low potential rural economy.	Farm household	In this model a farm household maximizes welfare given available biophysical, human, capital and information resources, and institutional constraints. This bioeconomic model uses a non-separable farm household model to determine the production, consumption and investment decisions interdependently in an intertemporal setting. The decision variables include crop and area choice by land type, levels of fertilizer use, allocation of land, labor and traction power in different seasons, seasonal labor and oxen hiring, livestock production, selling and buying crops and livestock, buying of farm inputs, choice of consumption good, savings and borrowing of credit, choice of level of soil conservation investments. A calibrated model is used to run simulations. The key output is a privately optimal land management practice under population pressure.	Soil erosion and nutrient depletion is estimated for the different land types that are examined. This in turn determines crop yield.	This model is applied in Ethiopia. The findings for better off households: When family labor is abundant, land is scarce and labor-intensive conservation technologies are available, capital market imperfections encourage investment in mitigating soil erosion. When land is abundant and shadow value of labor is high, household does not invest in conservation of soil. For poor households the model shows that scarcity of labor relative to land discourages investment in soil conservation. For poor, land-scarce, labor rich households, the investment in farm conservation will depend on the off-farm opportunities. i.e., When markets are imperfect, poverty in key assets (e.g., oxen and labor) limit the ability or the willingness of a household to invest in conservation.

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
SPATIAL MODELS					
Chomitz et al., 2004 (Transferable development rights (TDR) program)	To determine what the trading domain should be for a TDR program so as to minimize cost of compliance while resulting in environmentally preferable landscapes	Regional scale	This is an optimization model where the problem is to optimize the benefits from the land by determining how much land to leave in forest, how much land to retire from agriculture and, in the transferable development rights scenario, selling permits. The model simulates different policy scenarios, in each of which the equilibrium of supply and demand for land is determined. Also have biodiversity priority areas that are distinguished and the value of land is from land sale values. The model estimates the reduction in compliance cost and the rents earned by the suppliers of legal reserves. Key output of this model are maps regarding areas where forest cover would be preserved and the economic and environmental impact under alternative trading domains.	Focuses mainly on forest cover.	This is a theoretical model that is applied to the situation in Minas-Gerais, Brazil. The findings are that compared to the base scenario of command and control, the municipal level trading offers small changes in compliance cost. But when biome-basin level trading is allowed. The trading among landowners with forest area only results in a notable decrease in compliance cost. Forest-deficient households capture the savings. Similarly, when trading is allowed in the 'forest first' scenario (after trading forest area, can trade land retired from agriculture), the social cost of compliance is reduced (less than forest only) and again the savings accrue largely to forest-deficient households.
Chomitz and Gray, 1996 (Spatial Model of Land Use)	To explore the trade-offs between development and environmental damage posed by road building	National scale	This model assumes that land will tend to be devoted to its highest-value use, taking into account tenure and other constraints. The value of a plot depends on land's physical productivity for that use and the farm-gate prices of relevant inputs. A reduced-form, multinomial logit specification of this model calculates implicit values of land in alternative uses as a function of land location and characteristics. The resulting equations can then be used prediction or analysis.	Returns to activities on the land are a function of land suitability for the activity	This model is applied to Belize. The model reveals that (i) market access and distance to roads strongly affect the probability of agricultural use, especially for commercial agriculture, (ii) high slopes, poor drainage, and low soil fertility discourage both commercial and semi-subsistence agriculture and (iii) semi-subsistence agriculture is especially sensitive to soil acidity and lack of nitrogen (highlighting that subsistence farmers are able to judge the soil).

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
Newbold and Weinburg, 2003 (Targeting conservation programs)	Prioritization of sites for conservation activities taking into account the cost and trade-offs between different environmental services	Regional scale	This model uses spatially explicit models of production functions in an optimization framework. The objective is to maximize environmental benefits with a budget constraint (and have multiple environmental benefits being considered with different weights added to each). The model has three components, the first two are the models of the environmental benefits, and the third is the cost equation. Using the equations for the two environmental benefits, the benefit-cost ratios are calculated for each spatial cell that could be restored (assuming no restoration). The cells with highest benefit-cost ratios are restored and the benefit-cost ratio for cells in which the interaction are updated. The process is then repeated till the budget is completely expended. The key output is a map of sites that should be targeted for restoration.	Included in the biological benefits. E.g., mallard abundance is a measure of habitat quality, and reduction of nitrogen loading is a measure of water quality benefits	This model has not been applied to a specific context. However, it should be noted that the model can be modified by attaching weights to different environmental benefits and to species to reflect their value to society or use a measure of taxonomic diversity (Polasky et al, 2001 as cited in Newbold and Weinburg, 2003). One of the distinguishing features of this approach is that it takes into consideration the spatial pattern of different land uses and its impact on environmental benefits. The estimation of environmental benefits could be further refined.
Pfaff, 1999 (Economic model of deforestation)	Identify factors affecting deforestation	Plot and national scales	This approach uses an economic land use model. It allocates land to different land uses to maximize profit. The decision model involves identifying whether the land use of clearing forest results in greater returns than not clearing the land. Uses GIS, and spatial data as explanatory variables for deforestation at the county level. The output includes findings from a regression analysis.	Soil characteristics and vegetation type (*cerrado)* are explanatory variables	Applied to the Brazilian Amazon, this model finds that own and neighboring county paved roads increase deforestation while distance to national market has an inverse relationship with deforestation. Soil quality is positively related to deforestation and low clearing cost of *cerrado* can reduce pressure on forest areas, reducing forest clearing.

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
Wossink et al., 1999 (Network design modeling and conjoint analysis)	To examine the economics of joint spatial production of wildlife and agriculture at the regional level and incorporating farmers perception and preferences	Regional scale	Uses a mathematical formulation of a network problem. The model has a perception and conjoint analysis component through which land managers state their preferences for land use alternatives. The model, using the findings from the preference and conjoint analysis, examines select alternatives. The model minimizes costs subject to various constraints such as connectivity, allowable gap lengths, and other corridor requirements (e.g., the cost of leaving unsprayed edges is calculated using partial budgeting and programming techniques). Uses a GIS model (ECONET4) for the empirical application of this model. In ECONET4, can use either distance or edge weights (the latter is better for selection of cost effective network). The model provides a spatial representation of a set of edges and land use practices on these edges that satisfy the corridor requirements and the cost and wildlife preservation benefits associated with each alternative.	Used in the measure of biological output, using the most extensive species based state indicator (available for agriculture in the Netherlands)	This model is applied to farms in Haarlemmermeer in the Netherlands. Based on the perception analysis, it is found that farmers in the region prefer margins in regular crops than grass strops or fallow strips. The perception analysis reveals 4 key attributes for compatibility of unsprayed crop edge with farm organization: (i) width of the margin, (ii) the type of compensation payment scheme for implementing the unsprayed crop edges, (iii) guidance, and (iv) where margins should be included in the rotation. Using these findings a spatial model is used to simulate cost and benefits of 4 different strategies of network design. The authors find that using selective control lowers cost of wildlife preservation.
SYSTEMS ANALYSIS FRAMEWORKS					
Antle and Capalbo, 2001 (Econometric process models)	To simulate decision-making both within and outside of observed data in a manner that is consistent with economic theory and the bio-physical constraints and	Farm scale	This model combines econometric production model represented by a system of supply and demand equations and process-based representation of discrete land use decisions represented by equations of profit maximization with a discrete step function regarding crop choice. The econometric production model calculates expected net return in the simulation of land use decision. The land use decision for a site is made by comparing expected returns for different activities. For the selected activity the model generates factor demand equations and	Recognizes the spatial variation in physical conditions in the production function and in the crop models	Is able to simulate land use in unobserved situations. Also finds that when spatial variability in returns is simulated, the distribution of net returns varies according to the productivity level of the sub-area zones. This results in a non-linear characterization of supply response (which differs from the constant-elasticity supply function)

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
	processes.		determines the input use. This is then integrated into a biophysical model. Land use and other decisions are used to initialize computation of expected returns for subsequent period. The output is a joint distribution of outcomes in the population of land units or farms. It also provides mean net returns for the different price scenarios of the sub-areas via the production function. In this model the economic decisions are based on the spatial and temporal distributions of expected returns.		
Carpentier et al., 2000; Vosti et al., 2002; van Noordwijk, 2002; Suyamto et al., 2003 (Alternative to slash and burn trade-off matrix)	Objective of ASB framework is to evaluate alternative land-use systems based on their ability to address international environmental concerns, agronomic sustainability issues, and farmer adoption concerns.	Multiple scales. The actions for change are at the farm, and national and international policy levels	Different technical models (bioeconomic, agroecological, etc.) are used to estimate the elements that go into this matrix. The local benefits are measured via productivity and profitability, the regional ones are measured based on watershed functions and the global benefits are measured through carbon sequestration and biodiversity. The matrix has a column of different (relevant) land uses in the region. These are compared along a set of ecological, economic, agronomic, and policy criteria that are relevant to policy-makers and the farmers who would adopt the technology. The findings from the research are incorporated into a trade-off matrix. No weighting is given to the different criteria in the matrix, therefore those using the matrix information can make assess which land use would be most suitable given different objectives.	The models on carbon sequestration, and productivity take into account the biophysical elements	The findings vary based on the area where the studies are done. For example, Carpentier et al (2000) examined the adoption of four types of intensification and predicted their economic and environmental impacts using a farm level bioeconomic linear programming model. They found that although intensified land uses on all cleared lands (including pasture) had a low deforestation rate it resulted in the least amount of preserved forest after 25 years. In contrast, intensification on forested land, via low-impact forest management, slowed the deforestation rate, but deforestation did not stop unless timber prices were equal to or greater than a particular amount. The authors concluded that in the long run, there is a trade-off between farm income and forest preserved, which results from intensification of land uses on the cleared land. Other findings are discussed in this table (see Suyamto et al., 2003)

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
Crissman et al,2001; Stoorvogel et al., 2001; Antle and Stoorvogel, 2003; Stoorvogel et al., 2003 (Trade-off analysis approach)	To operationalize an ecoregional approach by linking disciplinary models of agricultural production and environmental health impacts. This enables an assessment of technology and policy analysis.	Regional scale with farm land as unit of analysis	The approach begins with stakeholders identifying the critical dimensions of concern (the sustainability criteria). These criteria form the basis for formulating hypotheses regarding trade-offs between competing objectives. The analytical model is based on the Tradeoff Analysis Model, which is an integrated GIS-based biophysical and economic modeling system. This model simulates land use and input use decisions. The model has prices, policy and attributes of human, physical and biological populations affecting land use and input-use decisions at the field scale. These decisions in turn determine agricultural output, environmental impacts and health effects. The analysis results in a joint distribution of management practices, environmental impacts and health outcomes for each unit in production as a function of prices and policy parameters. The outputs include two-dimensional trade-offs curves in terms of agricultural output, environmental quality indicators and health indicators.	As environmental attributes of the land which in turn affect production and management practices and agricultural output	The approach was applied in northern Ecuador and Northern Peru where the farmers use a range of highly toxic chemicals for pest management. The scenarios were increase pesticide price or IPM. The trade-offs examined were those between agricultural production and pesticide loading or neurological damage. The model finds that the tax or price policy typically resulted in movement along a tradeoff curve and therefore resulted in the same relationship, whereas the IPM solution resulted in improvement in one factor while the other factor was held constant.
Legg and Brown (2003a); Legg and Brown (2003b); and Brown (2003) (Dynamic spatially explicit village model)	To model the household level decision-making for selection of fallow patches for cultivation	Village / house hold	This is a spatially explicit system-dynamics model. Involves mapping the area, location, ownership and cultivation state of fields. This model follows the FLORES-type SIMILE model. There is multiple-instance land patch model that contains a sub-model for each agricultural system. These sub-models are models for the crops and other elements characteristic of the system. The multiple-instance household model has sub-models for population, labor availability, stocks and decision-making. Respondents scored each field type based on criteria to reveal the importance of these criteria for decision-making. The selection of the	This is included in the land patch mode - with information re: crop systems, and rainfall (which influences productivity)	Land use patterns change with differences in population density and market access. The age of the forest or fallow was the most important criteria for choice of location for new fields. Time required for vegetation cleared to dry was an important criteria. The presence of indicator species (for fertility), and (for forest melon fields) tree size were important. With the exception of monoculture fields, the size of the field is determined by food needs of the household and is limited by labor. Intensification of land occurs for a variety of reasons, not only the availability of land.

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			patches was then based on a "suitability index". An optimization model with a time step of half a year was used to rank the suitability index of each land patch for a household. A key output is a map of distribution of different patches, and therefore information on what lands are left fallow and for how long and what is cultivated in different places.		These findings differ slightly for each village. This information is then used for the simulation to determine patch selection/patch size.
Stoms et al., 2004 (TAMARIN)	To evaluate and compare different landscape configurations to achieve conservation goals - recognizing key principles (see comments)	Regional scale	TAMARIN builds on idea of setting general environmental goals and then using economic instruments to induce voluntary compliance. It simulates a range of programs involving economic instruments with flexible specification of program eligibility, payment rules and budget for the program. The model allows for detailed specification of spatially varying opportunity costs. The model uses three layers of spatial information in GIS - current land cover, ecologically distinctive sub-areas, and opportunity cost of conservation expressed as a value, which is assigned to each point on the landscape. There are four steps: defining the parameters of the scenario, selecting the sites for the portfolio, projecting future land use in the region based on portfolio, and evaluating the effects on the social, economic, and landscape configuration factors.	Incorporated in the parameter setting of a scenario.	No specific findings - this is a planning tool. This has currently being pilot-tested for the Atlantic Rainforest area of Brazil.
van Noordwijk, 2002; Suyamto et al., 2003 (Forest, Agroforest,	To explore the simultaneous impacts of changes in land use at a landscape scale -	Landscape or watershed	The simulation model predicts food self-sufficiency, soil fertility, carbon stocks, plant species richness and watershed functions on the basis of a number of biophysical and management parameters for a 100 grid-cell landscape. The model also includes options for	Includes carbon stock within forest, agroforest, fallow area, and below	Suyamto et al (2003) application in Sumatra found that a 25 percent forest cover of riparian forest has the lowest sediment load into rivers, compared to allocating forest to steepest slopes or ridge tops. The farmers' response to price

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
Low-value Lands or Waste (FALLOW) model)	examines the watershed functions within a dynamic landscape	scale	harvesting forest products and for changing the food crop based agricultural system into an agroforest or tree-crop system. It includes a simple water balance that predicts the resulting impact on the landscape using certain rules. The key outputs are trade-off curves. An additional output in van Noordwijk (2002) is a set of parameter values for the critical point at which the watershed functions 'crash'.	ground. Assesses change in biodiversity from leaving land fallow. Also Incorporates biophysical elements in the land use part - e.g., soil erosion, sedimentation, storm flow, etc.	shocks depends on their adaptive capacity to experiment and reorganize land use patterns. van Noordwijk highlights the importance of interpreting field-derived data in the context that they were derived rather than as system properties. The number of trade-offs between productivity, carbon stock and biodiversity depend on the scale of model application, the internal variability of the landscape, and the transient behavior under changes in land use intensity.
MACRO-LEVEL AND CGE MODELS					
Darwin et al., 1996 (Impact of Land cover change (GIS-FARM model - CGE))	Look at how global changes in climate, human populations and international trade policies might affect tropical forests	Regional scale	This model uses the Future Agriculture Resources Model (FARM) to evaluate impacts of global climate change on agricultural systems worldwide. This model has a GIS and a computable general equilibrium (CGE) component. The GIS links climate variables to land and water resources in FARM's environmental framework. The model also uses land class information. The economic framework links land, water, and other primary factors with production, trade and consumption of 13 commodities in eight regions. The model uses revenue from sale of these primary production factors to purchase consumer goods. Multiple situations are simulated. The outputs provide information on land use and land cover change in moist tropical areas under simulated scenarios.	Environmental framework - enters into the production function: has climate, length of growing season, runoff, water information, land class information.	The following situations are simulated in this paper: climate change with changes in water supply and distribution of land in different land classes, population growth with regional increases in population and labor, and trade policy (in the agricultural sector) by adjusting difference in producer price and foreign market prices (i.e. duties/tariffs). Global climate change threatens the health and integrity of tropical forest ecosystems and the biodiversity within them. As more area is converted to agricultural purposes, the forestlands in moist tropical regions will decline slightly (therefore deregulation of agricultural trade will pose a small threat).

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
Dyer et al., 2001 (Village-Town CGE Analysis)	To capture the "second and higher-round" effect of land degradation on households other than those directly affected.	Village level (regional)	This village-town CGE model is built on a series of models of agricultural households engaged in crop production and other economic activities, including migration. The farm households maximize utility, defined on consumption goods and savings. The general equilibrium equations local market-clearing conditions for factors and goods, a village-town savings-investment balance, and a trade-balance equation. The model provides information on the percentage change in fixed wage and endogenous wage in the different scenarios.	These are modeled implicitly - for example, changes in the bio-physical elements (i.e. land degradation) results in changes in productivity of crops. Or land is retired because it is degraded.	The model is applied in Mexico. It reveals that the high degree of diversification in the households shields them somewhat from land degradation. This model is useful to understand the effect in situation of market imperfections. For example, when the main staple crop's market in the village is closed (i.e., high transaction costs to trade with town), land degradation results in a change in endogenous price and may result in more intensive staple production and therefore more degradation.
Lewandrowski et al., 1999 (GIS-FARM (CGE) model for cost of land set aside)	To assess how setting aside of land reduces the gross domestic product and gross world product, and to examine the impact of a 10 percent global retirement plan on regional crop, livestock and forestry sectors	Global scale	The model uses the Future Agricultural Resources Model (FARM), which consists of GIS and a computable general equilibrium model (CGE model). It presents sectoral and regional trade-offs associated with incremental increase in the global land area set aside to protect biological resources. The CGE model extends the Global Trade Analysis Project (GTAP) model by including heterogeneous land endowments, introduction of water as primary input in the crop, livestock and service sector and modeling crop production as a multi-output sector. Production is determined by profit maximization and assumes competitive markets. To simulate implementation of land set aside, 5% to 15% of land is removed from economic use within each region-land class using 1% increments. The model output provides information on the	Incorporated this in the land classes identified for set aside - tundra, forest tundra, tropical seasonal forest, etc.	The findings from this model include: protecting five percent of the world's land area under this strategy reduces global GDP (1990) by approx. $45.5 billion. Increasing the land protected to 10 and 15% increases the cost to $93.3 billion and $143.8 billion. Most of the global costs (45%) fall on the densely populated and highly developed regions of Japan and EC. The United States will have to bear 15% of the cost.

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			regional economic and land use impact of land retirement at the different percentage levels.		
Polasky et al., 2001 (Selecting Biological Reserves)	To identify cost effective strategies for conserving maximum number of terrestrial species given a conservation budget	Regional scale	The model address a budge constrained maximal covering local problem. The model uses an integer programming formulation of reserve site selection. The model maximizes the number of species included in the network of reserves subject to two constraints. The first is that a species is not included if sites in which it occurs are not selected and a budget constraint (with expenditure being measures as the opportunity cost of land). The output is a cost-coverage curve and a map of which sites should be selected. The output can often have multiple combinations of sites that generate an optimal solution.	Uses biogeographic data that describes the range of each species in order to know if a species if found in certain sites.	This model is applied to conserve terrestrial vertebrate species in Oregon, USA. The model reveals that the level of coverage is less costly using a budget-constrained approach than a site-constrained approach. For conserving 350 species, the budget-constrained approach for site selection lowers costs by 10 percent. Moreover, covering the majority of the species costs less than covering the remaining 10 percent of species. The model can be modified to maximize a more complex function than number of species (e.g., a function that recognizes species value, etc.). This analysis is a first step in an effort to establish reserves.
Polasky et al., 2003 (Trade and Biodiversity model)	To analyze the effects of trade on land use and trace the likely effects of land use changes on biodiversity		The model is a two-good two-country trade model. The two goods in the model, grain and timber, are each produced by a fixed ratio of labor and land. Only certain lands (habitat types) are capable of producing each good. It is assumed that once land is converted to a productive use, it is incapable of supporting native biological diversity. Land that is not converted for production remains as natural habitat capable of supporting species. The number of remaining species remain is determined by a species-area curve relationship. Other assumptions include that consumers in each country	The model uses species-area curves	A theoretical application of the model compares an autarky versus free trade situation. The effect of trade on global biodiversity depends on the degree to species endemism in each country. The number of native species surviving in country 1 in a free-trade equilibrium depends on the distribution of species among habitat types and how this changes with productive use of land. Citizens utility levels under autarky or free trade depends the relative strength of their preferences for species conser-

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			have identical Cobb-Douglas preferences over timber and grain, and have separable utility over consumption goods and species conservation. The model maximizes social utility function. The utility function values both local species conserved and global species conserved.		vation versus consumption of private goods. The model reveals that the increased specialization associated with trade can have important consequences for patterns of habitat conversion. On the other hand, trade may increase welfare in situations with low endemism or with low importance of species conservation relative to consumption of private goods.
MIXED MODELS					
Bolwig et al., 2003 (Dynamic Research Evaluation for Management (DREAM))	To estimate the potential consumer and producer benefits, and export revenues of simulated changes at the subnational and national levels. The estimated impacts are always relative to a baseline ('no change') scenario	Regional or national scale	DREAM is a menu-driven software for evaluating economic impact of agricultural research and development. It is a single-commodity model designed to measure economic returns in predefined regions to commodity-oriented research under different market conditions. Its application can be made spatially explicit - as is the case here. The output includes maps that provide information on spatial distribution of producer surplus from the changes in productivity.	Agroclimatic suitability (based on length of growing period, not on soil or soil pH, etc.) is incorporated in the definition of the land classes	Application in Uganda: Finds that increased production in cotton does result in increased benefits and that this is occurring in areas which are not close to the markets.

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
Cacho, 2001 (Analysis of externalities)	To determine the optimal land use mix between forestry and agriculture in the presence of forest externalities. Emphasis here is on converting agriculture to forestry - improved land productivity in agroforestry system	Watershed scale	Maximizes the discounted value of net revenue over a rotation cycle. In the calculation of the net revenue, it includes the monetary benefits of the agricultural crop and the monetary benefits of the forestry operation. This is based on the marginal benefit of forestry being equal to the marginal benefit of agriculture. The value of the forest benefit is the improved agricultural yield because of the trees impacts on the biophysical elements and the benefits of selling the trees at the end of the rotation - does this for one 30 year rotation and for five 30 year rotations. This is to capture the context of sustainability. The model output provides graphical information on changes in discounted net present values as the area under forest changes, assisting to identify the optimal points in the graphs.	Incorporated in the yield function which is dependent on the state of the land (and recognizes that the state of the land depends on the previous state of land)	The model is applied to dryland salinity agriculture in Australia. The model uses a 30-year rotation. In the model the value of forest externality is critically affected by both the initial state of the land and the discount rate. In the multiple rotation example, the optimal decision rule species the area of trees to plant as a function of the state of the land at the time of the decision. Also the level at which the water table should be kept, depends on the discount rate. Therefore optimality does not imply sustainability (because based on discount rate, could have water levels that are higher than is sustainable).
Feather et al.,1999 (Non-market valuation)	To use non-market valuation techniques to quantify the environmental benefits and improve targeting farm acres	National scale	This method uses spatially disaggregated static models applicable across a wide geographic area. It estimates the benefits of CRP looking at recreational uses. The model uses a higher resolution than regions for the geographic and behavioral data. The three models use different activities in the calculation of the environmental amenity. Each model is a three step model: (i) determining how the CRP acreage creates physical effects, (ii) translating these physical effects into biological results, and (iii) examining how the biological results affect consumer welfare. For steps (i) and (ii) assumptions or indicators or extrapolations are used because of limited information. Step (iii) is the economic calculation of consumer surplus. The three models illustrate different means of accounting for variations in the price and quality of the site.	Integrated in the model as part of step two - where the physical effects are translated into biological results	Application in the United States: conclusions include that the benefits of freshwater recreation is greater than those associated with pheasant hunting. However change in consumer surplus is greater for the pheasant hunting than the freshwater recreation (suggesting that CRP provides a greater contribution to the benefits of pheasant hunting). This information is then used as baseline for a simulated targeting mechanism

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			The model output reveals the changes in level of consumer surplus associated with CRP. It also provides information on the relative value of the different recreational uses.		
Gobbi, 2000; similar study is done by Lyngbæk et al, 2001 (Benefit-cost analysis of certified crop)	To evaluate the financial viability of investing in the conversion of a coffee plantation to a biodiversity friendly coffee plantation.	Farm plot	The model is used for the different production systems. The model 1. estimates parameters of production and sale for the typical farm for each production system, 2. computes investments necessary to certify the farm as Biodiversity Friendly, 3. estimates the production costs and sales of the farm once certified, 4. uses Monte Carlo approach to incorporate risk for production and price variables, 5. estimates expected net present value considering the situation certified as biodiversity friendly versus non-certified. Also examines the sensitivity of investment to declines in production due to shade effects and to declines in premium levels. The output provides a financial analysis of adopting biodiversity friendly crop production under the different production systems.	Biological and biophysical factors are not explicitly measured. It is implicitly assumed that the different production systems have varying impacts for biodiversity.	Gobbi (2000) finds that the net present value of biodiversity friendly (BF) coffee (except for commercial polyculture) is more sensitive to declines in yields than anticipated premium levels. In terms of mean net present value (NPV) it decreases in the following order: farms with monoculture (above 1200m), farm with traditional polyculture, farm with technically appropriate shade at more than 1200m, farm with technically appropriate shade at less than 1200m, and farm with commercial polyculture. Small farmers may need additional help and incentives to adopt the BF certification criteria (if they are not starting with low shade cover).
Jagger and Pender, 2003 (Benefit cost analysis of crop use)	To do an ex ante benefit-cost analysis based on community and village level survey data to illustrate the effect of planting eucalyptus. To make policy recommendations.	Farm level	The economic component of the analysis involves a multiple year cost-benefit analysis (therefore with discount rate). Estimate a base case scenario and then consider the influence of variable harvesting periods and potential crop losses (due to nutrient and water uptake by eucalyptus) related to negative externalities. Benefit cost analysis is based on simple parameters and sensitivity analysis is used to reflect the key variables hypothesized to influence returns to investment for tree planting. Have institutional barriers to obtaining rights to	The ecological component of the analytical method involves reviewing literature relevant to Eucalyptus cultivation in Northern	This form of analysis is applied in Tigray, Ethiopia. The study reveals that the main factor influencing household or community decisions to invest in tree growing are the costs and returns of the investment. The harvesting period and the opportunity cost of land (especially where eucalyptus is planted on cropland) affects the rate of return. Management of woodlots by villages or individuals has higher rate of return than those managed by higher administrative level. The find-

Source (Name of approach)	Application	Scale	Characterization of methods and outputs	Ecosystem elements in model	Findings
			harvest both timber and NTFP, therefore estimate potential rather than actual benefits. The model estimates private internal rates of return estimates for the different scenarios.	Ethiopia based on studies in areas that are topographically and climatically similar.	ings however do not involve a detailed understanding of the markets.
Pender et al., 1999; Pender et al., 2001; Pender, 2003 (Development pathways)	To identify the major pathways of development that have been occurring, their causes and implications for agricultural productivity, natural resource sustainability and poverty	Community level	Identification of the pathways of development involves classifying the primary and secondary occupations in the communities. Then empirical analysis involves comparing descriptive statistics across pathways, econometric analysis, and qualitative information from the survey. Looked at econometric analyses to identify factors affecting pathway, factors affecting household responses, factors affecting collective resources, and factors affecting outcomes. They estimate direct and indirect impacts of marginal changes in factors that overlap in the different regressions on various outcome measures. The model provides an understanding of the key factors that explain the development pathways.	No biophysical or biodiversity variables included. These considerations are included by examining whether conservation measures are adopted (e.g., minimum till, incorporation of crop residue, etc).	Pender et al (1999) apply this approach to 48 communities in central Honduras. They have six pathways of development - 1. Basic grain expansion communities, 2. Basic grains stagnation communities, 3. Coffee expansion communities, 4. Horticultural expansion communities, 5. Forest specialization communities, 6. non-farm employment communities. The pathways are distinguished by comparative advantage, including agriculture potential, population density, access to markets and technology. Changes in poverty are not pathway dependent, but agriculture and resource management are. In the case of horticulture, coffee and non-farm employment pathways, productivity outcomes are more favorable, but the implications for resource conditions are mixed.

