Agroecology and the Search for a Truly Sustainable Agriculture

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Preface

Environmental education and training is the process whereby new knowledge and practices evolve to understand and to intervene in the solution of the complex socio-environmental problems of our time. Also, to construct a new social and productive rationality that would enable to transit towards a sustainable development. This process implies the elaboration of new theories, methods, techniques, and their incorporation in new educational programmes, productive strategies and environmental management projects.

To face-up this challenge, the publishing programme of the Environmental Training Network for Latin America and the Caribbean was established in 1995 to disseminate knowledge, methods and techniques for environmental management, in order to serve as basic educational materials for environmental training programmes and as an instrument to give support to the sustainable development policies for the countries of the region; to prepare different social sectors at different professional levels, as well as citizens groups and community development programmes. Ten years later, the ETN has published 40 basic text books and manuals, and a series on Latin American Environmental Thinking.

However, these publications have privileged the Spanish-speaking countries of the region. Now, we are thus proud to present this basic text book on "Agroecology and the Search for a Truly Sustainable Agriculture", by Miguel Altieri and Clara Nicholls. With this first title published in English we start to cover our debt to the English-speaking Caribbean sub-region and to the English-speaking countries at large.

The subject of this book is the sustainable agriculture and its importance to the sustainable development; capitalized agriculture impinged the earth's conditions of sustainability by ignoring its ecological conditions and potentials, deriving a devastation of resources, soil pollution, land erosion and loss of biodiversity. It broke the organization and resilience of ecological systems, degrading the planet's life support systems. All this caused productivity losses and rural employments, and a high rural migration, hampering the self-sufficiency and food security of an increasing impoverished rural people. The book analyze these problems to offer tools to enable a more ecologically rational use of our soils, land, biodiversity and natural resources, to preserve and enhance its sustainable productivity in order to ensure food security and the sustainable agriculture of the countries of the region.

Altieri and Nicholls do not only question the over capitalization of agriculture and its illusion of literally "planting with oil", and the evils of Green Revolution. They go further to demystify the latest wave of biotechnological revolution as a renewed panacea to solve the world's hunger. Agroecology seeks to root sustainable agricultural production in ecological potentials and cultural values, to open a dialogue between scientific knowledge and traditional wisdoms; to empower farmers, peasants and indigenous peoples as social actors to renew their community based productive practices, to enable them to inhabit their cultural territories.

A first version of this book was published in Spanish under the series of Basic Texts for Environmental Training in 2000. There, the authors developed problems derived from the capitalization of agriculture, the privatization of land, the Green Revolution and the production of transgenic crops that have generated serious problems of soil erosion and pollution, loss of biodiversity, hampering the sustainable ecological productivity of agricultural land and affecting the productive processes and livelihoods of rural populations of the Third World. After the false promises of Green Revolution, Agroecology emerged as a paradigm shift, to internalize the ecological conditions of agricultural production. Agroecology is the Science of the Ecological Management of Natural Resources. The book opens new paths towards agricultural sustainability, food security and self-management of the local resources through agroecological productive practices.

This updated English version is not simply a translation of that first publication in Spanish. The new book includes more recent studies and publications by Miguel Altieri and Clara Nicholls. Altieri has been a pioneer researcher and one of the most outstanding proponents and leaders of agroecology, particularly in the Latin American and Caribbean region. He is a promoter of this emergent field of knowledge, and practice and author of various seminal publications in the field of agroecology. He founded the Latin American Consortium of Agroecology and Development (CLADES) and the Project "Sustainable Agriculture Networking and Extension" (SANE). For over 20 years Altieri, later followed by Nicholls, promoted a change of paradigms in agriculture, contributing to the professional training of a network of scientists, technicians and practitioners trainers and community leaders in different Latin American and Caribbean countries and establishing a fruitful collaboration with the Environmental Training Network. With this book we intend to extend to the Wider Caribbean the benefits that agroecology can offer for the betterment of the livelihoods of the people and the sustainability of the territories of the Caribbean region.

Enrique Leff
Coodinator
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Introduction

There is increasing evidence that warns that the growing push toward industrialization and globalization of the world's agriculture and food supply imperils the future of humanity and the natural world. Industrial agriculture which is corporate controlled, and promotes agrochemically based, monocultural, export-oriented systems are negatively impacting public health, ecosystem integrity, food quality and nourishment, traditional rural livelihoods, and indigenous and local cultures, while accelerating indebtedness among millions of farmers, and their separation from lands that have historically fed communities and families. This transition is increasing hunger, landlessness, homelessness, despair and suicides among farmers. Meanwhile, it is also degrading the planet's life support systems, and increasing alienation of peoples from nature and the historic, cultural and natural connection of farmers and all other people to the sources of food and sustenance. Finally, it is also destroying the economic and cultural foundations of societies, undermines security and peace, and creates a context for social disintegration and violence. By confronting myth with reality, the objective of this book is to challenge the false promises made by the genetic engineering industry. The industry has promised that genetically engineered crops will move agriculture away from a dependence on chemical inputs, increase productivity, decrease input costs, and help reduce environmental problems (Office of Technology Assessment, 1992). By challenging the myths of biotechnology, in chapters of this book we expose pose genetic engineering (the latest wave of agricultural intensification) for what it really is: another technological fix or «magic bullet» aimed at circumventing the environmental problems of agriculture (which are the outcome of an earlier round of modern agro-technological fixes) without questioning the ecological upset that gave rise to the problems in the first place.