Chapter 6

Contributions of Agricultural Biodiversity and Natural Ecosystem Processes to Sustainable Agricultural Systems

6.1 Introduction

There is a burden of proof on proponents of ecoagriculture, as suggested in Chapter 2, to show that ecologically-based land-use and resource management practices can achieve enough complementarities and synergies, while avoiding tradeoffs, so that agricultural productivity is enhanced while environmental objectives are also achieved. If the farming systems proposed under the heading of ecoagriculture are to be attractive and acceptable, and thus to help meet world food needs and conserve biodiversity, they will have to demonstrate positive-sum dynamics rather than just zero-sum (or worse, negative-sum) outcomes.

To assess the opportunities for capitalizing on such positive-sum dynamics, we reviewed the state of knowledge and practice in a number of areas that can be characterized as integrated agricultural management systems. The topics chosen cover the breadth of research that underlies promising innovations in agricultural science and production. Proponents of these various systems are often yet not aware of ecoagriculture as an overarching, emerging field, but their methods enhance and exploit natural ecosystem processes in ways that can support agricultural biodiversity, resource conservation, and sustainable food production. They can contribute to ecoagriculture especially if links can be made to protection of wild biodiversity.

In-depth interviews were conducted with Cornell faculty and staff having expertise in these different topical areas (see Annex I-C). Key points from the interviews are included in this chapter, along with supporting materials derived from recently published literature. These provided the empirical basis for the presentation in Chapter 3. We have cast our net widely, looking for any and all documented findings that could bear on this subject. The categories of knowledge and experience reviewed in this chapter are:

1. Agrobiodiversity conservation and utilization;
2. Organic agricultural production systems;
3. Agroforestry;
4. Systems approaches to pest management;
5. Integrated nutrient management;
6. Soil health;
7. Contributions of below-ground biodiversity to sustainable crop production;
8. Management of the hydrological cycle;
9. Conservation tillage/conservation agriculture; and
10. System of Rice Intensification.

Because many of these areas of agricultural endeavor are relatively recent, there is not in all cases an extensive literature to draw on. This means that claims should be tentative, pending more confirmatory evidence. We report here on things that most scientists who have worked in the area for some years agree on, though there is not unanimity on all points. Where there is disagreement, we note this, trying to be fair to all informed points of view.

6.2 Assessing Ecoagricultural Alternatives

How feasible is it to achieve greater long-term agricultural sustainability and food supply by relying more on above-ground and below-ground biological processes, e.g., interactions among flora and fauna, and organic matter decomposition, to promote agroecosystem benefits such as nutrient cycling and disease and pest control in a manner that produces abundant crops from ecologically diverse, robust, and productive farmland environments?

This question summarizes the central opportunities and challenges for ecoagriculture. The same question applies, with appropriate changes in wording, to livestock production. The answer which emerged from the interviews and literature review is that increasing attention to natural and biological cycles, which are manifestations of biocomplexity, can contribute substantially to the improvement of nutrient and water cycling, pest control, and crop and livestock productivity. By mobilizing these processes in support of agricultural production, the efficiency and sustainability of operations can be improved at the same time that environments for biodiversity are enhanced, moving agricultural production parameters rather than simply making tradeoffs within them.

Analyses of cropping systems diversity and biological function require the use of multiple research techniques, including both traditional factorial experiments under controlled conditions and on-farm systems-related monitoring studies (Drinkwater 2002). Identifying critical parameters that reflect soil health and system productivity is essential for knowing what is happening within an agricultural system (and why), not just what results are obtainable with certain methods. Fortunately, monitoring studies and simulation models are becoming more robust in their capacity to evaluate complex systems. Many of the tools needed for monitoring and evaluation are still under development. Periodic and location-specific evaluation should become a reference point for helping farmers choose from among a number of improved management practices that address their particular needs and opportunities (H. van Es, interview).

Secondary environmental benefits are increasingly being focused on in scientific assessments of the agricultural sector (NRC 2003). This poses difficulties when doing economic evaluations because these benefits often are "externalities," not credited (or debited) to the cropping system adopted. Evaluations of ecoagricultural alternatives—to assess whether they are desirable or not from a societal perspective—should internalize any externalities, both positive and/or negative, that can be clearly attributed to the system or practice. Where net benefits are demonstrable, it becomes incumbent upon government decision-makers to find incentives and/or restrictions that make agricultural practices which are favorable in economic, social and/or environmental terms more attractive to resource managers and the public.

Different evaluation criteria are needed for different kinds of agricultural enterprises, and there can be no single solution or best-system for all of agriculture. Being concerned as we are with food security and livelihood generation as well as biodiversity conservation, we are particularly concerned with the incentives and benefits that affect smaller producers in the agricultural sector, and with households that derive their livelihoods mostly from agriculture, rather than primarily with larger producers. However, the latter make a major contribution to helping feed urban populations, and their impacts on the natural resource base can be greater over time because of their reliance on mechanization and agrochemicals. So we reiterate what has been said already, that ecoagriculture pertains to—has potential relevance for—the whole agricultural sector, not just smallholder production units. Inasmuch as ecoagriculture is based on sound scientific principles, it should be available and useful to larger farming operations as well.

Modern agricultural systems are facing instances of declining yield and factor productivity with increasing frequency, due to the consequences of intensive management, including compaction of soil and organic matter depletion (Wolfe, pers.comm.). Integrated ecological management practices can overcome the poor yields associated with such depleted systems and can address ecological weaknesses associated with intensively-managed conventional agriculture systems that have forgone the benefits of free or low-cost ecological services. What are the available means for tapping these potentials? The following sections review what has become or is becoming known about them.

6.3 Agrobiodiversity Conservation And Utilization

The promotion of agrobiodiversity often focuses principally on the conservation of crop genetic resources (Paroda et al. 1999; Hammer et al. 2003). This is expected to have benefits for future improvements in crop or animal genetic potential whether through conventional breeding or transgenic programs. This gives proponents of the most modern agricultural development a stake in farming systems that preserve agrobiodiversity, and not just for presently commercially exploitable species or their close relatives. Advances in technology have made it possible to derive benefits from the genetic potential of quite varied species (Tanksley and McCouch 1997). So the stake of high-tech agricultural science in the aims and achievement of ecoagriculture, with its emphasis on preservation of agrobiodiversity, is growing. The *in-situ* conservation of wild crop relatives and non-crop organisms is recognized as critical to the maintenance of long-term agricultural sustainability (Meilleur and Hodgkin 2004).

On-farm conservation of biodiversity is a stated priority of the Biodiversity Convention from the 1992 Rio Conference, but implementation of agrobiodiversity conservation policies have focused primarily on creating and operating *ex-situ* repositories for crop genetics (Wood and Lenné 1997). While genetic resources are an important part of raising and sustaining agricultural production, breeding and biotechnology should not be the sole or primary concern of agrobiodiversity conservation. Management of agricultural genetic resources that promotes eventual uniformity of crop genetics could give no option but to preserve genetic material only in repositories, but this would become narrower and narrower in its base and in its potential.

6.3.1 Strategies for More Diverse Genetic Resources

Along with the conservation of genetic resources, agricultural sustainability requires a wider focus on breeding for diverse crop traits that are often ignored but that could be of particular value for smaller, resource-limited farmers, such as chemical signaling to insect predators (Lewis et al. 1997), success in polyculture (Cox et al. 2002), and tolerance of nutrient limitation (Kamara et al. 2003).

Well-designed strategies for the conservation and promotion of agrobiodiversity would include:

- *in-situ* conservation of agrobiodiversity, including habitat protection of wild populations of flora and fauna, with maintenance of native species and traditional agroecosystems;
- *ex-situ* germplasm conservation, for development and introduction of improved varieties; and sustainable uses of biodiversity, including agricultural systems management and scientific research (Long et al. 2003).

To this, we would add the identification, evaluation and conservation of soil organisms, from microorganisms to macrofauna, classified in functional terms, for the sake of maintaining soil health and fertility over time. This could be subsumed under the first point above, but the unseen aspects of agrobiodiversity have been too often and easily overlooked, so explicit attention needs to be directed toward the preservation of *subterranean biodiversity*.

The importance of agrobiodiversity is ubiquitous. One of most striking examples of this is in the state of California, which has one of the most productive agricultural sectors in the world. The sector is thought of as well-endowed because of the fertility of California soils, the abundance of capital invested in the sector, and the education and talent of its labor and management. But the success of all California's productive enterprises depends, as mentioned in Chapter 2, on a diversity of biodiversity that extends from crops and livestock to their wild relatives, and beyond this to a vast array of pollinators, symbionts, competitors, pests, parasites, predators, and biological control agents, as well as soil organisms of myriad sorts (Qualset et al. 1995).

Long-term food security, even in a system as modern as California's, depends fundamentally on the conservation and utilization of genetic resources and native habitats so that the intricate and far-flung web of plant, animal and microbial organisms that help produce that state's food and fiber remains intact. Desired commercial crops are not obtainable from the land, and certainly not at acceptable cost, without maintaining the vitality of the complex ecological systems within which agricultural production processes are nested .

6.3.2 **Related Considerations**

Some specific observations that emerged from our review of the literature in this area include:

- A spatially and temporally diverse set of crops will have a rooting distribution that can exploit different soil resource pools (Jama et al. 1997). Total productivity from multiple crops is greater than with single crops, provided that appropriate weed controls can be maintained. Currently, the most common controls are chemical, but biological means are becoming better known and more widely used, such as mulches, crop rotations, and modified spacing and timing of cultural practices.
- Introduced cash crops have dramatically reduced agrobiodiversity in many areas, even as remote as the cold desert valleys of the Himalayas (Kuniyal 2004). This has adverse consequences over time for the sustainability and resilience of farming systems, with eventually rising costs. Enhanced food security is more likely with a mixture of traditional and introduced crops.
- Agricultural diversification in the Philippines has been found to increase food security, decrease the risk of temporary food shortages, and improve nutrition (Frei and Becker 2004). The increase of production and income with highly-specialized production systems did not, in this study, enhance the well-being of farm households even if there were short-term economic benefits as assessed in aggregated econonomic terms.
- To measure the impact of disturbance on diversity, it is necessary to identify and monitor species assemblages, e.g., functional groups, not just individual species (Belaoussoff et al. 2003). A study in Guelph, Ontario, concluded that diversity indices were not useful for detecting the possible effect of disturbance on assemblages of carabid beetles, which feed on insects that from a human perspective are mostly harmful. Such effects are easily overlooked.
- Productivity of pastures has been shown to increase with increasing species diversity, with the greatest gains occurring with the incorporation of three to four species, with diminishing though still positive gains beyond this (Fick interview). Studies in European grasslands have similarly observed a correlation, though not necessarily linear, between species biodiversity and productivity (Hector et al. 1999).
- Agrobiodiversity can increase wildlife habitat, productivity, and resource conservation (Alkorta et al. 2003). As the same time, agriculturally biodiverse farming systems can maximize ecosystem services, contributing to food security and promoting agricultural sustainability (Thrupp 2000).

6.4 Organic Agricultural Production Systems

Organic agriculture is quickly emerging as a popular and productive farming enterprise. For many decades, in the face of the development of intensive "Green Revolution" agricultural systems, organic agriculture often considered a fringe enterprise, based on "intuition" at best and "junk science" at worst. Yet, in the past 10-20 years, the changing context in which modern agriculture is practiced and an accumulation of scientific evidence (e.g., Kumar et al. 2004) have widely reoriented thinking. In a feature article considering this trend, *Nature* noted that:

> [i]n the past, organic agriculture has been set squarely against intensive farming and chemical-based agribusiness… in the media, these arguments rage more fiercely today than ever before. Yet behind the harsh rhetoric, a little-noticed convergence of views is taking place. For decades, the study of organic farming sat at the fringes of the green revolution in agriculture, as intensive techniques marched across the world, sending yields skyrocketing. But mainstream agronomists are becoming concerned about the long-term sustainability of this approach, and are increasingly focusing on soil integrity…. Mainstream agronomists now acknowledge, for example, that intensive farming reduces biodiversity, encourages irreversible soil erosion, and generates run-off that is awash with harmful chemicals, including nitrates from fertilizers that can devastate aquatic ecosystems. (April 22, 2004, p. 792).

6.4.1 **Difficulties in Evaluation**

The focus of discussion is turning, reinforced by consumer preferences for chemical-free food supplies, from whether or not organic farming is preferable, to whether it can be productive enough to compete economically with conventional practices. Given that costs of production can be lowered by avoiding or reducing chemical inputs, the evaluation often turns on the cost and productivity of labor and capital inputs in these alternative systems, as well as whether consumers will pay for the added value of food considered to be healthier. There is little debate about the desirability of reducing agrochemical usage, even if there is not agreement on differences in nutritional value and taste.

There is little disagreement that organic production is, in principle, more compatible with the conservation of biodiversity, including wild biodiversity, because of effects of chemical use beyond the farmed field on fish, birds, reptiles and other fauna. The question is not easily resolved, however, whether the differences are significant because all agricultural practices to some extent reduce biodiversity compared with uncultivated or ungrazed conditions.

One difficulty in making evaluations is that when practicing organic agriculture within a larger landscape where there can be impact from nearby chemically-intensive or biotechnological agricultural practices, the transfer of pollen, dust or water from surrounding farms can affect organic crops. The extent of such effects is still a matter of controversy, but positive and negative impacts do not appear to be symmetrical in that it is easier to move from a more to a less biodiverse situation than the reverse.

An additional difficulty in evaluating organic agriculture is that the balance of costs and benefits *changes over time* in a path different from conventional agriculture. The latter is more often subject to diminishing returns and increasing costs of production as the efficacy of chemical fertilizer and agrochemical sprays declines, so that more of these production inputs must be used to maintain output levels. This is often referred to as "the chemical treadmill."[1] Conversely, especially on soils that have been exposed to inorganic fertilizers and various chemical biocides, which have a depressing effect on populations of soil organisms, the productivity of organic (non-chemical) production methods is usually not as great in the first year of use as in subsequent years, as organic matter and soil populations increase over time with the addition of biomass amendments and plant roots' exudation. Accordingly, long-term trials are needed for valid comparisons of the productivity of alternative production systems when comparing organic with conventional practices.

6.4.2 **Measurement of Effects Associated with Organic Agriculture**

One of the most relevant assessments is by Mäder et al. (2002) who contrasted organic and conventional management systems in a long-term experiment, using identical crop rotations, varieties, and tillage for all treatments. They documented a 20 percent decrease in yield associated with organic practice, along with 30-54 percent reductions in nutrient inputs and 97 percent reduction in pesticide use. The organic plots exhibited increases of 10-60 percent in nutrient-use efficiency, soil fertility, phosphorus cycling, and aggregate stability; of 40 percent in biomass and in mycorrhizal symbioses; of 130-320 percent in microbial and earthworm decomposition; and of 200 percent in biodiversity and arthropod abundance.

Organic systems are commonly associated with increased populations and increased diversity of carabid beetles, weeds, earthworms, and soil microbes (Heyer et al. 2003). Ecoagricultural research and experimentation can be expected to reduce the costs presently associated with organic systems (increased management complexity, reduced yields, and some tillage-based erosion) and to increase benefits derived from capitalizing on more robust ecosystems processes (reduced inputs and input costs; increased profitability; weed, pest, and disease control). Whether yield will necessarily decline with organic methods remains a matter of contention. The rice production system discussed in Section 6.12, for example, shows increases in output associated with a reduction in chemical inputs when other methods that favor soil biological activity are introduced.

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[1] *Recall from Chapter 2 that pesticide use in the U.S., which has gone up 10-fold since World War II, has nevertheless seen the percent of crop losses due to insect damage increase from 7 percent to 13 percent (Pimentel 1997).*

6.4.3 Improving Genetic Resources for Organic Agriculture

Organic farms presently rely largely upon crop varieties bred for conventional farming systems. There is a need for crop (and animal) breeding programs that focus on organic alternative systems, so that the plants and animals being managed are ones better able to exploit naturally available nutrient pools and biologically diverse systems (VanBueren et al. 2002). Development of improved varieties for use in organic systems should enhance the profitability of organic farming beyond present levels.

Crops bred in this manner may also benefit conventional farming systems, because they are likely to exploit a broader diversity of available resources. Objections have been raised to crop or animal breeding programs that, to obtain the highest possible yields, have made selections based on "ideal" conditions, producing plants and animals that are accordingly more dependent on external nutrient provision and protection against pathogens. crops or animals bred to thrive under more normal conditions their

6.4.4. Assessing Systematic Effects

"Organic farming systems aim at resilience and buffering capacity in the farm-ecosystem by stimulating internal self-regulation through functional biodiversity in and above the soil, instead of external regulation through chemical protectants" (Van Bueren et al. 2002). Measures of system robustness (soil health, belowground biodiversity, agricultural diversity, contribution of community structure to pest and disease resistance, nutrient cycling, and crop productivity) would favor the goals decreasing inputs, decreasing pollution and resource loss, maximizing productivity, and maximizing ecosystem services.

Labile pools of soil organic matter (SOM) are definitely affected by long-term management practices, with organic systems supporting a larger microbial biomass and more active decompositional processes (Fliessbach and Mäder 2000). Biologically-active soil organic matter is positively affected by cover cropping and organic nutrient inputs (Wander et al. 1994).

Transition from conventional to organic farming systems resulted in increased inputs of carbon, phosphorous, potassium, calcium, and magnesium to the soil, increased soil organic matter and available phosphorous and potassium, and increased nitrogen storage (Clark et al. 1998). Overall, organic practices resulted in increased carbon and larger pools of stored nutrients, owing to the effects of organic fertilizers and cover cropping. These are, however, still fragmentary research results. Only a fraction of the research effort previously devoted to chemical-based agricultural practices has gone into studying the chemical, physical and biological dynamics and effects in soil systems under organic farming practices. Most of what has been measured and documented so far has pointed toward soil and above-ground environments that are more hospitable to biodiversity, supporting more robust and cost-efficient production, even if not always giving the highest yields in agronomic terms.

6.4.5. Organic Agriculture Research Needs

For the potential of organic agriculture to be both more (optimally) productive in economic and food-supply terms and more beneficial for maintaining biodiversity, there are a number of areas in which research should be undertaken. Faculty working with organic agriculture identified the following focuses for more systematic investigation:

- Improving integrated nutrient management recommendations for organic systems;
- Developing improved crop varieties for organic systems;
- Development of low- and zero- tillage organic farming systems;
- Overcoming the yield deficit between organic and conventional practices;[2]
- Refinement of measures for evaluating the benefits of organic systems: system robustness and function; characteristics of and impacts on biological systems; soil health; temporal trends in organic matter, nutrient availability and productivity; and

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[2] *Note that the system of rice intensification, discussed in 6.12, has demonstrated in many countries the ability, without reliance on fertilizers or chemical inputs, to raise production substantially, even in the first season of use. Thus, it should not be assumed that organic production methods will always give lower yields.*

- Improving the understanding of below-ground processes, interactions among soil chemical, physical and biological components, and contribution of natural processes (disease resistance, nutrient availability, etc.) to crop yield.

As noted above, there has been comparatively little research undertaken on organic agricultural systems and practices, reflecting the prevailing scientific paradigm and the availability of private-sector support for research. As noted at the start of this section, after years of separation and antagonism, there is now a growing convergence of interest concerning conventional and organic agriculture. The label "organic" has often been expressive of values more than empirical differences, with critics no less than proponents basing arguments on conventional wisdom rather than on objective study.

Fortunately, this polarization appears to be waning, as many agriculturalists—scientists as well as practitioners—turn their attention more and more to soils and below-ground processes (e.g., Kumar et al. 2004), recognizing that these are the foundation for all agriculture, including livestock production. What nurtures and conserves healthy soil systems, with their immense biodiversity, is good for long-term agriculture and thus for food security and livelihood generation.

6.5 Agroforestry

Agroforestry, like ecoagriculture, is a land-use strategy with the triple objectives of agricultural production, natural resource conservation, and livelihood enhancement. Since its inception as a field of research and a focus of development intervention from the late 1970s, aspirations and claims about agroforestry have centered on the conjunction of ecological, economic and social benefits that can come from diversifying production through the integration of trees and other large woody perennials into farming operations.

In recent years, agroforestry research has begun to adopt a landscape perspective. This is attractive because it enables scientists to scale up their results once they have a reasonable understanding of small-scale processes. This is important because the functions of tree cover manifest at landscape, regional and global scales as a result of larger-scale patterns and processes (Schroth and Sinclair 2003).

This year's World Agroforestry Congress (WAC) is focusing on the maturing of agroforestry as a sustainable land-use strategy over the past 25 years. The keynote address (Nair 2004) documents the solid scientific foundations and notable knowledge gains that have been made concerning the nature, extent, and processes of how trees and crops when growing together. Their multiple interactions affect their respective and mutual productivity and alter or sustain the environment at levels ranging from individual plants and plots to ecosystems and regions.

The keynote concludes that the rigorous scientific methods now available for doing biophysical and socioeconomic research and for measuring the benefits of agroforestry now enable us to make a host of definitive, scientifically valid statements about the roles and potentials of agroforestry. Nair challenges the agroforestry research community to capitalize on these opportunities and work with the rest of the scientific world and society to realize the unique potentials offered by agroforestry strategies for addressing the problems of food security and environmental protection.

6.5.1 Contributions of Agroforestry to Multiple Objectives, including Wild Biodiversity

The numerous ways that agroforestry can contribute to achievement of the Millenium Development Goals of the United Nations have been documented by the Director-General of the World Agroforestry Center (Garrity 2004). Among the most promising pathways for increasing on-farm food production and income through agroforestry are: fertilizer tree systems, tree cropping, and improved tree product processing.

These advances can be helpful also in addressing the need for more enterprise opportunities on small-scale farms, more equitable returns to small-scale farmers, reducing child malnutrition, and alleviating national tree product deficits. In addition to food, fertilizer and wood products, which can enhance livelihood opportunities, there are mechanisms being developed that would compensate the rural poor for environmental services that their agroforestry practices provide to society. Although these social benefits have not yet explicitly included wild biodiversity, as the value of this resource gains appreciation, movement toward ecological service valuation and compensation is likely to lead to this outcome.

A recent book entitled *Agroforestry and Biodiversity Conservation in Tropical Landscapes* (Schroth et al. 2004), edited by a large team of distinguished scientists, explores in-depth how agroforestry practices can help promote biodiversity conservation in human-dominated landscapes, synthesizing the current state of knowledge in the field and identifying areas where further research is needed. This volume will be of great value to those who are designing ecoagricultural strategies in tropical regions or trying to identify knowledge gaps and research needs.

Schroth and associates explore three hypotheses on how agroforestry can help to conserve tropical biodiversity: 1) by reducing the economic pressures to deforest remaining forest land and to degrade forest through the unsustainable extraction of its resources; 2) by providing suitable habitat for forest-dependent plant and animal communities; and 3) by creating a biodiversity-friendly matrix of regulated land-use areas to facilitate movement between existing patches of natural habitat and to buffer them against more hostile land uses.

The volume brings together much research-based evidence for how specific agroforestry practices, applied in particular economic conditions with respect to land, labor and capital availability, and in the presence of specific institutional support factors, can maintain or enhance the abundance and/or diversity of wild species in a land use system. Not surprisingly, it concludes that there are a multiple biological, socio-economic and institutional factors that condition the effective integration of agroforestry into each of these biodiversity conservation strategies.

Regarding agroforestry as habitat for native plant and animal species in agricultural landscapes, Schroth and associates (2004) explore the relationships between land-use intensification and the suppression of wild species. They conclude that where high diversity of wild plant and animal species occurs within agroforestry systems or landscapes, this is usually the result of extensive management or temporary abandonment of cultivated areas rather than specific management to promote its persistence (p. 492). They stress that increasing intensification of land-use practices in tropical regions, such as shortening fallow periods or reduction and simplification of shade canopies in tree-crop plantations, generally reduces the habitat value of these systems for native species.

Schroth et al. (2004) highlight the key role of management for providing habitat for various forest species. This is true whether windbreaks, hedgerows and intercropped plantations are being managed on a short rotational or a semi-permanent basis, no matter what the structural complexity and diversity of their shade canopy and understory or the degree of weeding, pollarding and pesticide use (p. 494).

Furthermore the abundance and diversity of plant and animal species will be greatly influenced by the *size* of the agroforestry system and its location, particularly its proximity and degree of connectivity to remaining forest cover. The authors also emphasize the role of hunting pressure on the animal diversity and abundance of agroforestry, observing that present levels of wildlife consumption in many tropical regions are unsustainable, regardless of the land-use regime.

Schroth et al. endorse “matrix management” in the design and implementation of biodiversity conservation strategies. The book explores the role of agroforestry in providing a smooth transition between open agricultural areas and forest boundaries, one that reduces edge effects and the incursion of fire into forest areas, and further provides connectivity between patches of primary habitat. The authors conclude that evidence supporting the hypothesis that the conservation value of habitat fragments is greater if they are imbedded within a matrix of agroforestry than if they are located in less diversified, structurally simpler agricultural land uses is still mainly indirect. But they note that direct evidence is slowly accumulating (p. 495).

6.5.2 **Issues of Genetic Diversity**

The issues of biological and genetic diversity management in agroforestry are extremely complex (Atta-Krah et al. 2004). Recent studies on the functional elements of traditional agroforestry systems and modern technologies demonstrate that the practice of agroforestry has been a system for the management and conservation of diversity. Yet agroforestry research, over time, has deemphasized the biological diversity issue in its evaluation. Since farmers value diversity and manage agroforestry from this perspective, notwithstanding the presumed benefits to society, Atta-Krah and his co-authors propose cross-disciplinary research to advance our understanding of species and genetic diversity at both inter-and intra-specific levels. Such knowledge should inform to strategies for enhancing both agrobiodiversity and wild biodiversity within agroforestry systems.

Certain agroforestry practices stand out among those that are best suited to harbor and foster biological diversity. Home gardens, known for the efficient nutrient cycling offered by their multi-species composition, have been documented throughout the tropical world to conserve biodiversity, while providing relatively secure livelihood support through product diversification (Kumar and Nair 2004). Given their proximity to the homestead, home gardens are not likely to offer suitable habitat for many human-adverse wild species. However, the relatively sustainable productivity that these complex systems exhibit may contribute to intensification strategies that can serve to release land from agricultural production elsewhere for the benefit of wildlife conservation there. Also, not all flora and fauna that need preservation are adverse to human proximity so long as their growing environment is favorable and they are not impinged upon.

6.5.3 **Agroforestry Variations**

"Forest gardens," sometimes referred to as "nature-analogous agroforestry systems," are often reconstructed natural forests in which wild and cultivated plants co-exist, thus integrating production and biodiversity values (Wiersum 2004). Known also as "complex agroforests" (Michon and de Foresta 1999), these ecologically sustainable systems have been documented to "conserve a good portion of the original biodiversity" (p. 395). They are often quite dynamic in species composition, in response to changing socioeconomic conditions.

There is agreement within the agroforestry research community that these complex systems have not been adequately researched, relative to the benefits that they could come from more thorough knowledge. Specialists who study these systems argue that understanding better the spatial and temporal variation in the composition and function of forest gardens (complex agroforests) should support broader applications of multi-functional agroforestry systems in a variety of settings. A thorough review of biodiversity in complex tropical agroforests is offered in Chapter 10 of Schroth et al. (2004).

An analogous agroforestry system in temperate North America is known as "forest farming" (Hill and Buck 2000). This system integrates high-value under-story and mid-story crops into mixed deciduous hardwood stands to improve the short-term economic returns to the forests that are being managed also for long-term timber production and wildlife habitat. By improving the value of standing forest through production of native specialty products including medicinal herbs, mushrooms, fruits, nuts, syrups and craft materials, it is hypothesized that economic pressures to convert such forests to less "habitat-friendly" uses will be reduced. To date, studies have not been conducted to test this hypothesis, however.

6.5.4. **Implications for Biodiversity**

Biodiversity conservation in agroforestry systems has been the explicit focus of several studies that have shown higher biodiversity in agroforestry systems than in other agricultural systems (Griffith 2000). In some cases, the levels of species richness are equivalent to those of forests (Estrada et al. 1993; Perfecto et al. 1996). However, there are many contingencies affecting these relationships. Perfecto et al. (2003) examined the species richness of birds, fruit-eating butterflies and ground-foraging ants along a coffee intensification gradient represented by a reduction in the number of species of shade trees and the percentage of shade cover in coffee plantations in Southern Mexico. They found that responses of the three taxa differed along this intensification gradient, and there was no correlation between them.

This suggests the importance of distinguishing among different levels of shade, and also that different taxa may respond to habitat changes at different scales. Considering economic, institutional and biological factors together, Current et al. (1995) found that farmers in

Central America are able to exercise long-term preservation of their farms as well as of the biodiversity associated with them, when they have legally recognized land tenure, access to bank credit, and an agricultural management scheme that includes a complex mosaic of fruit trees, timber trees and annual crops that can offset ecological and economic risks.

Huang et al. (2000) have assessed methods for quantifying the effects of agroforestry on biodiversity conservation. Their interdisciplinary team developed a functional-group-based Analytical Hierarchy Process (AHP) and a distinctness index of functional groups. With these tools they ranked the effectiveness of various agroforestry practices and plantations for the protection of natural forests with a long-term view. The authors propose that the AHP and functional-groups index will be useful for the integrated planning and evaluation of agroforestry management in biodiversity conservation areas, in addition to improving knowledge on the potential roles of agroforestry in biodiversity conservation.

Agroforestry has been characterized by Shanker and Solanki (2000) as an "eco-friendly land use system that is favorable for the management of insect pests and beneficial insects," affirming its contribution to agrobiodiversity. These authors show how the biodiversity found in particular agroforestry systems is amenable to incorporation into systems of integrated pest management (IPM), especially reliance on biopesticides and biological control, practices discussed in the following section. These techniques in turn provide an ecologically-favorable setting for economic ventures such as apiculture, sericulture and lac culture, which they calculate can be highly profitable.

A fuller exploration of agroforestry IPM systems in temperate countries of Africa, Asia and Latin America has been provided by Dix et al. (1999). They focus on the importance of incorporating a blend of short- and long-term, multiple-generation techniques for managing pests in multiple crops. They also point out the role of managing "edge vegetation" in diverse agroecosystems so as to enhance native natural enemies of pests. This international team of scientists proposed an agenda for improving IPM practices within agroforestry systems, focusing on knowledge needed and techniques for identifying, monitoring and controlling the populations of pests as well as beneficial species.

6.5.5. Issues of Domestication

Tree domestication is widely perceived as an area of agroforestry practice and science that can substantially enhance the productivity and profitability—and thus the adoptability—of agroforestry systems (Leakey and Tomich 1999; Simon et al. 2000; Leakey et al. 2002). Domestication involves the selection, propagation and management of trees to adapt them to agricultural systems. This could give value to a wider range of species than currently managed in intensive, monocropped systems of production. This research-supported process will be most efficient and effective if domestication initiatives are farmer-driven and market-led, according to Simon and Leakey (2004).

These authors propose that the objective of agroforestry domestication should not be just to select super-species or provenances, but should include the promotion of genetic diversity and matching intra-specific diversity to the needs of farmers, markets and plurality of environments. With different farmers using different provenances, on a landscape basis, there could be significant diversity within any particular species that is dominantly in use. Young and Boyle (2000) point out that out-crossing will result in gene-mixing in seed production, with a continuous creation of new hybrids and complexes that would broaden the genetic base.

6.6 Systems Approaches To Pest Management

It is a common observation, often considered a truism, that complex, healthy landscapes resist the spread of pests and diseases. That undesired organisms and pathogens exist in almost all situations is true, but their multiplication and dominance is usually a result of certain imbalances: changes in rainfall or temperature patterns from the usual or normal; changes in the combination of nutrients available, including certain scarcities or surfeits; changes in the nutrients available at cell level, making for malnourished cells more vulnerable to pest and disease attack.[3]

Maintaining robust agricultural production systems with diverse components is one way to facilitate natural control of pests and diseases that adversely affect crops and animals in farming systems. Natural habitats associated with farming systems can enhance agrobiodiversity and promote beneficial organisms that combat, check or control pests or pathogens. It is, of course, possible that such habitats can harbor pests and pathogens that have adverse effects on crops and cause unacceptable losses. This is one of many instances where location- and system-specific, knowledge is needed to make optimizing decisions. What our growing understanding of agroecology is pointing to is to give up "shoot first and ask questions afterwards" approach to crop and animal protection.

6.6.1 **IPM Alternatives**

A focus on integrated ecological management can provide long-term, lower-cost and sustainable pest control, in contrast to the chemical interventions that attempt to create an empty ecological niche, making it devoid of pests but also devoid of natural processes that limit pest abundance (McRoberts et al. 2003). So far, most IPM approaches have been only partial. We use the term "systems approaches to pest management" because this refers to managing whole agricultural systems for the objective of reducing damage by pests and diseases, rather than "managing the pests" per se, as the term IPM implies.

A volume written for the National Academy of Sciences (Lewis et al. 1997) has assessed the potential benefits of total systems pest management, comparing three approaches:

6.6.1.1 *The Therapeutic Approach*

Treat pest outbreaks with countermeasures, such as chemical sprays. The logic of this approach leads to preventive, pre-emptive and prophylactic measures as well. Precise application and careful timing can reduce the negative effects of chemical use, as can the replacement or more-toxic with less-toxic chemicals. But these are not optimizing solutions, as therapeutic chemical treatments lead to the build-up of toxic products, pest resistance, secondary pests, and pest recurrence.

6.6.1.2 *Revised Approaches*

These improved methods, which include integrated pest management (IPM), biocontrol, and biotechnology, can be effective by themselves. But they work best if utilized in ways that work *with ecosystem strengths*, not simply in a therapeutic manner. A broad interpretation of IPM can comprise all aspects of a systems approach to sustainable pest management. However, in practice, IPM has often been made into a monitoring program where chemicals are used on an as-needed basis as determined by economic thresholds. While this may reduce chemical application rates and improve farm profitability, it does not promote more sustainable systems of natural pest control. Similarly, although *biocontrol*—introduction of pest-specific control organisms—has often been very successful in controlling certain pests of some perennial crops, it has been less effective with annual crops. For the latter, treatment is mostly a therapeutic rear-and-release approach, not focusing on how to *strengthen natural biocontrol capacities in the agroecosystem*. *Biotechnology* holds definite promise for controlling pests and diseases, but the most successful applications will be to strengthen *systemic resistance to pests*, rather than develop biopesticides. It should be possible to integrate biotechnology into sustainable, ecologically-based pest management strategies.

6.6.1.3 *Recommended Approach*

Lewis et al. (1997) endorse ecosystem management, with a focus on crop attributes and multitrophic interactions and therapeutic applications carefully used to have minimal disruption of ecosystem dynamics. They recommend solutions that achieve net benefits *at the total ecosystem level* by harnessing inherent strengths for controlling pests and diseases within specific ecosystems, and that work in cooperation with natural systems

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[3] *This refers to the theory of "trophobiosis," which maintains that organisms what are optimally nourished are better able to withstand or resist predation, infection, etc. This is on its face a reasonable proposition, but it has been slow to gain scientific acceptance. It has been implicitly the foundation of FAO's very successful IPM program, which maintains that the best way to reduce pest and disease damage is to "grow healthy plants," i.e., to provide spacing, moisture regimes, etc. that optimize growth. Under such conditions, damage and losses remain below the economic threshold where it would be profitable to intervene with chemical prophylaxis or control.*

rather than compete with them. The authors elaborate on this alternative with these recommendations:

- *Ecosystem management*: Redirect pest management to incorporate year-round soil, weed, crop, water, and associated practices at farm and community levels, considering the effects of these practices on the overall fauna, nutritional state, and balance of local ecosystems. Develop multiple-function interventions such as cover cropping that provide nutrients, erosion control and habitat for beneficial organisms. Integrate cover-cropping with conservation tillage and crop rotation. Avoid large-scale monocropping which creates conditions for pest and disease success. Manage field boundaries to promote habitat for natural pests. Try to benefit from synergies within natural processes.•
- *Crop attributes*: Consider crop plants as active participants in multitrophic patterns of crop-soil-water-nutrient interactions together with a multiplicity of soil organisms, and do not neglect these traits when breeding for crop fitness and production. Investigate how soil, nutrition, and water affect the expression of traits that control a crop's interactions with pests and pest-control agents.•
- *Therapeutic interventions*: Use external inputs with the aim of bringing pest organisms and pathogens into acceptable bounds with as little ecological disruption as possible, rather than attempting to completely remove the organism. Avoid toxic, broad-spectrum pesticides, and use therapeutics only as a secondary tool, to be used in association with the promotion of robust natural defenses against pests.

Lewis et al. (1997) conclude from their review of alternatives that:

> Truly satisfactory solutions to pest problems will require a shift to understanding and promoting naturally occurring biological agents and other inherent strengths as components of total agricultural ecosystems and designing our cropping systems so that these natural forces keep the pests within acceptable bounds…. A fundamental shift to a total-system approach for crop protection is urgently needed to resolve escalating economic and environmental consequences of combating agricultural pests.

6.6.2 **Conditions Affecting IPM Effectiveness**

Crop heterogeneity is one solution to the vulnerability of monocultured crops to disease. Intra-specific crop diversification provides an ecological approach to disease control, as was demonstrated by the interplanting of rice varieties susceptible and resistant to blast in China (Zhu et al. 2000).

IPM, which has been very successful in protecting Asian rice crops, has been less successful in sub-Saharan Africa (Orr 2003). This is apparently because economic incentives are less when agricultural productivity is limited by depleted soil nutrients and soil biota and there is less immediate response to reduced chemical application, changing the economic incentives for using methods that are more labor-intensive even if capital-saving (Orr and Ritchie 2004). IPM in Africa may therefore make sense only as part of a holistic farm management strategy that first focuses on overcoming nutrient limitations and restoring soil biodiversity.

In the United States, IPM implementation and progression toward national program objectives is monitored and documented using the USDA Performance Planning and Reporting System (http://www.pprs.info) on a state-by-state basis. The National Roadmap for IPM (2003) presents an overall goal of reducing the use of highly-toxic, broad-spectrum pesticides, but otherwise does not seek to limit pesticide usage, focusing on the number of farms implementing IPM as a measure of success. From this data source, we know that:

- IPM was being implemented on about 71 percent of U.S. cropland in 2000, compared with 40 percent in 1994; application of the highest-toxicity pesticides had declined by 13 percent over this period.
- Overall pesticide application had, however, increased by 4 percent, indicating that IPM as currently practiced is not targeting reduced pesticide usage as a priority.

The research needs highlighted in the National Roadmap for IPM focus on precision-use of pesticides, not mentioning ecosystem or natural controls. Issues identified include the regulation of pesticides, groundwater contamination, and evolving pest resistance. IPM management strategies are usually subdivided by crop type, rather than by farming system, which deflects attention from the evaluation of inter-crop pest dynamics. The U.S. national IPM program could provide a powerful boost to adopting ecoagricultural management techniques if research were prioritized to address total-systems pest control with the goal of reducing pesticide application while strengthening natural ecosystem processes for pest control.

For improving the precision management of chemical or biological agents at IPM thresholds, data on climate (temperature and water balance) can be used to predict the outcome of competition between crops and weeds. This allows farmers to live with a higher threshold of tolerance for weed occurrence under conditions favorable to crop growth (Susan Riha, pers. comm.). As more such research is done, looking at when and how pests and diseases contribute to crop losses in a multifactorial manner, it should be possible to make further refinements that are beneficial both to farmers and to the environment.

6.6.3 Multi-Species Contributions to Pest Control

Plant diversity at plot, field, and landscape scales can promote more stable environmental systems, with natural processes controlling the spread of disease and the development of resistant pest varieties. Diversity can provide a dampening effect on the spread of pests and diseases, through natural competition with a diverse biota. Release of natural biocontrol agents has provided very successful control of pests in certain cases, particularly for perennial crops such as cassava (Sseruwagi et al. 2004). Large-scale "rear-and-release" programs for annual crops, however, are not as effective if the biocontrol agent is not able to establish a permanent population due to unavailability of suitable habitat or climate severity. With more knowledge, it should be possible to devise conservation strategies that support agricultural beneficials, identifying and developing them at both the field and landscape scales (Weibull et al. 2002).

Sunderland and Samu (2000) have provided a review of the effect of agricultural diversification on the abundance and pest-control potential of spiders, which are generalist predators that have been demonstrated significant pest-control benefits. "Interspersed diversification," including undersowing, partial weediness, mulching, and reduced tillage, has been shown to be more effective than aggregated diversification, e.g., intercropping or fallow strips, in promoting spider abundance. In-field habitat, more than field-edge habitat, seems to be critical for supporting in-field pest control by spiders, while diversity at the landscape level promotes airborne sources of colonization. These results imply that healthy populations of insect predators are best achieved through the promotion of high crop-residue, low-spray systems.

Predatory carabid beetles, another beneficial generalist insect, have been found to be healthier and larger and to experience increased reproductive success in small fields with large perimeters and in landscapes containing a higher percentage of perennial crops (Bommarco 1998). Of five monitored farms, the three that were managed organically exhibited greater spatial heterogeneity, crop diversity, and percentage of perennial crops. While this evidence is not extensive, it was carefully gathered and is consistent with many other studies.

Food availability is an important habitat-limiting factor for generalist arthropod predators, including carabids, cicindelids, mantids, and web-building spiders (Bommarco 1998). Diverse, low-spray agricultural systems that foster non-pest insect communities in fields and field-edges are therefore expected to provide more robust non-chemical control of pests than will large, uniform, low-residue, annual monocultures because the latter are more likely to maintain significant populations of predatory insects.

6.6.4 Agricultural Effects on Field Margins

Field boundaries are important semi-natural environments in agricultural environments. While it is true that cultivated fields may "encroach" on natural environments, the converse of this, given the way that ecosystems work, is that the latter in turn "intrude" on the former, unless inhibited by chemical or other practices. Plant assemblages in the herb layer of hedgerows respond to a complex set of environmental variables that are related to the diversity within the associated farming systems. Close collaboration between ecologists and agronomists is necessary to develop field-boundary management and planning strategies that optimize the presence of non-cultivated flora and fauna that benefit cultivated crops (LeCoeur et al. 2002).

Agricultural operations such as chemical application, can certainly affect the flora of field margins, with implications for the spread of pests and beneficials. Fauna are of course also affected. Improved management strategies, including maintenance of grass or wildflower border-strips, have a generally positive effect on populations of beneficial species. Biodiversity of the field margins is increasingly recognized as having important implications for conservation of wild biodiversity, as discussed by Marshall and Moonen (2002) for European agriculture.

A comparison of field-margin border plots sown with grasses found increased occurrence of non-sown species under organic management. Naturally-regenerating field-border plots (not seeded) took longer to establish groundcover, but eventually demonstrated increased species diversity and increased presence of *Coleoptera*. Field margins sown with a complex seed mixture, including forbs, under organic management, provided the greatest control of undesirable species, along with increased invertebrate abundance and diversity (Asteraki et al. 2004).

Organic farming practices were found to have significantly reduced adverse impact on hedge-bottom vegetation, compared to conventional practices, with an overall higher number of species found. Hedgerow species diversity, however, was greater in the conventional system, perhaps because of higher extinction rates resulting from pesticide drift (Aude et al. 2003).

Creating 3-meter unsprayed buffer zones along field margins was shown to be an effective method for reducing pesticide contamination of field-border ditches. This reduced risks to aquatic organisms, increased vegetation diversity and abundance, had significant increases in phytophageous insects, and increased foraging by an insectivorous bird (deSnoo 1999; deSnoo and vanderPoll 1999). A cost-benefit analysis showed that this practice was feasible for winter wheat and potatoes, but was too costly for sugar beets.

Maintaining 2-meter uncultivated borders along streams is required in Denmark, to stabilize stream banks and reduce erosion. Botanical quality of these agricultural border areas was found to be low when compared to natural-grassland stream-borders, however; many species were associated with eutrophic and productive biotypes (Hald 2002). This points out that border areas, while important for conserving soil resources, may not play a strong role in conservation of wild biodiversity. Perhaps they represent instead a fertile niche within agricultural systems for biomass production.

Regardless of farming system, farmers can, if they want to, reduce their environmental impact on near-field areas by reducing the intensity of their management at the edges of fields. Herbicide, pesticide and manure applications can be halted a few meters from the field edge to provide for a transitional zone, and care can be taken so that a meter of unplowed ground is left along the edge of drainage ditches to avoid erosion.

Much remains to be learned about managing pest and diseases in crops (and animals) in ways that effectively capitalize upon the control potentials of natural ecosystems within which the particular agroecosystem has been fitted and must somehow operate. There will continue to be a place for chemical controls in certain places, for certain crops, and under various conditions, such as where there are labor constraints or where previous management has depleted biological resources. In the latter instance, chemical control measures will do little or nothing to improve the long-term sustainability and profitability of farming operations.

Systemic approaches to integrated pest (and disease) management are gaining a more reliable knowledge base as more researchers investigate the complexity and robustness of ecosystem dynamics. This is probably the area within modern agriculture where scientific thinking has shifted most dramatically over the past 20 years, from high confidence in chemical controls to a growing skepticism and a search for more biologically-based alternatives. The search for these alternative methods is driven as much by the negative incentive of economic and environmental costs as it is by protective benefits, but the latter are increasingly demonstrated.

Fortunately, approaches can be combined to make them mutually more effective. Schroth et al. (2000) have shown positive feedbacks between agroforestry systems and pest/disease management. The planting of windbreaks and shade trees and the cultivation of crop and tree mixtures can have a demonstrable impact on the incidence and control of pests and diseases. Thus, in thinking about ecoagriculture it is important to think about overall strategies, rather than just the adoption and application of a particular approach.

6.7 Integrated Nutrient Management

Strategies built around integrated nutrient management are increasingly used to overcome productivity limitations exhibited by degraded tropical soils. They can also used to decrease downstream effects of over-fertilized agricultural systems by increasing internal cycling of nutrients and minimizing nutrient import. In both cases, biological productivity forms the basis for improving yields of crops and animal products, improving farm profitability, reducing nutrient losses, and increasing system sustainability.

Integrated management strategies are showing great potential to increase system yield through increased reliance on biological processes, discussed also in Section 6.9 below. These strategies depend on the identification of ecological and biophysical processes that support yield and ecosystem functions. Once weak linkages have been identified, management practices can be adapted to compensate for these constraints or gaps in nutrient cycling, using a variety of site-specific tools (Albrecht and van Es interviews). Management of the agrobiological system can restore system balance either by increasing inputs to compensate for weaknesses in nutrient cycling, or by decreasing the exports from cycles, often having the effect of reducing pollution.

Through more precise management of nutrient inputs and by ensuring biological resource compatibility, nutrient cycling can be improved to become both more productive and more conserving. Then when nutrient balance is improved to satisfy crop and livestock requirements, nutrients are produced on-farm to the greatest extent possible, and nutrient limitations and/or build-up of excess nutrients are minimized.

Internal effects of unbalanced systems include:

- Nutrient depletion;
- Soil degradation following compaction and loss of organic matter;
- Unwanted nutrient accumulation;
- Saturation of the soil's nutrient-holding capacity; and
- Nutrient loss in form of non-point-source pollution.

External effects of unbalanced systems include:

- Nutrient and sediment pollution of downstream ecosystems;
- Conflicts with neighbors; and
- Depletion of water table and stream flow.

These are impacts that can be found anywhere nutrient imbalance occurs in soil systems. The solutions to these problems will, of course, be location- and site-specific, responding to the influences of soil types, topography, climate, cost structures, etc. We consider experience in dealing with nutrient imbalances and finding integrated solutions in contrasting agroecosystems.

6.7.1 Improving Nutrient Use Efficiency in New York State

Agriculture is increasingly called upon to provide environmental services (NRC 2003). This especially true where the agricultural sector is able to produce surpluses, and the societal benefits from food and fiber production are diminishing relative to costs. Intensive input of agricultural nutrients can increase crop and livestock productivity, but over-fertilization can lead to saturation of soil-nutrient binding capacity, and increased risk of nutrient pollution. Reduction of negative downstream effects from agriculture (in terms of nutrient, chemical and biological pollution, soil erosion, and water consumption) is increasingly regarded as a critical component of healthy landscapes and productive ecological systems.

On dairy farms in New York State, imports of phosphorous and nitrogen are often 60 to 70 percent greater than the amount of nutrients exported in milk and animal sales (Klausner et al. 1998). This leads to excessive levels of soil nutrients and increased risk of nutrient pollution. The recent application of the Clean Water Act to agriculture has further motivated farmers, regulators, researchers, extension educators, and farm advisors to develop approaches for more efficient nutrient use.

The Agricultural Environmental Management (AEM) program in New York State, supported by Cornell, has developed nutrient management planning processes and certification programs to help farmers improve environmental performance and comply with laws, such as the Concentrated Animal Feeding Operation (CAFO) regulation (New York State Soil and Water Conservation Committee 2004; USEPA 2002). Effective development and implementation of farm-specific integrated nutrient management plans relies upon careful characterization of the farm system. Computer software packages are employed by farmers and their advisors to characterize complex production and environmental systems and guide implementation

An integrated nutrient management software package, the Cornell University Nutrient Management Planning System (*cu*NMPS) is now being used in New York to increase farm productivity while decreasing nutrient imports and exports (Fox et al. 2002). This results in improved nutrient cycling and decreased incidence of nutrient pollution for groundwater and surface sources (NMPWT 2004). The *cu*NMPS is a software suite and knowledge base for precision nutrient management planning across livestock and field crop systems on integrated farms.[4]

Coordinated precision management of each step of the dairy-farm nutrient cycle (feed inputs, in-cow processes, manure management, crop production) strengthens the efficiency of the biological cycle and reduces the need for imported feed and fertilizer. Productivity and profitability are increased by maximizing the on-farm production of high-quality forage and minimizing need for purchased inputs. On one monitored farm, milk production was increased by 13 percent, as farm profitability went up and nutrient imports were substantially reduced following the implementation of integrated nutrient management planning (Klausner et al. 1998). *This is an example of how reduced inputs can produce more output*. Producers value *cu*NMPS as an effective tool for managing their farms profitably, sustainably, and with environmental responsibility (Cerosaletti et al. 2003; McMahon and McMahon 2002; Tylutki et al. 2003).

*CU*NMPS does not explicitly consider wild biodiversity, and crop diversity is generally not increased on participating farms (Albrecht interview). However, because robust biological cycles are intentionally and holistically managed to increase productivity and increase ecosystem services, this integrated nutrient management program provides a good example of successful ecoagricultural management. The benefits for the farm are clear, documented by McMahon and McMahon (2002), and the positive externalities associated with increased nutrient conservation can have a significant beneficial impact on downstream habitats (streams, lakes, reservoirs, and estuaries), promoting wild biodiversity, healthy aquatic ecosystems, fisheries productivity, clean water supply, and numerous other environmental benefits.

- *Solutions*: Minimize external inputs; maximize internal cycling; connect manure application to crop production; connect crop production to livestock feeding; maximize profitable use of excess nutrients by composting and selling manure or by otherwise capturing nutrients for use within productive systems.
- *Tools*: Integrated nutrient management; Whole Farm Planning; identification and dissemination of on-farm best management practices; using nitrogen and phosphorous indices to reflect soil chemical status and hydrological controls on nutrient loss, and to avoid over-fertilization without reducing crop yields. Complex, integrated nutrient management systems benefit from the use of computerized modeling tools such as *cu*NMPS.

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[4] *The cuNMPS is currently comprised of Cornell Cropware for crop nutrient management and the Cornell Net Carbohydrate and Protein System (CNCPS) for herd nutrient management. Cropware is a product of the Nutrient Management Spear Program (NMSP 2004; http://nmsp.css.cornell.edu) in the Cornell Department of Crop and Soil Sciences and CNCPS is developed and delivered by the Cornell Department of Animal Science (CNCPS 2004; http://www.cncps.cornell.edu). The developers of cuNMPS collaborate with the broader nutrient management community through the Cornell CALS Nutrient Management for Dairy and Livestock Farms Program Work Team (NMPWT 2004; http://www.inmpwt.cce.cornell.edu). The NMPWT is comprised of farmers, researchers, extension educators, government agents, and private-sector agricultural consultants, and it serves as a forum for communication and development of research and extension proposals to address agricultural environmental issues.*

6.7.2 **Dealing with Productivity Limitations in Sub-Saharan Africa**

Depleted soil fertility is the fundamental biophysical constraint on many soils in sub-Saharan Africa, with profound ramifications agricultural productivity and human well-being. Traditional practices such as long-term fallows have broken down in the face of population pressure and poor infrastructure (Sanchez et al. 2001). Annual nutrient depletion rates are high, 20 kilograms nitrogen per hectare, 3 kilograms phosphorous per hectare, and 15 kilograms potassium per hectare (AEE 2000). Chemical fertilizer is often prohibitively expensive due to poor infrastructure, and fertilizer effectiveness is diminished by soil degradation following loss of organic matter. Low-input nutrient management systems cannot overcome severe soil nutrient deficiencies unless external nutrient inputs are first provided.

In degraded systems, biophysical factors such as compaction, depletion, nutrient sequestration, and salt accumulation can have a controlling effect on soil quality, such that yields dwindle even if conventional (Green Revolution) interventions are employed, i.e., farmers just use improved genetic materials and increase fertilization (Wolfe, pers. comm.).

Integrated management of inorganic and organic nutrient inputs, in combination with erosion control and crop diversification/intensification, shows great promise for restoring the productivity of degraded African soils (Sanchez et al. 2001; AEE 2000). Nutrient "re-capitalization" can jump-start the nutrient cycle and promote increased yields from a more robust system (Sanchez et al. 2001). Without integrated management of nutrient stocks and cycles, beneficial techniques such as cover cropping for biological nitrogen fixation have only limited impact (Sanginga 2003), but with integrated management, system productivity can be restored.

Loss of organic matter can create severe limitations on nutrient availability in low-fertility tropical soils, and effective soil and nutrient management systems focus on increasing soil organic matter contents through the application of manures, composts and biomass (Ganry 2001). Incorporating crop residues can provide a short-term organic matter pool that greatly increases fertilizer efficiency (Diop 2002; Yamoah et al. 2002). Loss of organic carbon to mineralization, erosion, and leaching can be offset by manuring, mulching, and minimum-tillage, but crop yields may not respond unless any phosphorus deficiencies are also addressed (Roose and Barthes 2001).

In eastern and southern Africa, an integrated program of nutrient input management has substantially increased soil fertility and maize yields (Sanchez et al. 2001; Jama et al. 1998a, 1998b; Jama et al. 1997). It combines rock phosphate applications, *Tithonia* biomass transfer, leguminous cover cropping, and improved fallows. Simultaneous implementation of erosion control methods such as use of grass strips is often necessary to conserve the invested resource capital. Only after soil fertility is restored can additional best-management practices such as improved crop genetics, IPM and agrodiversification be employed in an effective manner Sanchez et al. 2001). In Togo, integrated use of leguminous cover crops and phosphorus inputs resulted in increased nitrogen use efficiency and maize yield, according to Fofana et al. (2004), while in Zimbabwe, researchers concluded that cover crops alone are not sufficient to support high yields unless some fertilizer is also used (Chikowo et al. 2004).

There are numerous cases of improving crop yield with simple enrichment of soil organic matter. Biomass transfer of *Glyricidia* has increased income and maintained productivity of onions, cabbage and maize when used in place of inorganic fertilizer in Zambia (Kuntashula et al. 2004). Improved fallow systems using *Glyricidia* also increased maize yields in Mali (Kaya and Nair 2001). Short-duration *Sesbania* fallows similarly increased maize yields in Malawi; when a *Sesbania* fallow replaced a *Cajanus* catch crop, however, there was a resulting loss in pigeonpea harvest (Ikerra et al. 2001). Integrated nutrient management has also shown promise for increasing upland rice production in Tanzania (Meertens 2003).

Various approaches to integrated nutrient management in sub-Saharan Africa have had positive effects, while differing considerably in their effectiveness and resource requirements (Place et al. 2003). Systems of integrated nutrient management show great promise for improving crop yields and smallholder income. It is recommended that the focus of research remain on improving the productivity of smallholder farming systems, rather than promoting centralized management of large acreages (Sanchez et al. 2001), if intensification is expected to balance the effects of extensification. An example relating the adoption of large-scale soybean farming in Brazil to worker displacement and increased deforestation in neighboring regions is presented in McNeely and Scherr (2002).

Increased soil fertility can help resist the spread of invasive weeds such as *Striga* and *Imperata* which are promoted by conditions unfavorable for other plants (Abunyewa and Padi 2003; Gacheru and Rao 2001; Sauerborn et al., 2003), particularly if crop rotation is also practiced (Oswald and Ransom 2001). CIRAD researchers have found that the presence and spread of *Striga* are indicative of low soil organic matter, and that this crop-strangling weed can be controlled by raising SOM (Olivier Husson, CIRAD, pers. comm.).

Simple and effective methods for evaluating ecological health and farming systems productivity are necessary to identify obstacles to farm sustainability in sub-Saharan Africa (Lightfoot and Noble 2001). Crews and Peoples (2004), when comparing legume and fertilizer sources of nitrogen, conclude that legume-based systems have the potential to be more environmentally sustainable, and that many countries have the capacity to reduce or eliminate agricultural dependence on synthetic nitrogen fertilizers. (This is seen also in the discussion of rice production in Section 6.12.)

The rice-wheat rotational cropping systems in India are exhibiting a decline in productivity, low nitrogen-use efficiency, and declining soil health (Yadav et al. 2003). A field experiment demonstrated that inclusion of a biological nitrogen-fixing component (cowpea) in the crop rotation increased wheat yield by 20 percent and also soil organic matter and nitrogen-use efficiency. These kinds of documented improvements from capitalizing on natural ecosystem processes have prompted increasing interest among scientists and practitioners in pushing and possibly expanding the limits of what can be achieved agriculturally without relying on synthetic inputs. These explorations relate closely to the following subject.

6.8 **Soil Health**

A "healthy" soil has more capacity to support plant and other biotic growth, to sustain ecosystem processes, to sequester and decompose pollutants, and to resist disease (Doran and Zeiss 2000). Measures of soil health are diverse, depending upon the setting, soils, and management goals. Management strategies are similarly diverse, including cover crops, improved rotations, reduced tillage, and organic practices. The term "soil health" is used here interchangeably with "soil quality," although the latter has often been used by researchers that did not consider soil biological processes.

The concept of "soil health" requires integrated consideration of physical, chemical, and biological processes contributing to crop productivity and ecosystem function. The assessment of soil quality, and its change over time, is a primary indicator of sustainable land management (Doran 2002). Knowledge of temporal changes in soil properties is necessary to the evaluation of management practices (Arshad and Martin 2002). Critical values for soil quality indicators (organic matter content, topsoil depth, water infiltration rate, soil aggregate stability, macro- and meso-porosity, nutrient and pollutant concentration, microbial respiration, nematode diversity, crop yield) all need to be identified on a site- or system-specific basis (Ekschmitt et al. 2003).

Chemical and textural/structural analyses of soil are widely available and form the backbone of conventional agricultural methods. Soil systems, however, are composed of interactive chemical, physical, and biological components (Karlen et al. 2003; van Es, pers. comm.). Measures of soil quality in physical and biological terms are currently the focus of considerable research, following on advances in the understanding of underground processes.[5]

Simple, cheap and effective measures of soil health are very much in demand, to provide tools for growers

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[5] *At Cornell, a Soil Health Program Work Team is currently developing methodologies for measuring physical and biological soil properties that will be offered to New York State growers through extension and outreach channels (SHPWT 2004; Wolfe et al. 2003; Wolfe et al. 20043) through extension and outreach.*

enabling them to identify factors limiting productivity and to monitor changes in soil health following the adoption of improved practices (van Es, interview). Important measures that have been identified so far include: standard chemical and textural analyses (phosphorous, potassium, micronutrients, pH, organic matter content, cation exchange capacity; soil type/texture); physical analysis (bulk density; macropore and mesopore porosity; permeability at standardized moisture content; wet and dry aggregate stability); and biological analysis (microbial abundance, biomass and respiration; nematode diversity). Rapid tests for biologically active organic matter (potassium permanganate) and soil chemical properties (hyperspectral analysis) are also under evaluation (Shindlebeck, pers. comm.; van Es, interview).

Soil health and landscape diversity are components of the Healthy Landscapes Initiative that is currently addressing the human, ecosystem and socio-economic health of regions in five Eastern European countries (van Es and Huska 2001). While soil quality is acknowledged to be a critical parameter for maintaining agricultural productivity, and related research has increased exponentially in the last decade, there is no agreement yet on the effectiveness of soil health indices as a tool for agricultural management, because they are multidimensional and have limited field validation (Delgado and Cox 2003; Karlen et al. 2003; Letey et al. 2003).

Land quality indicators have been developed for African and Dutch systems by Bouma (2002), who relied upon crop simulation to develop a ratio of observed-to-potential crop yield that was used to evaluate sustainability of production. Sanchez et al. (2003) have developed classification systems for fertility and for monitoring tropical soil health and capability that appear to be effective. An integrated soil quality index developed in China has been shown to vary significantly among land use in Sichuan Province, ranging from 0.028 (cultivated land) to 0.80 (natural forestland). The low value for cultivated soils seemed to predominantly reflect poor values measured for soil bulk density, a parameter that can reflect many years of tillage or low soil organic matter (Fu et al. 2003).

Experimental results have demonstrated that crop species have differential effects on aggregate stability and biologically active soil organic matter (Haynes and Beare 1997; Scott 1998), indicating a potential for agrodiversity practices to affect soil quality and microbial processes. Plants have a direct effect on soil structure through physical and chemical processes as well as from root exudation and rhizodeposition (Angers and Caron 1998). It is, of course, true that long-term and accelerated nutrient extraction can lead to soil degradation and depletion of nutrient capital. However, that such effects are not seen under natural systems of vegetation raises interesting questions. Long-term experiments will be needed to evaluate cropping systems' effects on soil health, crop yield, soil fertility, and sustainability (Haefele et al. 2003).

How far agricultural production can be intensified through the exploitation of above-ground and below-ground ecological interactions to sustain soil fertility has not been systematically evaluated. As researchers delve more deeply into the parameters and dynamics of soil health, the recuperative capacities of natural systems become more evident and impressive, as does the interrelation of agricultural productivity and natural ecosystem processes (Wander and Drinkwater 2000). While previously it has been often considered that cultivated systems are strict alternatives to (and replace) natural ones, there can be considerable compatibility between productive agricultural systems and healthy and robust ecosystems, with the maintenance of healthy soils being a link and common denominator.

6.9 Contributions of Below-Ground Biodiversity to Sustainable Production

There is increasing awareness of the integral role of soil biology in biochemical and nutrient flow processes on a landscape scale (SWCS 2000). Soil biology is thus emerging as an increasingly active focus of agricultural research, due to the contributions that microbial processes can make to soil health, nutrient cycling, and disease resistance. A diverse and robust microbial community can contribute to ecological equilibrium, for example, such that the spread of diseases caused by fungal pathogens is resisted through direct competition (Hobbs interview). Microbial processes can play a ubiquitous role in regulating the conservation and availability of plant nutrients (Scott 1998).

Below-ground processes are highly interactive, and they are in turn affected by, and affect, the complex ecological interactions that occur above-ground, as well documented and described by Wardle (2002). Biodiversity in soils is normally extremely high (Wardle and Giller 1996), but it can be compromised and reduced by tillage, continuous saturation (hypoxia), or certain chemical concentrations, occurring naturally or man-made. Here we focus on microbial flora and fauna, though one should have an appreciation for all of the creature acting in intra- and inter-species communities, presented vividly and informatively by Wolfe (2001).

The Soil Quality Institute of the Natural Resources Conservation Service has published a Soil Biology Primer that aims to have cross-national validity (SWCS 2002). Soil food webs are extremely intricate and ramified. They include plants and especially their root systems, which exude into the rhizosphere around the roots a share of the carbohydrates, amino acids and other compounds synthesized within the plant; organic matter from deceased organisms of all kinds;[6] bacteria, fungi, protozoa, nematodes, arthropods, earthworms, and many other species of macrofauna (SWCS 2000). The main soil biological parameters currently measurable are: (1) microbial biomass, (2) microflora composition, (3) mineralization processes, and (4) synthesizing processes (Filip 2002). Critical limits within these parameters vary with soil type and also with climatic, topographical, and moisture-related parameters.

6.9.1 **Nutrient Cycling in Soil Systems as an Ecosystem Service**

Organic farming systems can often be said to "feed the soil, not the crop," because they rely upon biological uptake and decomposition to provide plant available nutrients, rather than the application of readily available fertilizers. Nutrient inputs in the form of manures, composts and cover crops, although less in chemical fertilizer, have been shown to promote below-ground diversity, carbon accumulation, improved soil structure, long-term nutrient release, and nutrient conservation (Eghball et al. 2004). This is because the nutrients are not supplied directly to the plants, but rather are utilized by soil flora and fauna, from micro to macro, which in turn increase nutrient availability for plants. This is done through mineralization, solubilization, physical transport (in the case of mycorrhizal fungi and siderophores), and other processes.

Microbial biomass plays an important role in regulating the turnover of fine particulate organic matter (Fliessbach and Mäder 2000). Labile pools of soil organic matter are distinctly affected by long-term soil management (particularly tillage) and some have been shown to support a larger microbial biomass and more active decompositional processes. While inorganic soil nutrient amendments can enhance microbial biomass by providing more nutrients to soil communities, they can also have negative effects such as suppressing the genetic expression of nitrogenase and phosphatase, enzymes that fix nitrogen and solubilize phosphorous (Tan et al. 2003; Turner and Haygarth 2001). This diminishes the "natural" supply of these nutrients for the soil and plants. On the other hand, nutrients provided in organic form are less likely to have effects and thus can have a nutritional *multiplier* effect beyond their initial amount, by supporting larger microbial biomass and more active decompositional processes.

Spatial variability in soils has been shown to be extremely high for physical properties (texture, bulk density), chemical properties (moisture, pH, carbon, nitrogen) and biological attributes (microbial biomass; microbial population size; and potential respiration, nitrification and nitrogen mineralization), even in fields that have been continuously monocropped for many years (Robertson and Klingersmith 1997). This diversity presents challenges for the development of sampling methodologies that accurately and adequately reflect the impact of experimental treatments. Well-designed interdisciplinary studies are necessary to characterize the linkages among below-ground communities that regulate important ecosystem processes (Wall and Moore 1999).

Application of chemical fertilizers can provide a reasonable supplement to nutrient-deficient soils to jump-start nutrient cycling (Sanchez et al. 2001), but manage-

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[6] *Conservation tillage resources on the internet include: Rolf Derpsch (http://www.rolf-derpsch.com); the Conservation Tillage Technology Center (http://www.ctic.purdue.edu/CTIC/CTIC.html); and the Rice-Wheat Consortium (RWC) (http://www.rwc-prism.cgiar.org/rwc).*

ment of biological cycles is a necessary component of sustainable nutrient management. Factors such as maintaining soil moisture through mulching and lowering soil temperature through cover crops can have a large impact on nutrient conservation and management processes below-ground (Sanginga et al. 2003).

Interaction among organisms can provide a slow release of plant-available nutrients to crops through decomposition of organic matter. In contrast, chemical fertilizers release soluble nutrients quickly, increasing the risk of nutrient loss to leaching (Drinkwater, interview). Also, there is much attention given in the soil literature to what is called "immobilization" (uptake) of nutrients by soil organisms, but less to the return provision of these to plants and other organisms when the consumers become deceased. This can happen very quickly through predation or senescence, in which case these nutrients become available. "Immobilization" sounds like a negative process, but in fact, such tying up of nutrients in soil spaces prevents or at least reduces their leaching or any other loss to the system.

An integrated nutrient management strategy based upon ecological concepts can make significant improvements in nitrogen-use efficiency by timing microbial decomposition to release nutrients during periods of crop growth and by sequestering nutrients that are not mined by the crop.

> Rather than focusing on soluble, inorganic plant-available nutrient pools, an ecosystem-based approach seeks to optimize organic and mineral reservoirs with longer residence times that can be accessed through microbially- and plant-mediated processes. This requires deliberate use of varied nutrient sources and strategic increases in plant diversity to restore desired ecosystem functions such as nutrient and soil retention, internal cycling capacity, or aggregation. Breeding for cultivars and associated microorganisms that do not require surplus nutrient additions is critical if plant- and microbially-mediated ecosystem processes such as mineralization-immobilization, biological weathering, and carbon sequestration are to be harnessed. Integrated management of biogeochemical processes that regulate the cycling of nutrients and carbon, combined with increased reservoirs that are more readily retained in the soil, will greatly reduce the need for surplus nutrient additions. (Drinkwater 2004)

Reliance upon biological processes to provide plant nutrients requires an increased understanding of below-ground nutrient cycling, such as short-term carbon dynamics following cover cropping (Puget and Drinkwater 2001) and the influence of legume-based cropping systems on conservation of carbon and nitrogen (Drinkwater et al. 1998).

6.9.2 **The Rhizosphere as an Ecosystem within Ecosystems**

The last decade has seen significant advances in the understanding of rhizosphere processes. Plants have been shown to support a diversity of microbial organisms in the rhizosphere, primarily by releasing carbon from their roots (Cheng et al. 2003; Hamilton and Frank 2001). The diverse rhizosphere community scavenges nutrients effectively and releases plant-available nutrients upon senescence. The below-ground biota can be adversely affected by tillage, chemical fertilizers, pesticides, crop diseases, poor crop health, and poor soil tilth can, on the other hand, be enhanced through crop diversification, cover cropping, organic matter inputs, and other management practices.

Measures that reflect the health and activity of below-ground communities are not unambiguous or always correlated. Microbial respiration, while easily measured, does not always correlate to the robustness of ecosystem functioning (Cadet et al. 2004), and studies of the effects of herbicides on microbial populations should examine, for example, community dynamics and soil health in addition to respiration. Sensitive indicators of soil biological health may include the rate of nitrogen turnover (Schloter et al. 2003), enzymatic activity (Schloter et al. 2003), nematode community composition (Cadet et al. 2004), the ratio of beneficial-to-parasitic nematodes, decomposition rate (Wolfe interview), abundance of predatory nematodes (Ferris et al. 2004), the ergesterol-to-biomass ratio (Dinesh et al. 2003), and mycorrhizal abundance.

6.9.3 Some Effects of Soil System Dynamics

Some results from field-based studies of below-ground dynamics and their impacts on agricultural production and/or biodiversity include:

- In South African sugar cane plantations, high productivity patches corresponded to changes in nematode communities and soil nutrient availability, but not to changes in microbial respiration (Cadet et al. 2004).
- In Belgium, chemical fertilizer application was associated with lower methanotroph richness when compared to use of organic fertilizers (Seghers et al. 2004). This supports the results of other studies, which have shown that the methanotrophic community is negatively affected by the application of chemical fertilizers. Results of the study, which used genetic markers to identify bacterial and fungal species, demonstrated that fertilizer applications affected both the bulk-soil and endophytic soil microbial communities, but that herbicide usage did not have an observable effect.
- A Swedish study (Dahlin et al. 1997) demonstrated that sewage sludge application, with associated low levels of heavy metal contamination, resulted in moderate impairment of microbial function, using a broad range of measures of microbial function.
- A study in India (Dinesh et al. 2003) demonstrated significant decreases in microbial activity following deforestation of a tropical forest area, likely due to reductions in organic matter. Measures used successfully included ergesterol-to-biomass ratio and metabolic quotient.
- A California study demonstrated that maintenance of conditions for biological activity (fall irrigation and carbon addition) resulted in increased abundance of beneficial nematodes in the following year's tomato crop. This result demonstrated the potential for specific agrosystem management to support organisms beneficial for agricultural purposes (Ferris et al., 2004).

These and other studies have shown the potential for managing plants, soil, water, and nutrients to promote the abundance and diversity of beneficial soil organisms.The prospects for successful ecoagriculture hinge very much on a better understanding and use of subterranean biodiversity. Much research is needed, however, as below-ground communities and processes remain inadequately understood and are challenging to study.

6.10 Management of the Hydrological Cycle

Water is conventionally regarded as an input to agriculture, not as something endogenous to crop and animal production systems. But water is produced by the interactions among plants, soil and microorganisms, affected by temperatures and other climatic factors themselves reflecting land use and vegetative cover. Ground cover affects rates of evapotranspiration that determine how much of water remains in the soil and how much exits to the atmosphere. Soil that is depleted of biological life lacks water-holding capacity. Thus, water is more appropriately viewed not as an "input," which reflects an industrial manner of thinking, but as a component (indeed, a *sine qua non*) of living systems—ubiquitous but variable, from the cellular level up to the atmosphere.

Water, which along with carbon is the most common constituent living organisms, is essential for both agricultural production and wildlife habitat through the maintenance of sustainable and semi-natural water supplies. There can be no agriculture of any sort, eco- or otherwise, without water. The question is whether better management of water resources can contribute to agricultural enterprises that are more productive, more hydrologically sustainable, and more supportive of diverse natural habitats. Improvements in agricultural resource management that increase the water-use efficiency of crops or livestock should be regarded as beneficial for biodiversity, including in many instances wild biodiversity, because this will reduce the impact of agriculture on natural hydrological cycles. In dryland areas where pumping rates are high and water tables are declining, reduction of crop evapotranspiration is also a desirable objective from the standpoint of biodiversity conservation.

Problems resulting from unsustainable water use are most dramatically seen where extraction from aquifers, rivers, and reservoirs reduces flows to streams, groundwater, and wetlands to such an extent that natural habitats are degraded or lost, with resulting species loss of fishes, plants, and other aquatic organisms. This conflict is seen increasingly in the western United States, but also occurs in India, China and elsewhere with less public attention. In areas with only shallow wells to support village water supplies, receding water tables are also a matter of great concern. Improvements in hydrological modeling are now allowing for more complex management of water resources, such that use of water resources can be more carefully managed (T. Steenhuis, pers. comm.).

6.10.1 Effects of Changes in Water Supply and Evapotranspiration

Most agricultural thinking looks to irrigation as a means of providing water for plant growth whenever water is in short supply at certain times or throughout the growing period. Improved irrigation management commonly focuses on reducing groundwater extraction rates (supply management) by pumping only as much water as can be used by the irrigated crops, and by reducing evaporation through precision irrigation. Groundwater depletion, however, is the result of the mass balance between inflows (recharge) and outflows (pumping). In areas with shallow unrestricted aquifers, water pumped in excess of crop requirements drains back into the groundwater supply so it is not really lost.

If pumping is reduced without reducing total crop transpiration, precision water application will, in many cases, reduce pumping rates without reducing the rate of water table recession, because the recharge of excess irrigated water declines. Precision water management might, in some cases, actually *increase the overall groundwater depletion rate*. This would happen if a reduction in the water required per hectare encouraged farmers to increase their area under irrigated crops (and thus increase evapotranspiration), assuming that there had been some actual water-saving.

Care must be taken to evaluate hydrological dynamics and water balances when assessing farming system sustainability. Some water "savings" that appear real are not, when evaluated on a watershed scale. Currently, many irrigation design efforts focus on maximizing water-use efficiency. This strategy will only slow groundwater depletion if and to the extent that it reduces evapotranspiration. This important consideration is often neglected by large-scale irrigation management projects. Governments can spend large sums on making management changes that do not result in any reduction in groundwater depletion.

The fundamental constraint to be reckoned with is the water demands of the particular crop sequence (Kendy et al. 2004). Similarly, other techniques that improve irrigation efficiency by reducing percolation, e.g., lining canals and implementing precision irrigation to the crop root zone, may have little effect on the overall hydrological mass balance and should not be relied upon to stop groundwater recession (Kendy et al. 2002).

6.10.2 Interactions with Cropping Patterns

Ecological imbalances in water-deficit areas can be redressed most directly by shifting to crop species that require less water. Water-use efficiency can be improved by changing crop species, such as the replacement of alfalfa with cereal-legume intercropping systems on the southern high plains of the U.S. (Lauriault and Kirksey 2004). In the case of the North China Plains, water budget modeling using 38 years of historic climate data identified the replacement of irrigated winter wheat with a more drought-tolerant crop within the present wheat-corn rotational farming system as the most effective method of stabilizing water extractions where the water table is dropping as much as 1 m or more per year (Kendy et al. 2004). It appears that if only cotton and millet had been grown, instead of corn and wheat, the water table could have remained stable. The current water table decline in North China is putting all organisms within the region, plant, animal, human, and microbial, at risk.

This research points out the risk of growing crops with a high water demand, without considering the effect that irrigation will have on the regional hydrologic cycle. Certainly water could be extracted from ground or surface water sources and applied through irrigation infrastructure to meet the demands of a high-water-demanding cropping system. But this can have adverse effects on the hydrological cycle An ecoagricultural approach consider developing highly productive cropping systems that more closely mimic the evapotranspiration rates of the native vegetation.

A review of African cropping systems that maximize water-use efficiency has been provided by Van Duivenbooden et al. (2000). Windbreaks if planted and maintained can reduce crop evapotranspiration significantly. In severely water-limited areas, a desirable practice such as cover-cropping for carbon and nitrogen production could be ecologically unsound if it increases overall evapotranspiration. Whenever water is a limiting factor, it is wiser to adapt the cropping pattern to the conditions than to assume that increasing supply will solve the problem. There are millions of hectares of soil on six continents no longer productive because of salinization due to irrigation practices that did not adequately account for and respect hydrological cycling and soil-water relations.

Water budgeting is an important tool for regions that are water-limited. Analysis of groundwater balances in Indonesia has identified management practices that improved water supply and downstream water use during dry months, while also permitting increased irrigation during the wet months (Peranginangin et al. in press).

By maintaining hydrological adequacy and diversity, conservation of on-farm wetland areas can strengthen ecosystem functions such as filtering of agricultural pollutants and preserving of wild biodiversity (Bedford interview). Hydrological modifications to farmland, such as artificial drainage, can result in nutrient pollution and degradation of wildlife habitat, so such changes should not be made without considering external effects. The agricultural sector is a major consumer of water throughout much of the world, and agricultural impacts on the surrounding landscape should be carefully considered, so that crop productivity can be sustained, and so that wetland and aquatic habitats, so important to wild biodiversity and healthy landscapes, are maintained.

As water becomes an increasingly scarce resource in this world, the demands of the agricultural system need to be modified and reduced through a combination of increasing the water-use efficiency of current cropping systems and changing the cropping systems themselves to promote more sustainable water usage. Fresh water is in some ways a more finite resource than land. It has the advantage of possible re-use, if quality is not degraded by use, but as population rises, its availability per capita will continue to decline (Elphick and Oring 1998).

Efforts to make production systems more water-efficient should include measures that promote sustainable management of the water balance; maintenance of soil organic matter and increases in infiltration and retention of water into and near the root zone; plus enhanced soil life. The latter requires water, but maintains and recycles soil moisture as an intrinsic quality. This is evident when one considers the desiccation of soil that has been lost all of its living organisms. A synergy is seen in the interrelationship of soil health with water retention and use-efficiency.

Ecoagriculture will need to find ways to economize on water use if it is going to meet food production needs without compromising the biodiversity of agricultural and wild areas. Fortunately, both of the next two focuses of discussion have the potential to increase yield while reducing water use, whether in rain-fed or irrigated agricultural systems, thereby fulfilling the objective of "more crop per drop" that is becoming an aspiration more and more widely shared.

6.11. Conservation Tillage/Conservation Agriculture

Conservation tillage systems, variously known as "low-till," "zero-till" or "no-till," avoid plowing in order to maintain soil cover, improve soil structure, and control erosion. By including also the improved management of crop residues, water resources and agricultural inputs, conservation tillage has evolved into a set of ideas and techniques now characterized by FAO as "conservation agriculture." It thus has many facets that make it quite consistent with ecoagricultural objectives. It should not be regarded, however, as a total system. Rather it should be considered and practiced as one component of a larger program of healthy landscape management that can address issues of agricultural sustainability and avoidance of pollution (P. Hobbs, interview).

The basic features of conservation agriculture include the following (Hobbs and Gupta 2004):

- Little or no soil disturbance, thereby promoting growth of native soil microorganisms and fauna, and soil biological processes;
- Ground cover from using green-manure cover crops and/or previous-crop residues will reduce erosion dramatically, and lowers soil temperature with beneficial effects for soil organisms;
- Crop rotation, helps control pests, diseases, and weeds;
- IPM practices integrated into farming system, saving costs and enhancing biological processes generally;
- No more burning of crop residues, which improves air quality;
- Use of agrochemicals is more efficient and often reduced, with a definite reduction in the use of fossil fuels;
- Increased profitability, due to lower costs of production, usually accompanied by yield increases, although these may not come immediately; a few years may be needed for soil quality to build up with the cessation of plowing;
- Profitability can often be further enhanced by stopping tillage, permitting farmers to plant their crop earlier, closer to the optimum time; and
- Water-use efficiency is improved with ground cover and no plowing.

In South Asia, zero tillage for wheat following the harvest of rice in rice-wheat cropping systems, promoted by CIMMYT, has been very successful and is being adopted more and more widely (Hobbs and Gupta 2004). From practically no area under no-till in 1997, its use in South Asia has expanded to over a million hectares without any significant investment in agricultural extension. The advantages that the new set of cultural practices bring to farmers has been enough to persuade them to take up conservation agriculture, aided to be sure by the recent design and availability of appropriate implements for planting through ground cover.

6.10.1 **Herbicide Use and Direct Seeding**

As currently practiced, no-till systems have the tradeoff of an increased dependency on the use of herbicides. South Asian farmers, presently wedded to the rice-wheat rotational farming system, have not developed more varied rotational systems that enable them to control weeds through a well-planned succession of crops as is being done in Latin America, nor have they developed implements for cutting plants in optimal ways so that chemical killing of the plants becomes unnecessary, also done in Latin America (Calegari 2002). There is an increased risk with some no-till systems of soil nutrient loss through percolation due to better soil aggregation which increases macropores. Also, without plowing in the spring, soil temperatures will be lower, and this can delay germination in some cases.

CIRAD in Brazil has developed and is promoting direct seeding into vegetative cover. This increases biological productivity and plant nutrition by trying to mimic natural forest conditions, having a robust method for weed and erosion control plus improvements in soil structure and nutrient use efficiency (Seguy et al. 2003a, 2003b). No-till agriculture adoption in Brazil has been linked to increased soil organic matter and increased soil fertility, particularly at shallow (0-5 centimeters) soil depths (Machado and Silva 2001). Rainfed rice yields in the range of 8-9 tons per hectare, well above usual irrigated yields, are being achieved in Brazil within 4-5 years of using these no-till methods, and production of maize and soybeans has been increased by about 50 percent with a similar reduction in costs of production.

Conservation agriculture is spreading rapidly, covering more than 70 million hectares by 2002. What has been demonstrated in the last three decades is that a system of agriculture that “imitates” nature can in fact be productive and profitable. Direct seeding mulch-based cropping systems have been increasing in popularity in Latin America, accounting already for 50 percent of cropped acres in Brazil, Paraguay, and Argentina (Scopel et al. undated).

This is not surprising given that changing management practices has had such a positive impact on profitability. The reduced consumption (combustion) of fossil fuels adds to air quality, as noted above, while reduced erosion and application of chemical fertilizers enhances water quality. Both create an environment more suitable for sustaining biodiversity. Unlike many conservation agriculture technologies that are labor intensive, low and zero tillage systems often demand less labor. The use of herbicides remains a controversial aspect of conservation agriculture where these are employed, however.

The control of weeds has been a principal reason for plowing through the years, and it is the main constraint when moving to no-till agriculture. In many regions, adoption of reduced tillage agricultural systems has been made possible by the development of herbicide resistant-crop varieties. Although the environmental impact of herbicides has been diminished in recent years with different chemical formulations, attention must be paid to possible secondary chemical effects on soil microbial communities, mycorrhizal symbioses, and soil health.

Recent advances show great potential for weed and pest control using non-chemical means, after the transition to a reduced tillage system has been made. These systems rely upon groundcover, crop rotation, cover cropping, and reduced soil disturbance to control weeds. As with other kinds of ecoagriculture, we see here that biological methods can be invoked to solve constraints in ways that are environmentally benign.

6.10.2 **Effects on Nutrient Availability and Management**

Multi-function cover crops lead to increased nutrient-use efficiency and economic and agronomic benefits to the farmer. Increased systems complexity, however, leads to increased complexity of management. Participatory research and farmer involvement is critical to the development of efficient and practical systems that farmers can and will manage effectively. Research should focus on how better to understand and enhance soil biological processes, reducing dependence on external inputs, and integrating livestock effectively into the new farming systems that emerge under the rubric of conservation agriculture.

6.10.3 **Other Issues Relating to Conservation Agriculture**

Certain reduced-tillage methods such as raised beds and ridged till provide alternative methods of cultivation that can be effective at conserving water and reducing tillage impacts (Sayre and Hobbs 2003). The Land Institute in Salina, Kansas, is working to breed perennial crops for grain production, seeding them in diverse groupings that mimic vegetation complexes found in natural prairies. This work focuses on hybridizing annual crops with perennial relatives, and on selecting for high grain production in existing perennials. Cox et al. (2002) advocate the development of a large and comprehensive breeding program for these purposes, based on their initial experience. Perennial grain cropping systems are an example of a "natural systems" approach to agriculture, where intact natural ecosystems are used as models for the design of nature-based agricultural systems that harness ecosystem functions to support production and pest control (Jackson 2002).[7]

Thirty years ago, practicing cropped agriculture without plowing was practically unthinkable. No-till agriculture was equated by some critics with atavistic, "dibble stick" cultivation. What has been demonstrated in the last three decades is that a system of agriculture that "imitates" nature can in fact be both productive and profitable. Conservation agriculture is getting comparable or often better yields. Even more often, it is producing higher net incomes for farmers, who see their costs of production decline, which makes it a stable innovation.

In the systems developed by CIRAD, within a few years, the yields are usually higher, which makes them preferable on both economic and agronomic grounds, and certainly they are more benign for biodiversity, wild and otherwise, than the more chemical-input-intensive systems that they are replacing. Most of the conservation agriculture systems developed initially were the temperate zones of the U.S. and the Southern Cone countries in Latin America. The CIRAD systems,

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[7] *Conservation tillage resources on the internet include: Rolf Derpsch (http://www.rolf-derpsch.com); the Conservation Tillage Technology Center (http://www.ctic.purdue.edu/CTIC/CTIC.html); and the Rice-Wheat Consortium (RWC) (http://www.rwc-prism.cgiar.org/rwc).*

mentioned above, have been devised mostly for tropical areas, although now they are adapted also for dryer, Mediterranean-type climates like Tunisia and southern France.

But there are drawbacks. While conservation tillage is amenable to mechanized agriculture and can economize on labor inputs, many other conservation agriculture technologies and practices require additional labor inputs, which may be unavailable or unaffordable at the prevailing agricultural wage, especially on a seasonal basis (Lee and Ruben, 2001). In addition, conservation agriculture innovations, like the next one discussed, have had difficulty attracting research funding because they are often relatively simple, not requiring high-tech research of the sort that is most interesting to donor agencies or to scientific journals that control the professional rewards of publication. The demonstrated environmental benefits, with higher production at lower cost, should make them of much interest to the scientific and donor communities.

6.12 The System of Rice Intensification

Ecoagriculture needs to demonstrate that there can be production gains, not just tradeoffs, resulting from agricultural methods that are more supportive of biodiversity, as suggested in Chapter 2. An example of such a system with evident positive-sum effects is the System of Rice Intensification (SRI). Although still controversial in some scientific circles (Dobermann 2004; Sheehy et al. 2004; Surridge 2004), the use of SRI is rapidly spreading. Five years ago, SRI was known only in Madagascar, where it had been developed in the early 1980s by Fr. Henri de Laulanié (Laulanié 1993). Today its potential to raise yields and factor productivity while reducing inputs (including water) and costs of production with beneficial environmental effects has been seen in at least 19 countries in Asia, Africa and Latin America (Stoop et al. 2002; Uphoff et al. 2002; Uphoff 2003, 2004).

Because scientific work on SRI began only in the last five years, it is too early to know how broadly its principles and practices can be adapted to other crops with similar success. The more that is learned about SRI, however, the more evident are a number of principles responsible for SRI results that are supported by current scientific literature and that should have some generalizability. Nothing definitive can be said yet about its sustainability, but many farmers who have used SRI methods for up to 10 years report that their high yields have been maintained and even increased by continuing to enhance soil organic matter rather than rely on inorganic nutrients for soil fertility.

As with all agricultural practices, there is considerable variation in the yields from resulting SRI practices within and between countries. Agricultural differs from industrial production in that the outputs associated with a given set and level of inputs can be quite variable because biological processes are involved. Also, the methods are not similarly productive everywhere. There are some climates or soil conditions where the results are disappointing, as with any agricultural technology. While some of the yields reported with SRI are quite spectacular, it is the changes in average yield that are more important, usually 50-100 percent with reduced inputs.

In Chapter 3, the findings of two evaluations of SRI were summarized, one undertaken by GTZ in Cambodia and the other by IWMI in Sri Lanka. They were done with randomly selected samples of farmers who are using SRI (at least partially) or who are not. The results of extensive data gathering and analysis confirmed what has been reported from less systematic and detailed evaluations for a number of years. So there should no longer be much question whether SRI methods work. The interesting questions are "how?" and "why?" as answers may give leads for making agriculture in the 21st century more productive, profitable, and environmentally benign.

6.12.1 Getting More Output from Fewer External Inputs

SRI goes against the usual logic that more or "better" inputs are required to get more output. SRI gains come with less or no use of chemical fertilizers and agrochemical protection, with 30-50 percent less use of water, with fewer plants/m^2 and by starting with younger and smaller plants when transplanting. No new varieties are required as the methods have evoked more productive phenotypes from any and all rice genotypes used thus far. The "trick" is giving plants a better environment to grow in.

First, wider spacing of plants generalizes “the edge effect” for the whole field.[8] Second, by alternately flooding and drying rice fields for periods of 3-6 days or just applying small amounts of water daily to keep the soil moist but not saturated—not keeping rice paddies continuously flooded, as has been the practice for most rice cultivation for centuries—the plants have an aerobic (or an alternating aerobic-anaerobic) soil environment, quite different from the hypoxic one that is created by conventional water management practices.

When rice roots are continuously hypoxic, they begin degenerating, so that by the time of flowering, when grain production begins, as many as three-fourths of the roots can have degenerated (Kar et al. 1974). It is true that rice plants can survive under flooded conditions, which has made it possible them to grow in environments where other crops could not. But they do not thrive. It can be demonstrated (and has been shown by replicated factorial trials) that especially when using other growth-promoting practices, the maintenance of mostly aerobic conditions is more favorable for rice production.

When rice roots are kept flooded and die back during the growth cycle, the plants must necessarily rely upon chemical fertilization because they do not have root systems that can access a greater volume of nutrients, and a greater variety of micronutrients. SRI was originally developed using chemical fertilizer, which was the norm in Madagascar. But when government subsidies were removed and small farmers could no longer afford to buy fertilizer, Fr. de Laulanié began using compost, and found that the results were even better, as well as cheaper for cash-strapped farmers. The advantages of organic fertilization, shown in replicated trials, are not unique to SRI, of course. The advantages of increasing soil organic matter and providing nutrients in organic forms have already been discussed (6.8. and 6.9.) While SRI is not organic in principle, it often becomes organic for pragmatic reasons.

The SRI methodology is quite different from the paradigm of the Green Revolution, which raised grain yields (a) by improving the genetic potential of crop plants, particularly their efficiency in utilizing higher inputs of fertilizer and water, and then (b) by increasing these inputs. More chemical means of protection had to be used because as is well-known, high applications of nitrogen fertilizer not only make plants more liable to lodging, because tillers and root systems have less strength, but also more vulnerable to insects and pathogens.

SRI makes neither kind of change, utilizing either modern or traditional varieties, and reducing rather than increasing external inputs. SRI is essentially a different way of managing plants, soil, water and nutrients and is thus variant on a generic agroecological strategy, similar to that adopted by CIRAD in its direct-seeding-through-vegetative-cover methodology but for different conditions and different crops. These four kinds of inputs are managed in ways that make plant roots larger and more effective. These changes also, partly because of the larger roots produce more exudates, induce definite changes in soil biological activity.

An interesting phenotypical change that results with SRI practices, which makes it of scientific interest, is that a long-standing constraint on rice productivity—an inverse correlation between panicle number and panicle size normally observed with flooded rice (Ying et al. 1997)—is broken. A positive correlation is generally observed instead, as SRI plants have both more panicles (grain-bearing tillers) and larger panicles (more grains per panicle). This is what makes possible the yield increases in multiples rather than increments. Only the latter are possible if the usual negative relationship (diminishing returns) holds. When SRI plants have larger root systems supporting bigger canopies, and vice versa, there is positive feedback with the plants becoming *open* rather than closed systems.

6.12.2. **Biological Dynamics**

The results of SRI above-ground are easy to see -- increased tillering where single plants have 50 to 100

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[8] *When taking crop-cutting samples to measure (estimate) the yield of rice or any other crop, people are always told to take them from the middle of the field—“to avoid the edge effect.” One gets unrepresentative samples from the edges of a field because it is known that plant growth is more robust there, where plants have more exposure to sun and light and less root competition. With SRI, by planting in a square pattern, 25x25 centimeters (or wider as soil quality improves with repeated use of the system), and only one plant per hill instead of 3-6 in each clump, the growing environment for rice plants is greatly changed.*

tillers or even more, compared with 15-30 for clumps of conventionally-grown, i.e., crowded and flooded, rice. Having fewer plants increases their exposure to the sun's radiation and to circulating air. Measurements made at the Indonesian rice research center at Sukamandi have found that illumination at lower levels within the canopy of conventionally-grown (close-planted) rice was not high enough to support photosynthesis, so that lower leaves were in effect being "subsidized" by the photosynthesis of upper-level leaves; with wider SRI spacing, all leaves received enough light for photosynthesis (Dr. Anischan Gani, pers. comm.).

Larger, more active root systems contribute to superior plant performance, although plant breeders preoccupied with increasing plants' harvest index (the percent of total biomass ending up in the edible portion of the plant) have considered roots "a waste." This is closed-system thinking. Root growth in all plants is encouraged by wider spacing and more aerated soil, especially if more organic matter provided through compost. SRI root systems require much more force to uproot, as much as 10 times more kilograms per plant, compared with conventionally-grown rice plants whose systems are smaller and necrotic. These differences can be seen when roots are inspected, and they can be measured precisely with some effort.[9] What is not so easy to ascertain is the effects and benefits of having more abundant and diverse populations of soil biota, most of which are invisible to the human eye.

SRI supports the advice given by organic farmers, "feed the soil, and let it feed the plant." While chemical fertilizer enhances yield with SRI methods, organic fertilization raises yield even more, because the latter provides better substrate for microbial populations. In section 6.9, we considered how various in the rhizosphere, on and around the roots, contribute to plant nutrition and health. We did not discuss much the contributions also of endophytic microorganisms such as bacteria species that live inside root tissues and fix nitrogen and provide other services (Dobbelaere et al. 2003). The application of inorganic nitrogen fertilizer can have a suppressive effect on these organisms, as Tan et al. (2003) have shown with very sophisticated analysis reported in Chapter 3; the application of inorganic nitrogen to soil affects the expression of nitrogen-fixing genes in endophytic bacteria that live in rice roots. This has also been seen in research by colleagues in Madagascar.

Research from the University of Antananarivo has shown that SRI practices are associated with large increases both in endophytic populations of a well-known nitrogen-fixing bacteria *Azospirillum* in plant roots and in crop yield (and tillering). Table 6.1 shows the results of replicated trials at the Beforona experiment station. Similar increases in yield have been seen on clay soil with SRI methods plus compost elsewhere in Madagascar so the yield results was not surprising (Randriamiharisoa and Uphoff 2002). What was significant to see were the 17- and 21-fold increases in endophytic populations when SRI methods were used and, even better, when compost was added to the soil. Students of microbiology know that such populations can easily vary by several orders of magnitude, and that the application of inorganic fertilizer has negative effects for soil organisms (in these trials, reducing the population of *Azospirillum* by 40 percent.).[10] Interestingly, the *Azospirillum* populations varied only within the roots, as the concentrations of this bacteria did not vary in the rhizosphere soil, remaining around $25x10^3$ ml across the six sets of trials.

No conclusion should be inferred the increase in *Azospirillum* populations in rice roots was itself or alone responsible for the measured increases in yield. This particular bacteria was studied because it is a known nitrogen-fixing agent and could be reliably measured at laboratory facilities available within Madagascar. It may be an "indicator" species for what is going on in the rhizosphere and in roots more generally, since it is known that effects on growth are more usually the result of microbial ecology rather than just the influence of

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[9] *Barison (2002) found that root length density (cm/cm^3) at a depth of 40-50 centimeters was on average 0.23 for SRI plants, and 0.06 for conventionally-grown plants. At maturity, root-pulling resistance (kg/plant) was 55.19 kg per SRI clump (a single plant) and 20.67 kilograms per clump for conventionally-grown rice (4-6 plants) (Tables 13 and 14).*

[10] *The work involved in setting up replicated trials was such that only the second and fourth treatments done on clay soil were repeated on loamy, less fertile soil. The results of these trials were also consistent with previous research findings on soil microbiology.*

Table 6.1. Yields and Tiller Formation Associated with Populations of Azospirillum in Rice Plant Roots in Response to Different Plant, Soil, Water and Nutrient Management Conditions

	Azospirillum count in roots (103/mg)	Tillers per Plant	Paddy Yield (t/ha)
CLAY SOIL			
Traditional cultivation, no amendments	65	17	1.8
SRI cultivation with no amendments	1,100	45	6.1
SRI cultivation with NPK amendments	450	68	9.0
SRI cultivation with compost amendments	1,400	78	10.5
LOAM SOIL			
SRI cultivation with no amendments	75	32	2.1
SRI cultivation with compost amendments	2,000	47	6.6

Data from Raobelison (2000), reported by Randriamiharisoa (2002).

an individual species.

Research on the various SRI processes and the synergies among them is still in its early stages, with more questions than answers. What can be said with some confidence is that it may be possible to produce “more” from “less,” that is, to get more outputs with reduced external inputs. For this to occur, there must be greater contributions from soil systems, and the plants’ own genetic operations need to convert inputs into outputs more efficiently. We have some evidence for the latter from a study in Madagascar where an analysis of SRI and non-SRI plants, using QUEFTS modeling techniques, found that paddy yield in response to comparable levels of nitrogen, phosphorous, and potassium plateaued around 10 tons per hectare with SRI-grown plants, whereas it leveled off about 5 tons per hectare for plants grown by conventional methods—by the same farmers, and on the same farms (N=108) (Barison 2002).

SRI does not require the addition of compost to the soil to get higher yields. However, yields are enhanced and made more sustainable by increasing organic matter in the soil to support a vast array of soil organisms, micro, meso and macro. These live in, on and around the plants’ roots providing a variety of benefits and services in terms of plant nutrition and protection, including:

- *Nitrogen fixation* by both endophytic and free-associated diazotrophs Döbereiner 1987; Boddy et al. 1995);
- *Phosphorous solubilization* by many different bacteria and fungi (Turner and Haygarth 2001; Gyaneshwar et al. 2002);
- *Greater access to nutrients and water from a larger volume of soil* due to the services of mycorrhizal fungi (Martin et al. 2001);
- *Making more nitrogen available to plant roots* protozoa when they “graze” bacteria that live on the exudation from plant roots, because they have a lower carbon:nitrogen requirement than the bacteria they consume, excrete “excess” nitrogen; nematodes in turn, consume protozoa within the underground soil food web and contribute nitrogen in the same way (Bonkowski 2004);
- *Producing phytohormones* auxins, cytokinins and other biochemical compounds that promote root

growth and benefit plants in many other ways (Frankenberger and Arshad 1995; Kapulnik and Okon 2001);

- *Protecting plants from the effects of pathogens* through competition, production of antibiotic protection, and induced systemic resistance (ISR) (Doebbelaere et al. 2003).

All of these processes are supported the *exudation* from plant roots of carbohydrates, amino acids, vitamins, enzymes and other compounds into the root zone, plus rhizodeposition of dead root cells (Brimecombe et al. 2001; Neumann and Römheld 2001). The combined effects of these processes is to assist plants in growing faster, larger and remain healthier. Specifically with regard to rice plants, Yanni et al. (2001) have documented the extent to which rhizobacteria in their root zone increase the protein content as well as rice yield per hectare.

There is a vast literature on these relationships, brought together in books such as Pinton et al. (2001), Waisel et al. (2002) and Wardle (2002), that examine what goes on in the rhizosphere and the rest of the soil. The incorporation of decades of research by microbiologists on plant-soil-organism-nutrient relationships into mainstream agronomic literature has been slow, but it is increasing. While these relations are acknowledged, most attention is still given to chemical and physical relationships in the soil, e.g., Brady and Weil (2002).[11] As noted already, much of soil and crop research has tried to "control for," by eliminating the effects of microorganisms and other creatures in the soil. SRI dramatically calls attention to the biological dimension of crop production and sustainability, supporting a more "biocentric" understanding of soil systems.

6.12.3 **Critiques of SRI**

As noted above, SRI is still controversial in some scientific circles, where the idea of "getting something for nothing" is difficult to accept. SRI does initially require more labor and certain much more knowledge and skill, so it is not exactly a "free lunch," but the returns to land, labor, capital and water are all increased concurrently with SRI, something hardly seen before. It has been objected that there are no scientific studies testing and validating the results reported. There are a number of detailed theses and studies in French and Chinese, but only few in English. It has been difficult to get agricultural scientists involved in studying and evaluating SRI because it represents such a different paradigm from mainsteam modern agriculture.[12] This puts SRI in a Catch-22 position since those most willing to give it enough credence to try the methods have been NGOs, farmers, and social scientists, all interested in innovations that would be particularly appropriate for small and marginal farmers and for benefiting the environment. We will review some of the critiques made against SRI as they are similar to ones made against other agroecological innovations. Each of these has to be evaluated on its own merits, to be sure, and with regard to particular places and seasons since one must be careful about generalizing any biological processes and potentials. However, some general principles can usually be educed.

6.12.3.1 *Unconfirmed Field Observations (UFOs)*

This is how Cassman and Sinclair (2004) have characterized and dismissed SRI because (not enough) results have not appeared in peer-reviewed journals. There are evaluations such as reported in Chapter 3 with unreproachable methodology that confirm the reports on SRI performance that have been coming in for half a dozen years. Leading rice research institutions in China, India and Indonesia, the three largest rice-producing countries and previously leaders in the Green Revolution, have now validated SRI methods to their satisfaction and are recommending them for dissemination. Probably the most eminent rice scientist in the world, Prof. Yuan Long Ping, known as "the father of hybrid rice" and co-recipient of the 2004 World Food

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[11] *However, as noted in Chapter 3, the amount of attention in the 13th edition of the major text on soil and crop science has much more detail on soil biological factors than earlier editions, and Chapters 11 and 12 represent an excellent introduction to 'life in the soil' and its implications for a more productive, sustainable agriculture.*

[12] *Sinclair (2004) begins his critique of SRI by saying that even "Discussion of the system of rice intensification (SRI) is unfortunate because it implies SRI merits serious consideration." No consideration is given of the extensive evidence of SRI benefits such as summarized in Chapter 3.*

Prize, has been working with SRI since 2000 and has been promoting its development in China. The Sichuan Academy of Agricultural Sciences has evaluated SRI since 2001 and reported 20-50 percent increases in the already high rice yields obtained with modern inputs and hybrid varieties (Zheng et al. 2004).

Ironically, when SRI methods have been tried on research stations, the yields are usually lower than on farmers' fields, reversing the common situation where farmers find it difficult to replicate good results that researchers have obtained. IRRI's first SRI trial yielded 1.44 tons per hectare, and the next season, the yield was 3 tons per hectare (Rickman 2003). SRI trials conducted by the Philippine Department of Agriculture's Agricultural Training Institute in southern Mindanao averaged 12 tons per hectare (ATI 2002.) Why the difference? It probably has something to do with the abundance and diversity of soil biota, probably adversely affected by decades of monocropping and heavy application of agrochemicals of many kinds. If the development of SRI had been left to scientists working on research stations, its benefits and opportunities would probably never have emerged.

6.12.3.2 *Limitation to Small Scale*

Because SRI was developed to be of benefit to small farmers in Madagascar, enabling them to feed their families without continuing to encroach on remaining forest ecosystems through slash-and-burn cultivation, it has been most demonstrated and most successful on a small scale. Its initial labor-intensity means that it is difficult to adopt directly on a large scale. It has been argued against SRI that it cannot have a significant impact on world food supplies for this reason. In fact, because there are many millions of small farmers in the world, an innovation that is particularly suitable for them could cover a large share of production areas. There is nothing wrong with an innovation that meets the food security needs of the poor directly. That it may not be appropriate for all farmers is no reason to pass up the benefits it could provide to those for whom it is suitable.

As farmer interest, confidence and experience with SRI increases, it is being used on a larger scale. This past rabi season (2003-2004), one large farmer, N. V. R. C. Raju in West Godavari, Andhra Pradesh, planted a large field of 44 hectares with SRI methods, and harvested a yield of over 10 tons per hectare, having organized and managed the operations with the skill that made him a successful commercial producer (Dr. A. Satyanarayana, Director of Extension, pers. comm.). Where there are labor supply constraints, such methods may not be feasible, but where they are raising labor *productivity*, there will be incentives to figure out how to utilize them. This applies to other agroecological innovations.

Where labor productivity can be raised by better use of other resources, mobilizing biological support, adoption and spread should become feasible. An evaluation of SRI in Cambodia among 120 farmers who have used it for three years found that 55 percent considered the methods requiring less labor and effort; only 18 percent reported that it was more difficult (Tech 2004). The GTZ evaluation of SRI in Cambodia, where farmers are gaining experience and confidence with it, analysis of actual labor expenditure found SRI to be labor-neutral, with some benefit from when labor requirements are reduced or increased (Anthofer 2004). There should be no limitations on such innovations according to scale. If productivity gains come from capitalization upon biological potentials, these should be accessible on various scales.

6.12.3.3. *Limitation to Certain "Niches"*

This has been concluded by Dobermann (2004), that SRI is indeed a productive innovation, but only for certain soil (e.g., high Fe content) or other conditions. This claim has been made without systematic evidence. As farmers have seen the benefits of SRI in Cambodia, it has been spreading throughout the country, and this year is expected to be used by 40-50,000 farmers. The noted rural development consultant, Roland Bunch, on a consulting assignment in Cambodia for the NGO ADRA, reported that 100 farmers in one village had tried SRI but only with assurances from ADRA that it would compensate them for any shortfalls in production because their average yield was very low, only 1 ton per hectare. When Bunch visited the village in May, 2003, he was told that the average SRI yield had been 2.5 tons per hectare, with not a single farmer asking for any compensation (Bunch, pers. comm.). In this case, an environment that had not been predicted to respond to the new methods (farmers there had little water control) gave a very good result even though the methods were not fully applied.

When SRI was introduced into Andhra Pradesh, India, the state agricultural university and extension service oversaw 300 on-farm trials across all 22 districts of that state. The average SRI yields were 8.34 tons per hectare compared with 4.89 tons per hectare with same variety on adjoining plots, measured by government personnel. In five districts, the average was over 10 tons per hectare, and only on saline soils was a substantial increase not seen. Thus, so far there is no basis for concluding that SRI benefits will be limited to only certain agroecosystem conditions.[13] The point here is that previous experience and scientific findings based on different growing conditions may not be valid for practices and farming systems that change the growing environment. Biological processes can change parameters, so that an empirical approach should be taken to evaluation rather than rely too heavily on a priori reasoning.

6.12.3.4 *Disadoption*

One study in Madagascar found that the rate of disadoption of SRI practices as rather high, 40 percent (Moser and Barrett 2003). This may have been true for the five villages studied, but there is evidence from the same part of the country that SRI adoption has proceeded very rapidly, even without systematic extension efforts, the area of SRI in a French irrigation project expanding from 35 hectares to 543 hectares over five years (Hirsch 2000). Average SRI yields were 8.55 tons per hectare, compared with 3.77 tons per hectare for the government-recommended "modern" system of rice production, and 2.36 tons per hectare for peasant practice. The spread of SRI in Cambodia, reported above, indicates that disadoption need not be a significant problem, though some will be normal with any innovation, as not all may benefit or get sufficient benefit from it.

The Moser-Barrett study usefully called attention to the fact that the very poor might not be able to adopt SRI because their income liquidity is so low that they cannot afford to invest more labor in an innovation even if it would yield them net economic benefits. And, of course, the additional labor requirements themselves may represent a critical constraint to adoption in some settings. The IWMI evaluation of SRI in Sri Lanka, on the other hand, found no difference in SRI adoption by richer and poorer farmers, and it even found that the poor were less likely to disadopt once they started (Namara et al. 2004).

6.12.3.5 *Soil Depletion*

A different critique of SRI, which at least implicitly acknowledges its productivity gains, is that such high yields will quickly deplete the soil unless nutrient amendments are made. As noted above, SRI and related agroecological improvements are not necessarily adverse to inorganic soil amendments. If a particular deficiency develops, such as phosphorous, there is nothing wrong with remedying this. What is suggested, though, is that there should be a burden of proof on this recommendation, that it will make net and sustainable improvements to soil fertility. With biologically savvy plant, soil, water and nutrient management practices, it is being shown that soil systems have more capacity to mobilize "unavailable" nutrients and make them available for plant nutrition than the mainstream approach to agricultural improvement allows.

Nitrogen, the main plant nutrient requirement, can be provided free from the virtually unlimited atmospheric supplies through a variety of biological pathways. There are vast amounts of phosphorus, often considered the most limiting nutrient in many soil systems, complexed in a wide variety of organic and inorganic molecules that can be accessed by soil microbes under supportive conditions. There is bound to be disagreement for some time as to how much, and whether adequate, supplies can be mobilized by these processes.

We do not want to present any overly optimistic conclusions. Our task here is not to recommend alternative practices. Rather, we are reporting opportunities that

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[13] *First-season trials in Mozambique with SRI methods on saline soils have produced yields as good or better (up to 2.5 times more) without chemical fertilizer and irrigation than the current average yield on good soils with fertilizer and irrigation, 3 tons per hectare (Maria Zelia Meneta, pers. comm.). A second season of trials is currently underway to check out these results further. But it appears that even soil salinity may not be a major constraint if soil organic matter is increased sufficiently.*

warrant further study and testing in the field, to ascertain their potentials and their limitations. The conclusion we can confidently offer is that the closed-system, zero-sum thinking about soil-plant nutrition is probably too reductionist and abiological. The adequacy or inadequacy of soil nutrient supplies should be treated as an empirical matter without presumptions that exclude examination of different plant-soil-water-nutrient management systems that could, by enhancing and mobilizing soil biological capacities, that could make agricultural systems more productive, profitable and sustainable, with positive externalities for the conservation of biodiversity. This extended discussion of SRI has not been intended to promote its adoption but to open up consideration of ways of practicing agriculture that could be supportive of the new directions proposed for ecoagriculture.

6.13 Discussion

Twenty years ago, two axioms of agriculture were (a) that good yields of field crops depend on plowing, and (b) the best yields from rice depend on maintaining constant flooding of fields. Both of these are being proven wrong by the experience with conservation agriculture and SRI. In both cases, higher production is being achieved with a reduction in most if not all inputs, contradicting the principle that to get more, you must invest more. This truism comes from the realm of industrial production, as for generations we have tried to “industrialize” agriculture. Yet, with a selective harnessing of biological processes and potentials, as seen not only with SRI and conservation agriculture, but also agroforestry, IPM, integrated nutrient management, and other ecologically-grounded approaches to agriculture, the sector is being reoriented to its biological origins. This is what ecoagriculture needs and encourages.

With a more biologically-based agriculture, intensification becomes feasible because it can be more economically productive as well as environmentally benign. By increasing production on areas that are suitable for such cultivation, the advantages of exploiting currently uncultivated areas should diminish, reducing threats to the future for wild biodiversity. We need to note, however, that intensification may be necessary but not sufficient for purposes of conservation. We need to avoid tradeoffs such as have been experienced in Brazil, where the introduction of low-tillage soybeans has caught on rapidly, leading to enhanced soil conservation and productivity on cultivated areas, but leading also to the centralization of ownership, with a corresponding migration of thousands of unemployed agricultural smallholders to less productive areas which were subsequently deforested (McNeely and Scherr 2002). This is why any evaluations need to take a systemic perspective, i.e., a “general equilibrium” analysis, not just a partial-equilibrium, *ceteris paribus* analysis, as discussed in Chapter 7.

6.14 Possible Contributions of Biotechnology

In thinking about ecoagricultural alternatives, we should consider what contribution, if any, biotechnology make to the conservation of biodiversity. Many claims are made to this effect. As a rule, advances in biotechnology have been attempted within the paradigm of the Green Revolution, seeking to *make inputs more productive* rather than to minimize dependence on external factors of production. Researchers have mostly looked for solutions that bypass natural system constraints rather than to work within them. This often neglects potentially beneficial natural system contributions that could be strengthened or reinforced

Future increases in crop yield will be beneficial if they also provide secondary benefits, such as greater suppression of weed growth due to direct competition by a robust crop. Great care must be taken to evaluate secondary effects of biotechnology, however, because risks can be increased. Critiques of genetic-modification (GM) technology have often turned not on the GM *per se* but on the effects of associated chemical inputs, such as the evaluation published by a committee of the Royal Society in the U.K. in October, 2003, which critiques adverse environmental impacts on biodiversity from the herbicides which Roundup-ready maize was engineered to tolerate.

Certain intensive and disruptive practices, e.g., glyphosate application to herbicide-resistant crop varieties, can facilitate the implementation of some resource-conserving agricultural practices, e.g., soil-conserving minimum-tillage practices, by overcoming certain limitations on productivity, in this instance, weed control.

Thus, blanket judgments about any particular category of practice are less tenable than more qualified, well-informed conclusions that address concrete situations and needs in their entirety. In general, it can be said that the sustainability of production can be greater with less adverse impact on biotic resources, by developing integrated cropping systems that rely upon cover cropping and crop rotation, for example, to maximize ecosystem contributions to fertility management and pest control. The use of chemical controls in such a situation is better regarded as an interim solution than a final one.

Care should be taken not to overexploit natural cycles that are most easily understood while neglecting important feedback effects that could tap broader ecosystem benefits such as disease resistance and sequestration of carbon. Providing ecosystem services through integrated management can protect soil health, downstream water sources, and the natural biota. There are multiple advantages from engaging endogenous biological cycles that support agricultural systems and practices so that reliance on exogenous inputs can be reduced, promoting healthier soils and more robust crops with concomitant economic profitability.

Given the large financial interests at stake with biotechnological development, the economic benefits to agrobusinesses are likely to remain a powerful force in future decision-making processes. Great care must be taken to ensure adequate scientific oversight and evaluation of proposed biotechnological solutions, and to try in all cases to promote the use of natural systems whenever possible. Otherwise, exploitation of the agricultural landscape without regard for the complexity of natural processes can lead to degraded systems and dwindling yields, ever more dependent upon external inputs, with increased potential for system collapse. This would have adverse effects not only for wild biodiversity but for human communities as well.

Ecoagricultural approaches appear to provide viable alternatives that are based upon scientific understanding and management of complex biological processes to promote more abundant crop yields, more sustainable resource use, and maintenance of wild biodiversity. However, biotechnological research could make a contribution by taking a broader view, rather than focusing just on fixing flaws with present practices. It cannot give up the reductionist and mechanistic methodologies that molecular biology requires. This is a strength whose limits are still not known. It is also a weakness whenever this focus is on single organisms without reference to what these organisms do to others and how they are in turn affected by others.

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Chapter 7

Integrating Agricultural Productivity, Biodiversity Conservation, and Livelihood Objectives

7.1. Introduction

The deliberate integration of wild biodiversity conservation objectives with agriculture and livelihood improvement goals distinguishes ecoagriculture from other land-use frameworks. Informed by the principle of ecological integrity,[1] ecoagriculture requires coordinated farm- and landscape-level strategies that accommodate the requirements of diverse assemblages of plant, animal and human populations. It will be impossible to accurately predict the effects of all the numerous interactions of interest within this complex sphere of ecological and human activity, in advance of launching an ecoagriculture initiative in a particular setting. Therefore, the implementation of ecoagriculture strategies will need to be *adaptive*, improved by learning through iterative planning, monitoring, and evaluation activities similar to what needs to be done in ecosystem management more generally (Walters and Holing 1990). To respond to this reality, it will be important to design ecoagriculture initiatives so that they can assimilate feedback and new information about the dynamic social and ecological conditions of the landscapes in which they are established.

The three general ecoagriculture strategies that McNeely and Scherr (2003) propose to make space for wildlife within agricultural landscapes[2] involve the management of biophysical and social processes at multiple geographic and temporal scales.[3] Planning, monitoring and evaluation of landscape-level initiatives needs to account for the *multiple scales* at which the various activities and processes occur. Ecoagriculture strategists need to find ways to link the *scale of management* with the *scale of the environmental issue* that is being addressed. It will be important therefore, to ground monitoring and evaluation schemes in "hierarchy theory," which maintains that to understand processes occurring at any particular scale, insights from *both the level above and the level below* are required (Campbell et al. 2001). In both planning and evaluation, information will be needed about the interactions that occur within and among systems that are functioning at these different scales.

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[1] *Ecological integrity "includes maintaining viable populations of native species, representation of ecosystem types across their natural range of variation, maintaining ecological processes, management over the long term, and accommodating human use within these constraints" (Grumbine 1996).*

[2] *The strategies associated with making space for wildlife within agricultural landscapes include: (i) creating biodiversity reserves that benefit local farming communities, (ii) developing habitat networks in nonfarmed areas, and (iii) reducing land conversion by increasing farm productivity (McNeely and Scherr 2003).*

[3] *For example, the different subsystems associated with modifications of soil, water and vegetative resources intended to enhance the habitat value of farmlands operate at different spatial and temporal scales. Soil management usually occurs at a smaller scale than that occupied by the production system of which it is a part. Yet the biophysical processes linked with soil health change faster than production-system-level processes (Izac 2003).*

This chapter addresses two central questions related to the potential for adaptive management of ecoagriculture strategies and initiatives:

i) What is known about landscape-level planning, monitoring and evaluation that can be applied to ecoagriculture to help translate the principles of the framework into practice; and

ii) How can the scientific knowledge that will be called upon to support the design and development of effective ecoagriculture practices be integrated into landscape planning and management frameworks?

Our aim here is to provide a basis for assessing current capacities to analyze and manage the highly integrative systems as required for successful ecoagriculture strategies, and for determining additional knowledge needs and corresponding research priorities in this arena. The chapter considers concepts and principles that are suitable for guiding multi-objective land use planning, monitoring and evaluation processes. Within this realm, it identifies frameworks, models and methods that have demonstrated some promise for integrating planning, science and management to promote ecologically and economically sustainable land use, including initiatives that link monitoring and evaluation with decision-making.

We begin with a brief overview of ecosystem-based approaches and discuss their relevance to ecoagriculture. We then review frameworks for planning, monitoring and evaluation that are conceptually consistent with these approaches.[4] We present distinguishing characteristics of selected methods that are applicable at different spatial and temporal scales, and how they may be used for integrative, adaptive collaborative management. Finally, we comment upon the challenges and areas needing further research in planning, monitoring, evaluation to support the effective management of integrative systems.

7.2. **Ecosystem-Based Approaches**

Recognizing the importance of interactions between different elements of a land-use system has led professionals from different disciplines to seek integrative approaches for understanding how and why landscapes are dynamic and ever-changing (Holling 1998). *Adaptive management* is a prominent translation of this understanding into practice. This approach frames problems in multidimensional contexts, extends analyses of natural resource systems beyond political boundaries, and examines interactions at multiple scales and across scales. Biological and social data, robust monitoring systems, and information feedback loops are built into this approach. Adaptive management treats human activity as part of the system and recognizes that learning is a social process. Accordingly, it fosters partnerships and provides for negotiation to meet both conservation and human needs.

Numerous factors stimulated the shift toward a landscape-scale, coupled framework for natural resource management that blends biological and human dimensions. Appreciation for the hierarchical, i.e., nested, interactions within a landscape underscores the need to preserve ecosystems so as to maintain valuable and vulnerable ecological processes (Izac 2003). The dynamic nature of ecosystems has made it evident also that complete information regarding any system will be unachievable (Holling 1998). However, recognizing the various subsystems within any ecosystem, and the myriad of interactions among them, can facilitate the examination of its functions and the identification of factors influencing change. This understanding was further reinforced by evidence of interactions among the social, political, economic, and ecological elements of the system (Vosti et al. 2002; Jagger and Pender 2003); the growing recognition that biophysical systems extend beyond political and property boundaries (Loomis 2002); and the orientation of new initiatives toward integrated objectives (Izac and Sanchez 1999).

Ecosystem-based approaches can certainly be applied to the sustainable management of agricultural lands. Research has revealed how natural and human elements of a landscape influence agricultural productivity (e.g., van Noordwijk 2002). Growing evidence of the impact of agriculture on biodiversity, and vice versa, and of the importance of agrobiodiversity in ecosystem functioning has underscored the realization that agriculture does not occur in isolation from its surroundings (Gleismann 1998; Brookfield 2001; Jackson and Jackson 2002).

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[4] *Some of the models discussed in this chapter have been highlighted in Chapter 5 already for their value in understanding tradeoffs between or among the three pillars of ecoagriculture.*

Therefore, accounting for interactions among the different elements within agricultural systems and between agricultural and non-agricultural systems is crucial to ensuring sustainable productivity.

7.2.1 **Adaptive Management**

Adaptive management uses policy interventions as “treatments” to test hypotheses about the effects they will have on ecosystem function and performance. Adaptive management emerged once it was accepted that knowledge of complex systems will always and invariably be incomplete. The approach is more than informed “trial-and-error” (Lee 1999). It uses the best available knowledge of the context and the system to generate “a risk-averse, ‘best guess’ management strategy” (Resilience Alliance 2004). As new information is generated, the “best guess” strategy gets revised. Adaptive management, therefore, emphasizes continuous learning and improving stakeholders’ understanding of a complex system as it evolves (Holling 1998; Salafsky et al. 2001). The adaptive approach gives new meanings to conservation strategies, making them “bioregional in scope and collaborative in governance, as well as adaptive in managerial perspective” (Lee 1999).

Conservation organizations agree that any framework for designing effective initiatives requires planning of both the actions and the monitoring and evaluation, then implementing both and analyzing data from these activities, using the results to revise and improve the initiative as experience unfolds (Conservation Measures Partnership 2003). It may be expected, for the sake of utilizing specialized expertise, that these responsibilities will be delegated to different agencies or actors. However, in the normal course of events, this will not produce integrated activities or much cumulative and corrected impact. Accordingly, the *integration of these roles* is as important as carrying out the respective activities themselves if management is to be truly adaptive.

7.2.2. **Adaptive Collaborative Management**

Ecoagriculture thinking derives from ecosystem management principles. One can anticipate that the application of these principles will transpire on large human-occupied landscapes that include stakeholders with varying values and frames of reference (Schelhas et al. 2001: xxv). Furthermore, the trend toward decentralization of decision-making for natural resource management (Agrawal 2002; Ribot 2002) and toward more diverse governance systems will expand the range of claims on resources and magnify the power dynamics associated with their control. Both latent and evident conflicts are likely to ensue, underscoring the need to facilitate joint understandings among actors and to negotiate concurrence on how best to proceed. This requires a greater degree and variety of participation by stakeholders than is usually provided for (and achieved) in conventional land-use planning and management processes.

Adaptive collaborative management (ACM) expands upon adaptive management to satisfy these conditions (Buck et al. 2001; Salafsky et al. 2001). ACM involves multi-stakeholder learning processes that do not follow a pre-determined course. It engages stakeholders in social learning through participation; considers mistakes, errors and/or failures to be sources of lessons and information; and uses different methods to generate knowledge that “keeps pace with ecosystem change resulting naturally or from expanding human activity” (Schelhas et al. 2001: xx). ACM identifies strategies for conserving biodiversity based on scientific knowledge in an adaptive management framework with participatory decision-making through a range of collaborative processes (Schelhas et al. 2001).

7.3 **Planning and Implementation Frameworks Consistent with Ecosystem-Based Approaches**

Ideal approaches to the planning, monitoring, and evaluating of ecoagriculture-based land-use systems would link, in an iterative manner, analytical models with planning and implementation frameworks that are consistent with ecosystem-based goals and approaches. Conceptually, these approaches would use the types of analytical models discussed in Section 5.3.1 to identify trade-offs among wild biodiversity conservation, agricultural productivity, and rural livelihoods. This information would feed into implementation frameworks and models for planning, monitoring and evaluating ecoagriculture land use, such as those described in this section. New findings from the planning, monitoring, and evaluation processes would, in turn, be used to update the analytical models and fuel successive iterations of analysis, planning, monitoring and evaluation.

Planning and implementation frameworks that are consistent with ecosystem-based approaches include spatially-explicit planning frameworks (Dolman et al. 2001; Hawkins and Selman 2002); frameworks that integrate planning, monitoring and evaluation (Campbell et al. 2001; Conservation Measures Partnership 2003); and systems-based monitoring and evaluation (Bellamy et al. 2001). Each of these frameworks has an analytical component embedded within it. The analytical models build on different combinations of the principles discussed in Chapters 3, 4 and 5 of this report. This section reviews characteristics of these frameworks that pertain most directly to the particular challenges and opportunities of ecoagricultural land-use approaches. The overlap among the different frameworks reflects a convergence in thinking about complex natural resource management issues. Annex 7A presents concrete applications of these frameworks in summary form.

7.3.1 **Spatially-Explicit Frameworks**

Spatially-explicit research and planning frameworks are crucial for conserving wild biodiversity within productive landscapes. These frameworks use biological and social science concepts and methods to model and map the characteristics of a specific system, exploring the impacts of changes at the macro- and micro-scale. They also engage stakeholders in designing land management strategies, in assessing the suitability of specific policies, and/or validating models.

A landscape is a heterogeneous area within which the units of analysis, evaluation and action can be denominated as "patches," basic units of land use that are relatively homogeneous (Liu and Taylor 2002). Its boundaries are set by some agreement among relevant actors that the units within it have enough interaction and interdependence that it is both illuminating and practical to consider the patches within this particular area concurrently and as a set rather than in association with some other set of patches. The functionality of a landscape is maintained through flows of matter, energy, and organisms across patches through processes such as migration and dispersal. Modeling the complex interactions within and among different ecosystems that together constitute a landscape, therefore, requires understanding the *flows* of biological and non-biological resources across it.

Spatially-explicit models use simulation and visualization tools to capture how changes in policy, regulations, demographics and/or land management practices alter characteristics of that landscape. For example, spatially-explicit modeling is central to the Gap Analysis Program (GAP), a nationwide effort in the United States to comprehensively inventory and computerize the kinds and geographic distributions of species of plants and animals that contribute to biodiversity (Smith 1998). Conservation scientists, economists and planners are using information from GAP to identify biodiversity hotspots and to assess the impacts of specific policies. In Europe, approaches that integrate landscape ecology measures, such as landscape stabilization and new landscape creation based on focal species, are being used (Hawkins and Selman 2002). How to integrate a participatory approach into these planning procedures is still evolving (Ford and McConnell 2001).

Quantitative simulation models such as those discussed in Section 5.3.1 are key components of spatially-explicit planning frameworks. These models define relationships among system components and can represent relevant changes across large geographic scales (and in some cases, temporal scales). Simulation models can be used to optimize land use as attempted in a watershed in the Lake Erhai basin of China (Wang et al. 2004). Or they can be used to develop scenarios and engage stakeholders in designing, validating and/or utilizing the outputs from models. In Sweden, for example, simulation models were used to identify optimal strategies for minimizing pollution of water bodies from agricultural practices (Arheimer et al. 2004). Information generated from the various steps in spatial planning can be used subsequently to refine the simulation model (Ellis et al. 2000).

Stakeholder participation in spatially-explicit planning varies as to timing and method. Decision-makers can help to define the starting conditions (Arheimer et al. 2004) or stakeholders can be involved to specify goals at the outset of the process, also shaping the set of acceptable combinations of policy changes and new management practices. Trade-off assessments have applied the latter approach (see Crissman et al. 2001, in Annex 5). Stakeholders can be involved, also, in validating the accuracy of the spatial model as exemplified by an effort to monitor land- cover change in Amazonia (Sydenstricker-Neto et al. 2004). Or they can select management options based on simulated outputs. In a spatially-explicit planning framework for sustainable rural livelihoods and land uses in Uganda, stakeholders interacted with researchers to define and evaluate alternate rural development pathways based on prior identification of feasible intervention opportunities (Bolwig et al. 2003). Regardless of when stakeholders become involved, effective facilitation by persons responsible for and skilled in encouraging dialogue and giving it shared meaning is critical to getting successful and encompassing participation. Facilitators must overcome obstructions to open and constructive interaction among the different actors.

Ecoagriculture strategies for creating wildlife habitat in agricultural landscapes will benefit from frameworks that encompass changes at large scales across different political and property boundaries. Spatially-explicit planning models can create the needed interface between research and practice while being accessible to stakeholders and using their input in the design and/or refinement of models. For ecoagricultural initiatives, the participatory component will need to be tailored to the temporal and geographical scales of particular initiatives, as well as to the unique and variable characteristics of the political system and stakeholders involved.

7.3.2 **Systems-Based Monitoring and Evaluation Framework**

Monitoring and evaluation of biodiversity conservation initiatives should begin at the start of a program and generate feedback into planning and implementation mechanisms (Conservation Measures Partnership 2003). When integrating conservation and development at multiple scales, processes of monitoring and evaluation must accommodate: (i) multiple scales of interactions and responses; (ii) the non-linearity and time lags in complex systems; (iii) multiple stakeholders' often contrasting objectives that make it difficult to identify common research and management aims and to sort out tradeoffs between them; (iv) the characteristics of the research site; and (v) the challenge of maintaining integration with numerous components and interactions (Campbell et al. 2001).

Bellamy et al. (2001) characterize a monitoring and evaluation system-based approach used in Australia that accounts for each of these factors. The approach evaluates natural resource management initiatives as a system that links the objectives and rationale of the program or policy with performance on the ground. The systems approach has to:

- assess public and private investment in integrated approaches to natural resource management;
- identify social, economic, institutional, environmental and technological factors that influence natural resource management initiatives;
- develop suitable performance criteria for assessing the potential impacts and influences of a resource management approach on institutional arrangements and society more broadly;
- identify the outcomes and expectations of an integrated resource management initiative; and
- establish guidelines and techniques for identifying progress toward agreed objectives and outcomes (Bellamy et al. 2001).

Bellamy et al. (2001) have developed the approach to evaluate a variety of natural resource management initiatives including a community-based Integrated Catchment Management process; a community-based resource information center; and a decision-support system for sustainable grazing management. These evaluations have been implemented and coordinated by a research organization together with other stakeholders. The approach of the Bellamy group appears particularly relevant to the challenges of ecoagriculture since it can be implemented at any scale, it engages stakeholders with diverse capacities and interests, and it is founded on rigorous scientific methodology.

7.3.3 **Frameworks that Integrate Planning, Monitoring and Evaluation**

Appreciating the need in natural resource management to blend hard and soft sciences (e.g., positivist and constructivist approaches) has led to an experimental-science approach to planning, monitoring and evaluation. Monitoring and evaluation are integrated with planning through the use of information gained through monitoring to refine or revise processes and objectives of planning. Adaptive management and ACM approaches, discussed above, are outcomes of this direction in thinking. The implementation of such approaches is challenging, however, and few efforts have completely embodied the key principles (Lee 1999).

The Conservation Measures Partnership (2003) is testing a framework for translating adaptive management into practice in the arena of biodiversity conservation. Annex 7-B expands on this and other partnership and network initiatives. The framework is applicable at any scale and to any set of actions, ranging from a single project or program to coordination among several programs and regional initiatives. The elements of the framework include:

- defining objectives that are relevant to a given context;
- planning both actions and their monitoring and evaluation;
- implementing the actions and their monitoring and evaluation;
- analyzing available data to evaluate the effectiveness of the activities;
- using these results to modify actions to maximize desired impacts;
- communicating the results to key external and internal audiences; and
- iterating the process with the objective of improving the actions (Conservation Measures Partnership 2003).

Principles that guide the whole framework include stakeholder involvement, a clearly defined timeline, and allocation of adequate financial resources and human capacity for each element.

Integrated planning, monitoring and evaluation frameworks use a variety of models to guide the selection of actions and analyses. Salafsky et al. (2002) maintain that the approach should be tailored to the conservation target and further that the underlying conceptual model employed be able to reveal direct threats, indirect threats and opportunities for meeting the goal. Scientists' and stakeholders' interests and perspectives will also inform the targets and objectives.[5] An ideal approach would have an in-built "learning program" that promotes systematic learning from the actions undertaken to determine how and why they contribute to specific conservation and development objectives (Salafsky and Margoluis 1999). The program is an iterative process that engenders continuous learning and improvement of outcomes.

Integrated planning, monitoring and evaluation frameworks require new processes for researching complex and coupled natural and human systems. Integrated natural resource management (INRM) is an example of innovative efforts designed to embed research in a multi-stakeholder learning process. INRM is oriented toward augmenting social, physical, human, natural and financial capital (CGIAR 2002). It involves orienting the objectives of research toward these ends, adding weight to participatory approaches for implementing research, using guiding principles for research that broaden the temporal and spatial scales of analysis, and using a variety of analytical tools (Sayer and Campbell 2001).

INRM brings together different forms of knowledge to identify the key problems from the relevant spatial and temporal scales and the underlying forces affecting them (Izac and Sanchez 1999). In INRM, interdisciplinary research identifies a range of economically viable land-use practices that rehabilitate and/or strengthen ecosystem function in agroecosystems. The trade-offs associated with the different land-use systems are reviewed, using inputs from stakeholders. It also uses research findings to examine trade-offs between perspectives and interests of different stakeholders and to shape partnerships (CGIAR 2002).

The Alternatives to Slash and Burn (ASB) program is an example of INRM research (see Annex 7-B). This

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[5] *Often there are multiple targets related to both conserving biodiversity and improving local welfare. In these cases, Salafsky et al. (2002) recommend developing separate conceptual models for each target.*

program uses interdisciplinary research to evaluate the performance of different land uses according to global environmental measures, agronomic sustainability, smallholders' socioeconomic interests, and policy and institutional measures. For example, in the Brazilian Amazon, ASB examined the adoption of four types of intensification and their economic and environmental impacts using a farm-level bioeconomic linear programming model. The study revealed that there is a trade-off between farm income and forest preserved as a result of the intensification of land uses on the cleared land. Of the four intensification types, intensification on forested land, i.e., low-impact forest management, slowed the deforestation rate, but did not stop it unless timber prices exceeded a certain value (Carpentier et al. 2000).

Integrated natural resource management embodies the principles of ACM by ensuring that: (i) management approaches are adaptive; (ii) INRM research is transferred into practice; and (iii) the approach provides for, and is based upon, negotiation among all stakeholders. INRM creates an interface between science and practice through its use of stakeholder knowledge in defining the main problems and constraints in the system. Associated with this process is empowerment of relevant stakeholders and addressing their conflicting interests (CGIAR 2002).

Approaches that integrate planning, monitoring and evaluation are being encouraged in community-based natural resource management (Baron 1998; Margoluis and Salafsky 1998; Johnson 1999).[6] Other efforts to integrate planning, monitoring and evaluation include the ecoregion-based planning process in Madagascar, which uses a collaborative process for identifying the actions and strategies for integrating biodiversity conservation and with livelihood enhancement (Cowles et al. 2001).[7] In Uganda, the implementation of a spatially-based planning framework for sustainable rural livelihoods and land use also incorporates monitoring and evaluation and creates an iterative process by which strategies for poverty alleviation and sustainable natural-resource-based development are adapted (Bolwig et al. 2003).

7.4 Planning, Monitoring, and Evaluating Ecoagriculture

Planning, monitoring and evaluation of ecoagricultural land use need to embody a constructivist perspective, being sensitive to cross-scale impacts of activities and interconnected with a systems perspective. Methods will need to be tailored always to the ecoagriculture strategy employed. Depending on the strategy of any particular initiative, different actors need to be brought together during various stages of the planning, monitoring and evaluation to collaborate and coordinate actions, and to exchange information and knowledge regarding elements of the system. In addition, feedback from these processes should inform learning and adaptation of the approach being used. The how and when of planning, monitoring and evaluation are important for learning about systems and improving practice (Douthwaite et al. 2002). The use of appropriate tools and techniques will assist in gaining a greater understanding of the system, more learning, and further improvement of appropriate strategies (Saterson et al. 1999).

7.4.1 Important Considerations

7.4.1.1 *Scale*

Considerations of scale should guide the planning, monitoring and evaluation of ecoagriculture initiatives even though it makes these activities more complex. Three relevant scale considerations have been distinguished: scaling-out, scaling-up, and spatial scaling-up.

- *Scaling-out* involves spreading innovation from farmer-to-farmer, community-to-community, and within the same stakeholder groups.
- *Scaling-up* results when there is institutional expansion from grassroots organizations to involve policy makers, donors, development institutions, and other stakeholders able to create an enabling environment for change.

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[6] *Community-based natural resource management is the management of natural resources under a detailed plan developed and agreed to by all concerned stakeholders. Communities are the primary implementers of the plan, with assistance and monitoring by external organizations (USAID 2000, as cited in CBNRM Net http://www. cbnrm.net/resources/terminology/cbnrm.html).*

[7] *The pilot phase of this effort was too brief to implement monitoring and evaluation.*

- *Spatial scaling-up* involves the widening of scale of operation from, for example, experimental plot to farm and to watershed (Douthwaite et al. 2003).

Scholars and practitioners of ecoagriculture need to be careful not to mismatch the scale of assessment with the scale of management as these are not always ideally the same, and to select and tailor tools accordingly (Cash and Moser 2000).

7.4.1.2 *Characterization of Landscapes*

Knowledge of the condition of agroecosystems and of the landscapes in which they are embedded is essential for the effective planning and evaluating of ecoagriculture-based initiatives. As a first step, the location and extent of current land uses need to be determined (Wood et al. 2000). A realistic characterization and classification of landscapes is needed to facilitate the planning of corridors and other habitat configurations for wild biodiversity and for the enhancement of ecosystem services that are important to local communities and wider areas.

Spatial information, discussed in Section 7.4.2.4, increasingly is used to characterize land cover. Classification and interpretation of spatial information makes clear the extent of different land uses including agriculture. It is common to find differences, however, in the extent of agricultural land use that is predicted by common global land-cover databases and higher-resolution spatial information (Wood et al. 2000). These discrepancies arise from under-reporting of agricultural area by satellite remote-sensing, due in part to this technology's inability to discriminate certain agricultural crops and pastures that appear similar to natural forests, woodlands and grasslands, and partly due to its limitations in identifying agriculture within landscapes where this is less than 30 percent of the land cover.

Efforts to plan and evaluate ecoagricultural land-use initiatives would benefit from more systematic characterization of landscape types for this purpose. The typology should capture both spatial and seasonal variations in vegetation cover and represent agriculture realistically, where it is not the dominant land cover.[8] The latter is important because landscapes in which cropped area is not dominant can make greater contributions to maintaining diverse wild biodiversity in the system through judicious use of technologies and landscape planning (Scherr 2004, pers. comm.).

7.4.1.3 *Criteria and Indicators*

The selection of suitable criteria and indicators for monitoring ecoagriculture will be challenging because there are multiple stakeholders, and they have often diverging interests. A participatory assessment process for identifying the indicators to use and what would be considered a favorable outcome can overcome some of these obstacles of differing interests (Campbell et al. 2001). Monitoring and evaluation approaches should employ techniques that create conducive conditions for stakeholders to engage in the definition of criteria and selection of indicators.

The criteria used will influence monitoring and evaluation findings, which in turn inform the selection of geographic areas for intervention, adaptation of interventions, and the associated learning (Perez and Tschinkel 2003). The selection of suitable criteria and indicators should be practical and scientifically justified. Criteria used by land managers and scientists may differ because of their different knowledge and understanding of the system (Oba and Kotila 2001). In such cases, it is important to facilitate the formulation of criteria and indicators jointly through the use of suitable decision-support techniques.

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[8] *Sebastian et al. (2000) have refined the characterization of landscapes to recognize the extent of agriculture in landscapes where it is not dominant, in part by distinguishing among three agricultural intensities. In this characterization, the agricultural-extent descriptions include: (i) agriculture-dominated landscapes, with more than 60 percent under agriculture; (ii) agriculture and natural vegetation mosaic, with 40-60 percent land under agriculture; (iii) landscapes with agriculture that is not a dominant class, with 30-40 percent under agriculture; and (iv) other vegetated land cover, with less than 30 percent under agriculture. McNeely and Scherr (2003) use a similar typology in their discussions of ecoagriculture. The typology being used distinguishes the following landscape types: (i) urban/agriculture dominated landscapes, with over 80 percent of land under crops or infrastructure; (ii) agriculture-dominated landscapes, with 60-80 percent of land under crops; (iii) agriculture-nature mosaics, with 30-60 percent of land under crops; and (iv) nature-dominated mosaics, with less than 30 percent of land under crops (Scherr 2004, pers. comm.).*

7.4.1.4 *Collaboration and Learning*

Translating ecoagriculture visions into reality will depend on sustained and effective collaboration between scientists of different disciplines, and among scholars, donors, policy makers, practitioners, land managers, and other key stakeholders. Stimulating collaboration, however, requires building trust, partnerships, and networks that minimize associated transaction costs and elicit collective action. Organizational support and suitable institutional arrangements for information exchange can enhance the creation of horizontal and vertical partnerships and networks. These in turn can facilitate the transfer of information, coordination of research and actions, and learning.

Negotiation will be important to reach collaborative arrangements, to address trade-offs associated with ecoagriculture, and to adapt strategies. Stakeholder groups engaged in negotiation will have different understandings of how their and others' actions influence outcomes and, accordingly, they will start with varying interpretations. Research and development organizations can provide tools to help facilitate stakeholder consultation and negotiation processes (van Noordwijk et al. 2001). The use of multiple tools and approaches to generate information and data in a manner that stakeholders consider reliable can contribute to dialogue and learning about the system and identification of suitable actions.

7.4.2 **Approaches and Tools**

Effective approaches and tools for guiding the development of ecoagriculture land use will integrate disciplinary and multidisciplinary variables, highlight key issues, create an interface between science and practice, and facilitate the design of intervention strategies. Techniques associated with conflict management, participatory action research, participatory research appraisal, facilitation, and negotiation will be invaluable. A few such approaches and tools are identified below, that can be useful in addressing the challenges of scale, uncertainty, learning, and coordination among multiple stakeholders. Annex 7-A presents additional information on these and related approaches and tools.

7.4.2.1 *Scenario-Based Methods*

Developing implementable visions for ecoagriculture in a particular landscape setting will require that multiple stakeholders be involved in strategizing. Scenario methods will be useful in facilitating this process. Scenario methods are a category of techniques associated with such "visioning" processes (Wollenberg et al. 2001). They can be used to help stimulate creative ways of thinking about alternative futures. These methods are suitable for planning when uncertainty and complexity are high. Future visioning can be used to reveal different perspectives regarding a situation and/or divergent interests. It can also provide a starting place for negotiation among preferences and for aggregation of different ideas. Future visioning can also foster learning if it is situated within a decision-making context.

To be used most effectively, scenario-based approaches should have clearly defined purposes and involve facilitators who have extensively researched the context and understand the feasibility of potential outcomes. The approach can be applied at any scale and in different contexts. However, the scale, context, and objectives will influence the specific selection of tools to be used. At a large landscape scale, for example, Geographic Information Systems (GIS) may be used to simulate conception and evaluations of different scenarios, as was the case in Oxfordshire, where GIS simulations were used to elicit farmers' perspectives on whole-landscape planning (Dolman et al. 2001).

7.4.2.2 *Decision-Support Systems*

Decision-support techniques can facilitate the selection and prioritization among multiple planning objectives as well as evaluation criteria. These techniques are based on systematic pair-wise comparisons and/or ranking of objectives and criteria by which land-use alternatives are evaluated. Examples of decision-support techniques include: analytic hierarchy processes and voting theory, multiple attribute utility approaches, and SWOT methods (assessing strengths, weaknesses, opportunities and threats) integrated with an analytic hierarchy process (Pesonen et al. 2001; Laukkanen et al. 2002; Prato 2003). In Finland, the Finnish Forest and Park Service (FFPS), which employs now a participatory planning process, tested a decision-support approach to establish priorities among different management scenarios in the state forests of Western Finland. An Analytical Hierarchy Process in Strengths Weaknesses, Opportunities, and Threats Analysis (A'WOT) was used to evaluate four alternative management strategies that met different land-use requirements in this area. The strategies allocated varying amounts of land among three different uses, recreation, habitat protection, and production. Using A'WOT, the strategy that allocated the most land to recreation received highest priority followed by the protection strategy (Pesonen et al. 2001).

Simple decision-support tools are helpful for aggregating the indicators of multiple monitoring criteria in an integrative manner. Possible mechanisms include creating simple additive indices, deriving compound variables using principle component analysis, or using canonical correlations to combine indicators across scales (Salafsky and Margoluis 1999; Campbell et al. 2001). For example, an additive index of capital asset indicators (created by adding together the values for natural capital, physical capital and financial capital) can be used to compare three different land management scenarios and determine which one generates the greatest asset value (Campbell et al. 2001). Radar diagrams and two-dimensional plots can also be used to visualize changes in indicators (Campbell et al. 2001). The selection of an appropriate mechanism should complement the objective for the monitoring and evaluation and the choices of data.

7.4.2.4 *Spatial Information Generation*

Remote-sensing tools, including satellite imagery and aerial photography, allow researchers or managers to collect spatially detailed information without direct physical contact (Liu and Taylor 2002). Satellite imagery is increasingly becoming affordable, and the resolution of images is improving greatly. Aerial imagery is also increasingly more affordable, and in some cases resolution is sufficient to eliminate the need for validation of information through field-based data collection (Kadyszewski 2004, pers. comm.). The accuracy of remote-sensing data is still variable and depends on spectral, spatial, temporal, and radiometric resolution (Degloria 2004, pers. comm.). Inaccurate interpretation of remote-sensing data can result in inappropriate recommendations regarding land use and natural resource management.

Geographic Information Systems have become important mechanisms for storing, manipulating, analyzing and integrating both spatial and non-spatial data (Liu and Taylor 2002). They are becoming widely used for planning purposes and increasingly in collaboration with land managers (Ford and McConnell 2001; Brown et al. 2002; Sedogo and Groten 2002; Parisi et al. 2003; Sydenstricker-Neto et al. 2004). The Florida Agroforestry Decision-Support System is an example of a spatially-explicit planning tool. It informs landowners and extension agents about the potentials of agroforestry for a particular area with certain features and guides the selection of appropriate tree or shrub species to be used in given local conditions (Ellis et al. 2000). The Threat Identification Model is another spatial tool for assessing agricultural land management sustainability at suitable land unit scales (Smith et al. 2000).

TAMARIN is an example of a spatially-explicit planning tool used to evaluate and compare economic compensation mechanisms for achieving specific biodiversity conservation goals by examining the landscape configurations resulting from a compensation scheme (Stoms et al. 2004).[9] This tool could be particularly useful in formulating and monitoring ecoagriculture strategies that develop habitat networks in non-farmed areas and create biodiversity reserves. TAMARIN currently is being piloted in the Atlantic rainforest of Brazil with government agencies, donors and non-government stakeholders (Stoms et al. 2004).

7.4.2.5. *Community-Based Data Collection*

Ecoagriculture strategies for making more space available for wildlife within agricultural landscapes require information about patterns of land use and interaction among elements in the landscape (McNeely and Scherr 2003). Planning, monitoring and evaluating these strategies requires methods that encompass research findings across large geographic scales and can manage multiple observations. In addition to remote-sensing, field-based mechanisms for data collection are crucial to validate spatial information and monitor biological changes at a large geographic and temporal scale.

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[9] *This model is reviewed in Annex 5.*

Citizen-based data collection is becoming a more widely accepted approach for obtaining social, biophysical, economic, and ecological information that can be used for scientific studies, policy analysis and advocacy (Fleming and Henkel 2001) Citizen-based data collection, or 'citizen science' as it is often called, is widely used in ornithological research and ecological monitoring (Alliance for Chesapeake Bay 2004; Cornell Lab of Ornithology 2004). Citizen science involves building community capacity to undertake monitoring, through a sequence of activity:

- enabling citizens to understand the measures that represent the health of their local environment;
- training individuals and groups interested in monitoring through a step-by-step process from learning what to monitor to how to do it;
- entering data in a distributed network and sharing them with others; and
- analyzing the data and taking appropriate next steps (Wildlife Habitat Canada 2004).

Citizen science can be used to obtain data on those variables for which data collection techniques are simple, standardized, transferable, and inexpensive, and which are rewarding to individuals. The approach can be used to collect field-level data across a wide geographic area and for an extended period of time. Citizen science approaches have been used in developing a biodiversity registrar in India and in monitoring water quality and fish populations in the Northwest United States (Gadgil et al. 2000; Alliance for Chesapeake Bay 2004).

7.4.2.6 *Integrative Knowledge Management*

Monitoring and evaluating ecoagriculture practices will benefit from knowledge-management techniques that facilitate relevant learning from these activities. Integrated System of Knowledge Management (ISKM) is an example of such an approach. ISKM uses workshops, interviews, visual representation of ideas (with software such as VENSIM) and community dialogue to facilitate communication among stakeholders and to stimulate collaborative planning (Bosch et al. 2003). Allen et al. (2001) apply this approach to bovine Tb vector management in North Canterbury, New Zealand. The authors worked with an advisory group in pest management composed of farmers, local government and pest management agency representatives. Information regarding ideal management was elicited from these actors and other stakeholders. This and other sources of information are managed via the Internet in a user-friendly format that allows for addition and extraction of new and relevant information (Allen et al. 2001).

7.5. Challenges and Future Directions

Efforts to successfully implement landscape-level visions for ecoagriculture will require deliberate goal-setting and strategy formulation. Integrated models of the system based on empirical evidence of relationships between biological and social dimensions, relating resource availability to stakeholder interests and capacities, should inform goal-setting. Strategy selection should be based on knowledge about the main threats to achieving the goals that is obtained from predicting, monitoring and evaluating the effectiveness of a particular strategy for mitigating threats to biodiversity and livelihood objectives.

We have described in this and previous chapters, various tools and approaches that may be used and/or modified to plan, monitor and evaluate efforts to achieve the multiple objectives of ecoagriculture in a certain setting. In bringing together information on different elements of the system, the methods should account for the importance of scale. Scale should be treated in an iterative manner, leading to nested processes of planning, monitoring and evaluation that rely on scale-sensitive information about activities and their effects.

7.5.1 Expected Difficulties

Adaptive, collaborative planning, monitoring, evaluation, and management, while theoretically grounded, are difficult to implement. Lack of conducive institutional and policy contexts for adaptive management, including divergent interpretations of its meaning and conflicting power differentials among prospective actors, are two key problems. In addition, incompatibilities between project-funding timeframes and the time required for institutionalizing an adaptive process, limited funding for applied interdisciplinary research, and data-intensive models, all create obstacles.

In ecoagriculture, the issue of scale generates additional challenges. Transferring information from one scale to another is not a linear process. Whether or not a process at one scale occurs at another scale depends on how the associated biophysical and social sub-processes change at the new spatial scale (van Noordwijk et al. 2001). Similarly, rules or relationships that are applicable at one scale may not transcend scales, and approaches "successful" at one scale may have a neutral or negative impact at another scale (Lovell et al. 2002). Van Noordwijk et al. (2001) have provided the example of erosion at the plot level resulting in impoverished soils in one place but enriching them in another, with relatively little soil actually being redistributed on a larger scale. For biodiversity, scaling-up is complicated because taxonomic or genetic diversity at any scale depends both on richness at a smaller scale and on the level of similarity between units at the same scale (van Noordwijk 2001).

A consequence of this scaling challenge is that stakeholders have available limited scientific information regarding interactions between different elements of complex land-use systems and biodiversity, especially at the landscape scale. Approaches and models used in planning, monitoring and evaluating integrated systems are often confined by the availability of data and resources, and by the need to make models tractable and valid. As a result, few models have incorporated the temporal element of systems or the dynamic nature of interactions within these systems which are needed to approximate real-world outcomes. Nevertheless, among the efforts that are in place, progress is being made to better understand relationships between causes and effects.

7.5.2 **Future Directions**

Ecoagriculture is confronted by a split between the philosophies, understanding and approach of the scientists and managers involved in wildlife conservation and those active with agriculture production. Forging sufficient common ground between these two cultures to initiate viable ecoagriculture plans and projects will put state-of-the-art collaboration and social-learning approaches to the test.

Partnerships and networks can engender collaboration among scientists of different disciplines and with other stakeholders. The last decade has witnessed the formation of new partnerships and network-based initiatives that are focused on integrating science and practice with a multidisciplinary orientation. Two broad categories of partnerships can be distinguished: (i) organizational partnerships and (ii) information dissemination, partnership-building and coordination networks. Organizational partnerships are composed of a well-defined group of non-governmental, governmental and/or research organizations that work collaboratively to address specific issues. An example is the recently formed Conservation Measures Partnership which is a joint venture of conservation NGOs and other collaborators who have come together to work on designing, managing and measuring impacts of their conservation-oriented activities.

In contrast, information dissemination, partnership-building and coordination networks are created around a broad area of concern. Networks are open to all interested parties, tend to be internet-based, provide a forum for exchanging information regarding current and future activities, coordinate research, and/or the building of new alliances. Networks can vary in character, depending on how structured they are and whether a facilitator is involved. The People Land Management and Ecosystem Services (PLEC) is a prominent example of a network that aims to identify, test and promote locally-developed, multi-objective land management practices. This and other examples of networks and partnerships that appear relevant to ecoagriculture are described in Annex 7B.

Ecoagriculture Partners, formed in 2002, serves to catalyze interactions among scientists of different disciplines and key stakeholders at multiple levels. It could be beneficial to the future of ecoagriculture if Ecoagriculture Partners were to support both an organizational partnership component and a network component. The organizational partnerships could be comprised of a well-defined group of organizations that would address key concerns or issues surrounding ecoagriculture practice and research. The network component would be a vehicle for disseminating information on research and practice in this area while stimulating information exchange, formation of new partnerships, and social learning. Key to its success will be transparency and participation (Bruce et al. 2002).

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ANNEX 7-A: A Summary of Planning, Monitoring and Evaluation Models for Integrating Multiple Objectives

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Scenario-Based Methods						
Arheimer et al. (2004)	Landscape Planning with Actor Game	Identify an effective way for reducing pollution from non-point source pollution	Landscape including multiple farms	Involve stakeholders in creating different management scenarios using the actor game. Use a quantitative model to simulate changes in pollution levels, using these different land management scenarios, and identify optimal management strategy.	Stakeholders are involved in defining the management scenarios and can see the future impact of these scenarios. This information, along with additional discussion, is used to identify an optimal management practice.	Arheimer et al (2004) applied this approach to a catchment in Southern Sweden. The scenario modeling revealed that possible modifications in agricultural practices (such as timing of fertilization and plowing, changed crop cultivation) could reduce the nitrogen load to the sea by some 30%, while wetland construction would only reduce the original load by approximately 5%. Therefore changes in agricultural practices can be the most effective and less expensive way to reduce nitrogen transport from land to the sea.
Dolman et al. (2001)	Whole Landscape Planning	Improve planning of farm lands for amenity, biodiversity and other environmental benefits	Landscape including multiple farms	Farmers provided information regarding management. This information is used to build scenarios developed along with surveys of biological and biophysical variables. Using visualization tools (3-D visualization and 2-D GIS maps of changes), scientists validate the relationships included in the model. Farmers are then invited to share their perspectives regarding different scenarios.	This approach does not have a dynamic interface. It uses information regarding practice to create the models, but there are not mechanisms for dialogue among stakeholders.	Dolman et al. (2001) pilot-tested this approach in Oxfordshire, UK. Future scenarios of integrated whole-landscape management were developed with different levels of amenity, environmental and biodiversity benefits. Of the different scenarios considered, the reactions to buffer strips round streams and field margin prescriptions were universally favorable. All the farmers were willing to enter into such arrangements if an appropriate compensation was provided. However, the majority wanted to see only select hedges and field margins altered. In contrast, the scenario involving restoration of wetlands, extensive grassland and seasonal flooding to formerly dry arable land within the floodplain was not as easily accepted because it involved significant changes in resource management.

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Wollenberg et al. (2001)	Future Scenarios	Identify or assess feasible decision options in natural resource management	Multiple scales	The process of constructing future scenarios involves: (i) defining the purpose of the scenario, (ii) collecting the necessary information regarding the system, its structure and drivers of change, (iii) generating the scenarios, and (iv) discussing and evaluating the scenarios.	Stakeholders are involved in generating and creating the scenarios, which can be linked with model or statistical forecasting methods as appropriate	
Decision-Support Systems						
Laukkanen et al. (2002)	Multicriteria Approval	Support group decisions associated with multiple-objective natural resource management and planning (in an objective manner)	Multiple scales	Multi-criteria approval involves multiple steps: (i) determine natural resource management alternatives and criteria by which alternatives will be compared, (ii) have decision-makers rank the criteria in terms of importance, and (iii) determine which alternative is favored for each criterion. For each step, can use different approaches, e.g., pair-wise comparison can be used for step (iii).	Decision-makers (and stakeholders) can be involved in determining the criteria and relevant alternatives. Research-based information or simulation models are used to determine how alternatives would perform according to these criteria.	In Finland, this approach was used to facilitate planning the management of a forest area co-owned by multiple owners. The owners had different, and in some cases, multiple objectives, including: timber production, preservation of scenic beauty, habitat preservation, biodiversity conservation, and wild berry yield. The multiple-criteria approval tool was used to select between 20 alternative forest plans for a 10-year planning period. Software was used to determine how the different plans performed according to measurable criteria. Two plans were selected through this process, one maximized net income and scenic beauty, the other maximized net income and berry yield (Laukkanen et al. 2002).

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Pesonen et al. (2001)	Analytical Hierarchy Process in Strengths Weaknesses, Opportunities and Threats Analysis (A' WOT)	Improve the quantitative basis of strategic planning processes	Multiple scales	A' WOT involves: (i) a SWOT analysis of the relevant factors identified in the internal and external environment of planning, (ii) a pair-wise comparison between factors in each SWOT group (i.e., strength, weakness, opportunity and threat), (iii) a pair-wise comparison between SWOT groups, and (iv) pair-wise comparison between alternative strategies subject to all SWOT factors.	Stakeholders can be involved in designing the strategies to be evaluated using A'WOT. They share their perceptions of the importance of different SWOT factors and groups. Research and existing knowledge are used to identify the relevant factors.	The Finnish Forest and Park Service (FFPS) has adopted a participatory planning process. In western Finland there are differing interests in the forest lands managed by FFPS. Citizens are most interested in recreation and nature protection, and the FFPS manages forest for wood production. A'WOT was used to evaluate four alternative strategies meeting land-use requirements in this area, with varying amounts of land allocated to the different uses. The strategy that allocated most land to recreation received highest priority followed by the 'protection strategy' (Pesonen et al., 2001).
Prato (2003)	Multiple Attribute Evaluation	Evaluate alternative management systems	Multiple scales	This approach involves identifying management objectives and alternatives, attributes of objectives, and assigning weights to these. For weights uses a hierarchical approach in which weights are first assigned to objectives and then the weight for each objective is allocated to the attributes that describe the objective. The attribute weights and values are combined in a utility function that is used to score the alternatives. Scores are used to rank alternatives.	Stakeholders compare alternatives based on their preferences for attributes. The value of the attributes under the different management alternatives is estimated using technical models (e.g., CENTURY model) or by using expert-based methods.	Prato (2003) used this approach to compare five management approaches developed by the Army Corps of Engineers for the Missouri River. He used hypothetical weighting schemes for ten attributes to evaluate the options. Utility scores for the alternatives were obtained using a linear additive utility function. These scores indicated that the modified conservation plan, one that incorporates adaptive management with increased drought-prevention measures, changes in dam releases and unbalanced levels in the upper three reservoirs, was preferred to the current water control plan with the neutral, pro-recreation/fish and wildlife, and pro-fish and wildlife weights.

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Approaches for Community-Based Data Collection						
Alliance of Chesapeake Bay (2004); Cornell Lab of Ornithology, (2004); Wildlife Habitat Canada, (2004)	Citizen Science	Monitor biological factors in defined ecosystems	Multiple scales: local watershed to eco-region	Involve citizen volunteers in monitoring of biological factors using pre-designed tools and guides for monitoring.	Data collected via citizen monitoring are used by scientists to understand patterns of change in natural resources. The findings are made available to a broad audience to stimulate learning of the ongoing natural resource and biological processes.	The Alliance Citizen Monitoring program is a regional network of trained volunteers who perform weekly water-quality tests. The information is used to track the condition of waters flowing toward the Chesapeake Bay. The Cornell Lab of Ornithology uses data collected from citizen monitors to monitor bird populations, migrations, behavior, and disease. Wildlife Habitat Canada uses citizen monitors regarding the status of streams, wildlife populations and invasive species.
Gadgil et al. (2000)	People's Biodiversity Register	Document the status of biodiversity	Multiple scales: local to regional	Engage local communities, interviewing key informants and groups, map the study site landscape; visit representative elements of this landscape with key individuals; discuss resource use at the study area with villagers and outsiders familiar with the resource base.	This approach empowers local communities by valuing their traditional knowledge for comprehending changes in natural systems.	During 1996–1998, 52 People's Biodiversity Registers were prepared from village clusters distributed in eight states and union territories of India, representing a broad range of ecological and social regimes. These registers revealed a generally declining productivity and diversity of living resources outside of intensively-managed ecosystems. They also documented a gradual disappearance of practical ecological knowledge and erosion of traditions of sustainable use and conservation.

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Approaches for Knowledge Management and Stimulating Collaborative Learning						
Allen et al. (2001)	Integrated System of Knowledge Management (ISKM)	Improve information exchange among stakeholders (can be regarding specific issues or more broad considerations.	Multiple scales	Multiple stakeholders are involved. Their involvement starts from the beginning (defining scope) and is maintained through the whole process. Create a user-friendly internet-based interface for information exchange as part of the information exchange and management.	Practice informs the research priorities. Also the scientific information and the practice-based knowledge are used together in decision-making.	Allen et al (2001) apply this approach to bovine Tb vector management in North Canterbury, New Zealand. They work with an existing advisory group in pest management composed of farmers, local government and pest management agency representatives. Information regarding ideal management is elicited from the stakeholders. This information, along with other sources, is managed via the Internet in a user-friendly format that allows for addition and extraction of new and relevant information.
Bosch et al. (2003)	Integrated System of Knowledge Management (ISKM)	Integrate science and management by improving understanding between scientists and managers	Multiple scales	Workshops, interviews, visual representations of ideas (using VENSIM), and community dialogue for collaborative planning. The information is used to facilitate dialogue among stakeholders who are crucial to problem-solving in this approach.	A key dimension of this process is adaptive management and ongoing knowledge-building. This approach is based on the principles of experiential learning and systems thinking. It is cyclical and iterative.	Bosch et al (2003) deal with weed management in New Zealand using a systems framework. They facilitate community dialogue and access local and scientific information to identify best management practices. They use the internet to manage and allow information exchange. The same authors, in another example, use VENSIM and INFLUENCE software to show commonalities and differences in stakeholders' understanding of hydrological issues, and use this as a starting point for dialogue.
Sheil et al. (2002)	Multidisciplinary Landscape Assessment	Generate information that can be used to make better decisions regarding resource management	Multiple villages	Community meeting; community mapping; community-based data collection; transects; ethnoecology; GIS. The community is involved in conducting research, as field guides and for local information. These inputs are used to guide later stages.	Use local knowledge regarding uses of forest resources, and scientific knowledge regarding other resources, together for better resource management.	This effort is ongoing in Indonesia.

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Approaches and Tools for Landscape Level Planning						
Bentrup and Leininger (2002)	Agroforestry Mapping	Determine the best location to grow certain species in agroforestry systems	Multi-county, sub-watershed	GIS, with spatially-explicit soil, weather and slope/aspect information, and species requirements.	The conditions for growing certain species are known from practice and research. The selection of species to cultivate in agroforestry systems uses market information.	Bentrup and Leininger (2002) use this approach to determine suitability of agroforestry systems using both single species and multiple species in Nebraska. They found that decorative willows will tolerate most soils, while only a few areas in south eastern Nebraska are suitable for growing mushrooms, medicinal herbs and other high-value specialty products.
Brown et al. (2002)	Interactive Distributed Conservation Planning	Facilitate information exchange among stakeholders in process	Multiple scales	Identify the data that conservation planners require; then develop a prototype to bring these spatial data to planners over the web. This tool was built on an interactive GIS format. The key is providing the information at the right scale. Aerial photography images could be helpful. Can have web-based modules into which higher resolution information is entered (e.g., regarding a specific field) and can generate information that is of relevance to planners (e.g., soil erosion, etc.).	Information from the GIS tool can be used to identify high-risk areas, and then planners can focus on human activities and best management practices to address the problem. These areas would need to be assisted through extension, education and awareness-raising programs, and outreach efforts.	This project was conducted in the United States, specifically in Michigan, linked with federal/state programs.
Ellis et al. (2000)	Florida Agroforestry Decision Support System	Determine the potential for specific agroforestry systems and species	Multiple scales	GIS integrated with soil and climate information, and combined with a plant database.	Practice and research are used to identify suitable conditions for species. Queries are used to identify the suitability of agroforestry and specific species.	

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Ford and McConnell (2001)	Geomatics and Participation Approach	Facilitate community-based conservation planning	Local to regional	Low-cost air photography and computer-mapping technology, facilitation of dialogue.	The community uses the aerial photography to discuss various different land uses for village-based land-use planning, seeking to integrate their objectives into the regional co-management plan.	Geomatics was used in the fourth phase of a five- phase participatory planning process in Madagascar around Mantadia National Park. The geomatic images provided a basis for discussion in the village-based land-use planning and resulted in the creation of four new 'user groups' in the buffer zone. It was also agreed in the co-management plan of the national park that 50 percent of park revenues would be invested in joint development projects. and that people would not expand their slash-and-burn activities any further into the park.
Parisi et al. (2003)	GIS integrated with Environmental Protection Agency's Better Assessment Science Integrating Point and Nonpoint Sources (EPA-BASIN)	Integrate information on the human dimensions of land use patterns	Watershed	GIS is used to provide information regarding the locality of human settlement, the level of social capital, the economic capacity of the community, and demographic characteristics.	Incorporation of human information shows differences in human relationships with natural resources given the characteristics of the community from the demographic and economic information incorporated. These differences in relationships between people and their environment need to be considered in water management policy-making.	This approach was applied to the Upper Pearl River Basin in Mississippi, revealing differences between communities situated in the upstream watershed and those living in the downstream watershed. Communities in the former were more rural-oriented, had lower levels of human capital, smaller labor forces, higher unemployment rates, higher poverty rates, and the local economies were predominantly based on extractive industries (agriculture, mining, forestry, and fishing) compared to those in the downstream watershed.

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Sedogo and Groten (2002)	Geoinformation Approach	Integrate local participatory land management in regional planning with GIS	Local to regional	GIS, local PRA surveys, structured systems approach (for integration of the data). Users' perceptions help to inform a conceptual model of system.	Biophysical information available as GIS layers is integrated with stakeholder information regarding practice.	This approach was applied in Burkina Faso, where local-level data and regional data were integrated in GIS. Using the information collected via PRAs at the local level, different orientations can be given to the regional planning process. For example, local- level information reveals that almost half of the province where the study is conducted is facing either a potential labor shortage for implementing land management activities or potential local-to-regional planning conflicts. Less than 25% are facing both constraints. Building on these results, regional planners can explore different scenarios to support local plans.
Smith et al. (2000)	Threat Identification Model	Assess the unsustainability of agricultural land management *ex ante*	Multiple scales	(i) Identify and rate potential hazards to land-use sustainability (e.g., to productivity), (ii) identify land management options available to land users, (iii) identify the relationship between these land management practices and hazards, (iv) rate the suitability of land management practice on land units based on previous information, and (v) identify potential secondary hazards to sustainability from the practice. This is done by linking a relational database (e.g., Microsoft Access) to GIS	Information from this model improves land-use planning as compared to the traditional land evaluation approach. *Ex ante* information regarding the land-degradation hazards can assist in modifying practices and adopting more suitable land-management options. This approach requires information pertaining to the relationships between land management practices and land-degradation hazards, as well as on the reversibility of hazards.	The model was tested in North Queensland, Australia, using the case of sugar growers in the area. According to the TIM, if the most common land-management practices used for sugar production in the sub-catchment were implemented on the example land units, land degradation (soil structural decline, soil erosion, soil organic matter decline, reduced soil water retention) would be likely. To maintain the sustainability of the farm, the farmer should identify alternatives to disc plowing and disc harrowing, using trucks in harvesting operations, and cultivating differently to achieve pest, weed and disease control.

Source	Name of Approach/ Tool	Application	Scale	Approach Involved and/or Tools Used	Research-Practice Interface	Outcome of Application
Sydenstricker-Neto et al. (2004)	Participatory Reference Data Collection	Determine land cover change in colonization area; engage community stakeholders in processes of mapping and in assessing the accuracy of maps, and in evaluating relevance of maps for understanding community-based land use dynamics.	Large forest area	Start with digital images from satellites. For the reference data collection, field data are collected by local individuals to assist in the development of spectral models of each land cover type for image classification, and interviews.	The visual map engenders discussion and awareness regarding land cover changes. Farmers' realization regarding the land cover changes over time stimulates debate on the incentives for forest conversion versus the constraints imposed by the agricultural systems adopted by farmers.	This approach was applied in a large colonization area of Amazonia, Brazil. The accuracy of land cover classes was between 85 and 89 percent. Another outcome was farmer empowerment. Farmers gained a greater appreciation for the development patterns that they were not aware of. Also, they felt that a deeper understanding of what was happening in their area would enable them to better respond to local needs and contribute to state-wide discussions on promoting environmental sustainability.
Wang et al. (2004)	Integrated GIS and Optimization Modeling	Allocate land spatially to optimize land use	Watershed	GIS integrated with optimization model.	This approach presents a scientific approach to formulating policies and strategies of environmental management. Interpretation of the environmental planning results can be used as a policy-support document for government authorities and industries that have direct or indirect connections to land development and water- quality management.	Wang et al. (2004) applied this approach in the Lake Erhai basin of China. According to the optimization results, the land use expansion includes paddy farming by 1.561 km2, vegetable farming by 0.037 km2 and forest by 13.948 km2. The land uses to be reduced included dry land farming by 1.110 km2, industry by 0.001 km2, and barren land by 14.435 km2. GIS is used to determine where these changes should be made in the landscape. For example, in the case of sub-area 1, the GIS-optimization model recommends a reduction of industrial and dry-land farming uses and the expansion of paddy and vegetable farming area.

ANNEX 7-B: Examples of Partnerships and Network Organizations Supporting Ecoagriculture

Name	Objective	Geographic Coverage	URL
Organizational Partnerships			
Millennium Ecosystem Assessment (MA)	The Millennium Ecosystem Assessment (MA) is an international program designed to meet the needs of decision makers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes. The MA focuses on ecosystem services (the benefits that people obtain from ecosystems), how changes in ecosystem services have affected human well-being, how ecosystem changes may affect people in future decades, and response options that might be adopted at local, national or global scales to improve ecosystem management and thereby contribute to human well-being and poverty alleviation. The assessments are done by scientists in national and international research organizations. MA uses the web to exchange information, is product-oriented, and the activities associated with the assessment will be repeated every five years.	Global	http://www.millenniumassessment.org/en/index.aspx
Alternatives to Slash-and-Burn (ASB)	ASB is a global partnership of over 50 institutions with a shared interest in conserving forests and reducing poverty in the humid tropics. ASB was founded in 1994 as a system-wide program of the Consultative Group on International Agricultural Research (CGIAR) with the objective of mitigating destructive shifting cultivation by addressing the underlying social and ecological causes and reducing damage to forests by promoting sustainable management of areas adjacent to the forests. ASB is convened by the Nairobi-based World Agroforestry Centre (ICRAF) and is governed by a global steering group of 12 representatives from participating institutions.	Brazil, Cameroon, Indonesia	http://www.asb.cgiar.org/home.htm
IUCN Sustainable Use Initiative (USI)	The Sustainable Use Initiative is a global technical effort to increase knowledge and understanding of factors that influence the sustainability of natural resource use. The initiative is made up of 16 decentralized networks of regional Sustainable Use Specialist Groups (SUSGs). The SUSG mission is to promote conservation of biodiversity and alleviate poverty by: (i) improving understanding of social and biological factors that enhance sustainable use of wild living resources, (ii) promoting understanding to IUCN's members and decision-makers and others, and (iii) assisting IUCN members, partner organizations and government in applying this understanding. These groups are made up of practitioners who analyze and compare local use systems through case studies, regional re-	Global	http://www.iucn.org/themes/ssc/susg/sui.html

Name	Objective	Geographic Coverage	URL
	views, workshops and symposia.		
Program on Forests (PROFOR)	PROFOR is a multi-donor partnership formed to pursue a shared goal of enhancing forests' contribution to poverty reduction, sustainable development, and protection of environmental services. Through improved knowledge and approaches for sustainable forest management (SFM), PROFOR seeks to encourage the transition to a more socially and environmentally sustainable forest sector supported by sound policies and institutions that take a holistic approach to forest conservation and management. PROFOR fosters such policies and institutions through support to participatory processes, such as national forest programs, and knowledge generation in four key thematic areas: forest governance, forests' contribution to livelihoods of the rural poor, mitigation of adverse cross-sectoral impacts on forests, and innovative approaches to financing SFM.	Global	http://www.profor.info/
Conservation Measures Partnership (CMP)	The Conservation Measures Partnership (CMP) is a joint venture of conservation NGOs and other collaborators who have come together to work on issues related to impact assessment and accountability in an effort to find better ways to design, manage and measure the impact of their conservation actions. CMP's mission is to improve the practice of biodiversity conservation by developing and promoting common standards and an auditing mechanism for the process of conservation and measuring conservation impact. Each organization within CMP has biodiversity conservation as its primary goal, focuses on field-based conservation actions, and is working to develop better approaches to project design, management and assessment. The core members of CMP include African Wildlife Foundation, Conservation International, The Nature Conservancy, Wildlife Conservation Society, and the World Wildlife Fund. Collaborating organizations include Enterprise Works Worldwide, World Commission on Protected Areas/IUCN, and Foundations of Success. FOS serves as the CMP coordinator, carrying out the day-to-day management of CMP and facilitating the completion of various technical projects.	Global	not available

Name	Objective	Geographic Coverage	URL
System for Analysis, Research and Training (START)	START establishes and fosters regional networks of collaborating scientists and institutions in developing countries. The networks conduct research on regional aspects of environmental change, assess the impacts and vulnerabilities resulting from these changes, and provide information to policy-makers. START acts to enhance the scientific capacity of developing countries to address the complex process of environmental change and degradation through a wide variety of training and career development programs.	Global	http://www.start.org/
Networks for Information Dissemination, Partnership Formation, Social Learning, and Coordination			
Collective Action and Property Rights (CAPRi)	CAPRi is a web-based network that disseminates information among researchers, practitioners and other individuals. It fosters research and promotes collaboration on institutional aspects of natural resource management between Future Harvest Centers, National Agricultural Research Institutes, and others. CAPRi intends to contribute to policies and practices that alleviate rural poverty by analyzing and disseminating knowledge on the ways that collective action and property rights institutions influence the efficiency, equity, and sustainability of natural resource use.	Global	http://www.capri.cgiar.org/
USAID-based Network of Resources for Africa (FRAME)	FRAME is a community of experts and practitioners active in the management of Africa's natural resources. It is also a knowledge-based tool that shares this community's lessons, best practices, and solutions. FRAME creates an opportunity for analysts and decision-makers to think strategically about environmental and natural resource management issues as they relate to the challenge of sustainable development in Africa. It builds a dynamic that brings together people who rarely interact, catalyzing new working relationships that facilitate the exchange of information and broadening of perspectives. FRAME is designed to facilitate the increased use of up-to-date information by environment/NRM decision-makers and practitioners as they analyze issues, plan strategically, and advocate their positions. FRAME seeks to generate and provide information (from within and outside Africa) to help answer strategic questions facing environment and natural resources management in Africa: (i) What are the key environmental and natural resource management issues confronting Africa? (ii) Where are people addressing these issues in innovative and effective ways? (iii) What factors helped people achieve this progress? And (iv) What will it take to achieve broad-based changes in the management of the environment and natural resources which are required to support sustainable development in Africa?	Africa	http://www.frameweb.org

Name	Objective	Geographic Coverage	URL
People, Land Management, and Ecosystem Services (PLEC)	PLEC aims to identify, test and promote locally developed management practices that: (i) combine traditional knowledge and approaches with new knowledge and technologies; and (ii) embrace ecosystem functions and processes for enhancing livelihoods, principally through optimal degree of structural, spatial, temporal, trophic, species and genetic diversity. The project involves local farmers and scientists in setting up demonstration sites in critical ecosystems and areas of globally significant biodiversity. The PLEC network uniquely provides for South-to-South cooperation and South-to-North arrangements. The project is organized into a network of locally-based clusters and representatively-diverse regions that have been established in Africa (Ghana, Guinea, Kenya, Tanzania, Uganda), Asia-Pacific (China, Thailand, Papua New Guinea), and Latin America (Brazil, Jamaica, Peru, Mexico) with participation of scientists from the North (currently United States, Japan, Australia, and Britain). Each cluster is multidisciplinary, based in a national organization in collaboration with several institutions.	Global	http://www.unu.edu/env/plec/index.htm
International Sustainability Indicators Network (ISIN)	The International Sustainability Indicators Network is a member-driven organization that provides people working on sustainability indicators with a method of communicating with and learning from each other. Through listserv discussions, virtual and in-person meetings, and special programs and trainings, the Network facilitates shared learning and development among sustainability indicators practitioners and others. This website also has links to ongoing efforts to set up indicators.	USA	http://www.sustainabilityindicators.org
Sustainable Communities	This is an electronic newsletter that has information for community based programs/activities/ efforts to protect and manage resources. Community involvement in natural resource management is a major area of focus. This section presents various approaches and techniques used successfully in different communities to protect and restore their natural resources. Under each of the resources (biodiversity, land and agriculture, water, etc.) there is a list of institutions that are working on the issue and also a few case studies and recommended reading. The objective of this network is to widely disseminate information regarding various approaches and techniques successfully used by different communities to protect and restore their natural resources.	USA	http://www.sustainable.org

Chapter 8

Conclusions

8.1 Biodiversity Contributions

The concept of ecoagriculture as a multi-objective land-use strategy that can deliver agricultural productivity, livelihood support and biodiversity conservation benefits at farm and landscape levels has a foundation in scientific knowledge and understanding. This assessment has found that there is considerable evidence, some of it rigorously quantified, that a variety of agricultural practices throughout the world provide habitat for locally and globally important species of wildlife at the same time they produce food and other benefits, including livelihood creation. Practices that deliver habitat benefits most consistently to the broadest spectrum of taxa, according to our analysis of a sample of studies from the recent literature, are hedgerows and woodlots adjacent to farm fields, organic production systems, and shaded tropical tree crops, especially coffee and cacao (Chapter 4).

From many of the studies examined, it can also be inferred that "biodiversity-friendly" agricultural practices were also delivering substantial livelihood support. However, few studies addressed this aspect directly, and thus they offered little insight or evidence on how socioeconomically viable or how sustainable the practices being evaluated may be. This is an important limitation to much of the biophysical literature, and one that should be addressed to strengthen the scientific underpinnings of ecoagricultural land use in the future.

Our assessment has identified and characterized a variety of agricultural production approaches that are consistent with the premises of ecoagriculture and that illustrate the potential for "positive-sum" relationships between agricultural productivity and ecosystem functions. Evidence for achieving synergistic relationships through effective management of interactions among biological components of agricultural production systems is found in the literature on agroforestry, agrobiodiversity conservation and utilization, conservation tillage, organic production systems, systems approaches to pest management, integrated nutrient management, soil health, below-ground biodiversity in agricultural systems, management of the hydrological cycle, and the system of rice intensificationBiological dynamics give ecoagriculture a chance, even with low external inputs, to achieve reasonably high levels of productivity and to be economically profitable. Further, synergies are possible between agrobiodiversity and wild biodiversity especially considering the dynamics of ecosystems underground. What is not known, given limited experience with ecoagriculture practices and even less with evaluation research, is how far these emerging approaches can be developed to improve upon, or become an alternative to conventional agriculture, and in what and how many places.

8.2 Agricultural Sector Contributions

Four conclusions can be drawn from our review of agricultural literature and experience. First, there are substantial *opportunities* for agriculture in the future to become more productive, profitable, sustainable and environmentally friendly by relying more on energy and nutrients made available through biological processes. These processes can be favorably affected by making changes in management practices for soil, water, plants, animals, and nutrients. This trend will not replace all use of chemical amendments, but the presumption appears to be shifting from chemicals *substituting for* or *compensating for* biology, to chemicals *supplementing* biology. This is the direction in which we see 21st century agriculture moving. Ecoagriculture to be successful and to spread will need to have strong foundations in agricultural science and practice that are both "good agriculture" and "good ecological stewardship."

Second, two of the longest-held and most firmly believed precepts in agriculture—that *plowing* is required for crop cultivation and best results, and that *continuous flooding* of rice paddies is necessary for the highest production—are being proven wrong by experience with conservation agriculture and the System of Rice Intensification. These methodologies are getting very beneficial, cost-effective results by changing the way that plants, soil, water and nutrients are managed. The reasons for this are fully explainable by what is already known and accepted within the crop and soil sciences, but an old paradigm of production has often kept scientists and practitioners from seeing and accepting the new opportunities when first presented, even evoking strong resistance at first. We do not know in how many other respects conventional wisdom subtly incorporated into science is limiting future opportunities that would be supportive of ecoagriculture.

Third, *biotechnology* is opening up many new possibilities, but so far it has been applied mostly within existing Green-Revolution production paradigms, not being connected to the emerging agroecological paradigm which focuses on *ensembles* of organisms and on their *interactions* rather than on *species in isolation*. USDA research reported in Chapter 3 (Kumar et al. 2004) shows how the most advanced techniques for genetic analysis can be used to illuminate how changing plants' environmental conditions, particularly in the rhizosphere, can give better results, higher production and more tolerance to disease. It does this by identifying which genes express themselves differently and trigger different physiological processes and responses when, in this case, a leguminous mulch was used with less urea, compared with plastic mulch and higher N fertilization. The organic agriculture adage that instead of "feeding the plant" we should "feed the soil and the soil will feed the plant" is gaining scientific respectability. These are complicated processes, and scientific knowledge is still accumulating, not final, while some of what we now know is being unlearned. Linking biotechnology and agroecology, with special interest in soil biology and ecology, including more study of plant roots and the rhizosphere, is a promising new frontier (*Science* June 11, 2004) that would benefit ecoagriculture.

Lastly, farming systems research has progressed to produce more scientifically informed analyses and recommendations for farming systems such as agroforestry and crop rotation that capitalize on biological processes and potentials and become cost-saving, more profitable and environmentally benign. A present constraint on such systems is often their *labor-intensity*, as they often require additional labor inputs that may not be available at prevailing wage rates or within the household. Work is underway modifying many systems to account for this constraint, and labor intensity has the benefit of creating employment and livelihood opportunities. But it remains an important constraint. How much of a constraint labor-intensity is will depend in large part on what happens to *labor productivity*. New practices and farming systems that raise the productivity of labor, as well as other resources, will become attractive and certainly gain acceptance. Ecoagriculture will not succeed if it is labor-intensive without giving farmers and agricultural sectors higher *total factor productivity*, including greater labor productivity. This is a tall order, but current scientific knowledge and practical experience suggest that it is feasible in many cases.

8.3 Livelihood Contributions

Our review of the literature on economic and livelihood considerations has yielded several conclusions relevant to the socio-economic dimensions of research relevant to ecoagriculture. To begin, ecoagriculture is inherently a *multi-objective strategy* in which livelihood generation must be achieved simultaneous with crop productivity and biodiversity conservation. This means that evaluating the multi-dimensional outcomes of empirical research is central to evaluating ecoagriculture strategies; yet, in fact, most relevant research to date has yielded results and outcomes that are partial in nature, only infrequently addressing all three dimensions of ecoagriculture. This makes it difficult at present to assess comprehensively the tradeoffs and complementarities that arise in ecoagriculture strategies because the relevant research is so sparse. Rigorously and comprehensively addressing the research challenges introduced by ecoagriculture in enough real-world contexts to frame generalizable conclusions about its viability will require a much more concerted approach among researchers to broaden their analytical frameworks and outcomes.

Second, in the limited instances where multi-dimensional results are rigorously derived and available, the research suggests that *tradeoffs are at least as common* *as synergies* in accounting for the relationships among production, livelihood, and biodiversity objectives. In other words, achieving results with respect to one objective—whether higher crop production or productivity, or enhanced household livelihoods, or preserving biodiversity—more often than not comes at the expense of one or more of the other objectives. This is not compatible with what ecoagricultural strategies seek. We have raised, but certainly not answered, the closely related question of "separation versus integration" which is also highly relevant in this context. To the extent that situations exist where production, livelihood, and biodiversity objectives can be equally (or better) achieved in spatially distinct contexts, then the central premise underlying ecoagriculture may be flawed in these cases. Given that the research record on all of these issues is sparse, it will be necessary to expand not only the scope of relevant research but the specific applications (geographic, systems, scale, etc.) in order to derive a better sense as to the conditions (economic, biological, climatic, etc.) under which specific ecoagricultural strategies may be expected to thrive and succeed.

Third, one of the central notions behind ecoagriculture is that of addressing *externalities*—including but not limited to biodiversity preservation—that may be inadequately or ineffectively reflected in current private resource-use decisions. As we have seen, much of the current interest in valuing ecosystem services is based on the idea of incorporating previously ignored externalities into private decision-making by attempting to value the underlying services that have previously been treated as public goods, often resulting in resource overuse, degradation, and unacceptable social costs. Whether ecoagriculture is in the long-run successful in helping preserve biodiversity will depend on better success than has been achieved to date in valuing these and other ecosystem services and developing replicable, institutionally sustainable, adequately funded, incentive-compatible programs that can adequately address issues of externalities.

Finally, it is important to mention a broader point regarding *scale, "scaling up," and aggregation* that has not been explicitly elaborated in this report. Much relevant research pertaining to ecoagriculture, if not directly labeled as such, has been conducted at the farm, household, or community level, at most the sub-watershed level. This is understandable, and results from many reasons: the core interests of many researchers and development practitioners in conducting micro-level research; the complexity of farms and households and the decision-making underlying these units; the relative expense and analytical complexity of conducting research at more aggregative levels; and so forth. But the focus on micro-level research often fails to incorporate effects that may be only realized at a broader scale, yet which may become critical to decision-making in farms and households.

For example, much of marketed farm production in any country goes toward feeding urban residents. But those consumers may be indifferent to consuming domestically-produced foodstuffs versus imports, and will often choose the cheapest alternative. Focusing simply on increasing domestic production or productivity in an ecoagriculture (or any other) context may "win the battle and lose the war" if we fail to consider what is happening in international markets and among urban consumers. A second example is the familiar economic problem of "immizerizing growth," wherein increased production may result in lower prices and offsetting terms-of-trade effects that may counteract the economic incentives that originally gave rise to increased production. This has been common, for example, in non-traditional export markets, such as those for horticultural products, where simultaneously increased production in many countries has driven down market prices for these products, jeopardizing the diversification strategies that gave rise to production in the first place. The point here is that scale and aggregation are important. Deriving highly successful ecoagriculture solutions that meet production, livelihood, and biodiversity objectives in confined micro-level situations may still be problematic when scaled up geographically or aggregated up in regional and international markets. Researchers and policy-makers must be aware of these limitations.

A further tradeoff issue that deserves more attention, is whether, or to what extent, the intensification of agricultural production in areas better-endowed for agricultural production and raising yield there will in fact reduce pressure on the more fragile, "marginal" areas. It has been argued that millions of hectares of biodiversity-rich lands have been preserved because of the productivity gains achieved through the Green Revolution. This is certainly true to some extent, but it is not clear by how much. This logic applied to peripheral zones around protected areas, for example, can be defeated if the higher productivity promoted around a park draws more population toward the vulnerable natural resources. The apprehension that this will happen has led toward more ecoregionally-defined conservation efforts, for example, in Madagascar, seeking to promote economic development and opportunity on a broader landscape or regional scale, not just in proximity to vulnerable areas. Though the existence of these tradeoff is logically appealing, there is little direct evidence showing any 1:1 substitution of production increase in favored areas offsetting demand for equal production increase in areas where biodiversity is still rich. This adds to the case for examining ecoagricultural alternatives and promoting viable ones, not following a dichotomous strategy to conserve wild biodiversity but rather a more integrated one.

8.4 Combining an Integrative Vision with Making Difficult Choices

While there is reason to conclude that notions of ecoagriculture are scientifically grounded, the foundation is hardly rock-solid. Indeed, our assessment uncovered rather few rigorous studies that have examined crop productivity, biodiversity conservation, and livelihood support as *joint outputs* of an agricultural system. The assessment has highlighted notable examples of a few studies that did assess simultaneously the levels, and interactions among, productivity, poverty alleviation, and ecological services such as carbon sequestration and/or hydrological function, producing at least some intermediate if not final results. Integrating direct measures of biodiversity conservation into these multivariate, integrated studies, however, remains a task of the future.

This assessment concludes that although there is scope for synergistic effects and positive-sum interactions between and among the three legs of the ecoagricultural "stool," trade-offs are likely to be the more prevalent outcome and decision rule at present and for some time into the future. Difficult choices will be necessary not only among or between agricultural productivity, local livelihood sustainability, and biodiversity conservation within a particular area and time frame, but also within each domain. Should we be predominantly concerned with conserving agrobiodiversity or wild biodiversity in a certain area or with a certain farming system, for example? Perhaps a tougher choice is whether species richness is an appropriate measure of biodiversity when it may represent a greater abundance of common species at the expense of a few rare or threatened ones? Trade-offs between livelihood benefits will pit present vs. future, local vs. global, along with more qualitative (moral) questions such as to whether it is sufficient simply for populations to survive or should we be satisfied only if they thrive? To what extent should some stakeholders be allowed to profit at the expense of other actors and elements of an ecoagricultural system? These are all difficult questions, which are often hard to address in an informed or authoritative way through existing institutions and decision-making processes.

It is important to the future success of ecoagriculture as an approach to land-use analysis and practice that planners, managers and policy-makers remain realistic about how much any particular system can deliver. Exalting ecoagriculture as a simple answer will limit its viability as an integrative vision and concept. Therefore, robust models and methods need to be designed and used to systematically and reliably assess synergies vs. tradoffs in ecoagriculture systems. This work remains to be done.

At its present stage of development, ecoagricultural thinking is perhaps at best an attractive visioning process for improving land use. Already this vision has identified a good number of land-use systems throughout the world that appear to be managed, whether incidentally or deliberately, for agricultural productivity, livelihood support, *and* conservation of biological diversity. As an emergent interdisciplinary field for the applied biological and social sciences, ecoagriculture is gaining the attention of ecologists, biologists, economists, political scientists and sociologists as well as planning and management specialists who are prepared to work within various "systems" frameworks to understand interactions that affect the three essential outputs of any ecoagriculture system. Furthermore, agronomists, plant and animal breeders, plant pathologists, hydrologists, geographers and scientists of other disciplines are inclined and equipped to contribute to the pursuit of ecoagriculture goals.

As global society comes to terms with the need to reconcile expanding human activity with the survival and well-being of other life forms on the planet, and as institutions charged with finding mutually satisfactory solutions to human welfare and biodiversity conservation needs gain popular and political footholds, we can anticipate that interest in scientifically-sound knowledge and information about ecoagriculture will expand. To help accelerate these conditions, concerned scientists should seek funding and use the resources at their disposal to advance research within the arena of ecoagriculture. Indications of movement in this direction are the inclusion of a suite of ecoagriculture sessions in the World Agroforestry Congress held in Orlando, Florida, June 2004, and the interest of a large number of agriculture scientists and conservation biologists in participating in the International Ecoagriculture Conference and Practitioners' Fair, to take place in Nairobi, Kenya, September 2004.

This review and assessment of the scientific foundations for ecoagricultural land use has shown that there is a tremendous amount of literature and web-based information on this subject as well as numerous projects and knowledgeable people who can contribute to the understanding needed to advance this field of knowledge and practice. The fledgling field is not unified, however. To harness these resources and improve access, more deliberate coordination mechanisms are needed. The formation and mission of Ecoagriculture Partners (EP) is a significant move in this direction. EP, whose core partners include leadership of the World Agroforestry Center, IUCN, and the NGO Forest Trends, appears well-suited to stimulate the high level of organization and authority that will be required to generate sustainable research and development momentum from the initial flush of enthusiasm for ecoagriculture that this assessment has documented. The outcome of the planned international conference in September will give a better reading of how far and how fast this collaborative effort will proceed. EP needs to remain especially attentive to the need to channel findings from research and development initiatives through its portals to keep everyone interested adequately informed.

8.4.1. **Bridging Gaps in Thinking and Analysis**

The efforts of a few pioneering scientists who have forged ahead in the domain of ecoagriculture notwithstanding, our assessment has detected a continuing division between mainstream agricultural and conservation scientists. Their different worldviews lead to different and often divergent objectives, study sites and conclusions concerning how best to develop, use and manage renewable natural resources. While this situation limits progress at present, relative to the challenges that opportunities for ecoagriculture pose to the scientific community, we anticipate that gaps and differences will be overcome in time. The process will accelerate as appreciation is gained for the global conservation community's increasing inclination to encompass agricultural lands and "working landscapes" in its conservation strategies. Furthermore, as agricultural scientists trained to think agroecologically gain maturity and status within their organizations, and as cases are highlighted of where conservation programs and practices generate sustainable economic benefits for local people, making conservation more generally acceptable and attractive, ecoagriculture approaches will advance

To bridge the chasm in a timely manner, however, will require concerted efforts on the part of numerous individuals and insti tutions working together. This assessment has tried to address key definitional and conceptual issues up front, in particular biodiversity, intensification, and trade-offs vs. synergies. Misunderstandings regarding these terms have slowed progress toward collaboration among the diverse people and organizations working in this area. We hope that this assessment has contributed also by identifying the types of partnership and network organizations that are demonstrating effectiveness in meeting challenges of integration and collaboration.

8.4.2. **Engaging Multiple Disciplines**

Understanding the numerous scale issues that ecoagriculture poses presents both methodological and cross-disciplinary challenges. This assessment has noted the importance of accounting for scale effects in different ways: 1) spatial scale: the need to link scales of analysis and action according to the issue involved and the units of measurement and management; 2) aggregation and scaling up: larger spatial units present challenges of combining and integrating efforts, including the difficulties of collective action; and 3) measurement scales: recognizing that the relations among scales of analysis are not linear and must deal with emergent properties at the same time that good reductionist analysis is carried out. These issues will have to be reckoned with in any forthcoming evaluations of ecoagricultural land use.

There are numerous pathways into the interdisciplinary field of ecoagriculture. Landscape ecology – the study of the interactions between the temporal and spatial aspects of a landscape and its flora, fauna and cultural components (Smithers 2004)—is probably best suited to organize the field's core knowledge domain. Landscape ecologists generally can be expected to have the background and orientation to promote communication, interdisciplinary research, and the development of knowledge and interaction between scientists and those engaged in the planning and management of landscapes. Conservation biology, ecological economics, and agricultural sciences need to be securely positioned within integrative frameworks that landscape ecologists, planners, and managers take initiative to shape.

8.5 Research Needs and Opportunities

Long-term, landscape-scale experiments are needed that encompass communities of farms and attempt to improve economic viability, agricultural productivity and conservation of biodiversity, simultaneously in aggregative and cumulative ways. The landscape of farms, which would encompass a variety of experiments on the productivity effects of different methods, would be managed to see to what extent species of plants or vertebrates that were not there at present could be induced to colonize or re-colonize the area, or whether existing diversity can be maintained over long periods of time. While such outcomes, if achieved, would be good for biodiversity, what specific changes would they induce, over time, and would this be good for the other two legs of the stool: how, why, and under what conditions?

Perhaps the greatest near-term current research need is to develop measures and indicators of wild biodiversity, with respect to its variety and abundance, that can be easily incorporated into modeling approaches and used in a meaningful fashion both for research and policy analysis. In addition to better measures and indicators, we need better modeling methodologies that can evaluate alternative outcomes with respect to the objective of biodiversity conservation. With these measures and tools in hand, biodiversity conservation values can be integrated into some of the numerous extant models of agriculture and natural resource land use and economics, and others could be adapted for the expanded purpose.

Related to this, we need to know *how to measure and assess biodiversity* in general more quickly, efficiently and accurately in the field. For this we need to develop protocols for the widespread use of these methods.

We need also to know more about *corridors* through agricultural landscapes. Do they work, and under what design parameters and management conditions? There has been a lot of discussion of corridors as valuable for biodiversity shaped by thinking and experience with large fauna. A corridor that goes from high elevation to low elevation and back to high elevation may be tenable for mobile mammals, but it has little relevance for plants.

In addition, more needs to be known about the *relationships between below-ground and above-ground biodiversity*. Related to this, are some general rules of farm management that are almost always correlated with enhancement of wild biodiversity? Fewer chemicals, less tillage, better soil health, more tree cover?

We would like to see a table constructed of currently documented examples of how wild biodiversity specifically contributes to or enhances crop and animal production, and a protocol for documenting additional examples from around the world. Building up a systematic knowledge base on these relationships would strengthen the case for making eco-friendly transitions in farming systems.

An important question that needs answering is: what can particular agricultural practices and/or landscapes do for regionally or globally rare species of fauna or flora? Also, how do terrestrial practices affect aquatic and/or marine ecosystems? Any habitat manipulation will inevitably favor and disfavor some particular species. Given that any agricultural practice is bound to help some species and displace others, it would be instructive to have a list of species that are known to be extremely important in terms of ecosystem services, or that are rare regionally or globally, or that are good indicator-species for other groups of species. At the same time we need to identify which agricultural practices and agricultural landscape-design features can actually help these selected species. It will be insightful, then, to evaluate how livelihood support indicators correspond to these relationships.

Ecoagriculture Partners is uncovering a vast network of agricultural practices and practitioners around the world that are allied with ecoagriculture thinking. The proclaimed interest of many hundreds of organizations in joining EP to gain recognition and momentum for their activities suggests a powerful opportunity to establish a global, practitioner-based ecoagricultural monitoring system. The leadership of EP will presumably use the upcoming conference as an opportunity to mobilize the scientists and organizational leaders in attendance to initiate a strategy for more systematically measuring and evaluating ecoagricultural phenomena so that governments, donor agencies, NGOs, local government bodies and, most of all, rural communities and resource-users can make better informed decisions about how they can “eat their current cake” and still “have a desirable future cake” as well.

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