Despite all the above problems associated with industrial agriculture, there are many optimistic developments. Thousands of new and alternative initiatives are now flowering across the world to promote ecological agriculture, preservation of the livelihoods of small farmers, production of healthy, safe and culturally diverse foods, and localization of distribution, trade and marketing. Throughout the developing world there are still microcosms of intact traditional agriculture which represent millenary examples of successful forms of community-based local agriculture. These microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain year-round yields. Such systems have fed much of the world for centuries, while conserving ecological integrity through application of indigenous knowledge systems and continue to do so in many parts of the planet. Today we can witness around the world, new approaches and technologies spearheaded by farmers, NGOs and some government institutions which are making a significant contribution to food security at the household, national, and regional levels while conserving natural resources. Yield increases have been achieved using technological approaches based on agroecological principles that emphasize diversity, synergy, recycling and integration; and social processes that value community involvement and empowerment.

When agroecological principles are adopted, yield enhancement and stability of production are achieved, as well as a series of ecological services such as conservation of agrobiodiversity, soil and water conservation and enhancement, improved biological pest control, etc., regardless of scale or farm size. What varies are the technological forms utilized to optimize key agroecological processes. This variation is best done by farmers themselves; in industrial countries is expressed as organic agriculture while in the developing world it takes the form of a myriad of traditional biodiverse farms. In this new approach to agriculture, social capital formation is as important as the regenerative technologies involved, because what is key to local livelihoods is the capability of local communities to innovate, evaluate, and adapt as they involve themselves in a development process based on local knowledge and organization. These experiences which emphasize farmer to farmer research and grassroots extension approaches, represent countless demonstrations of talent, creativity and scientific capability in rural communities throughout the world. They point to the fact that human resource development is the cornerstone of any strategy aimed at increasing options for rural people and especially resource-poor farmers.

Another agriculture is not only possible, it is already happening taking a multitude of expressions of alternative agriculture, from various variations of organic agriculture to more peasant based, subsistence oriented traditional agriculture. In this book we explore the extent, features and ecological, social and economic benefits of both forms of sustainable agriculture. In this report the agroecological features of organic agriculture as practiced in North America and Europe, and of traditional agriculture involving millions of small farmers and/or peasants in the developing world are described with emphasis on their contribution to food security, conservation/ regeneration of biodiversity and natural resources and economic viability. The book also depicts an agroecological path to reach a truly sustainable, biodiverse and socially just agriculture.

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Chapter 1

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Modern Agriculture: Ecological Impacts and the Alternatives to Conventional Farming

Until about four decades ago, crop yields in agricultural systems depended on internal resources, recycling of organic matter, built-in biological control mechanisms and rainfall patterns. Agricultural yields were modest, but stable. Production was safeguarded by growing more than one crop or variety in space and time in a field as insurance against pest outbreaks or severe weather. Inputs of nitrogen were gained by rotating major field crops with legumes. In turn rotations suppressed insects, weeds and diseases by effectively breaking the life cycles of these pests. A typical corn belt farmer grew corn rotated with several crops including soybeans, and small grain production was intrinsic to maintain livestock. Most of the labor was done by the family with occasional hired help and no specialized equipment or services were purchased from off-farm sources. In these type of farming systems the link between agriculture and ecology was quite strong and signs of environmental degradation were seldom evident[1].

But as agricultural modernization progressed, the ecology-farming linkage was often broken as ecological principles were ignored and/or overridden. In fact, several agricultural scientists have arrived at a general consensus that modern agriculture confronts an environmental crisis. A growing number of people have become concerned about the long-term sustainability of existing food production systems. Evidence has accumulated showing that whereas the present capital —and technology— intensive farming systems have been extremely productive

[1] Altieri, M.A. 1995. *Agroecology: the science of sustainable agriculture.* Westview Press, Boulder, CO.

and competitive, they also bring a variety of economic, environmental and social problems[2].

Evidence also shows that the very nature of the agricultural structure and prevailing policies have led to this environmental crisis by favoring large farm size, specialized production, crop monocultures and mechanization. Today as more and more farmers are integrated into international economies, imperatives to diversity disappear and monocultures are rewarded by economies of scale. In turn, lack of rotations and diversification take away key self-regulating mechanisms, turning monocultures into highly vulnerable agroecosystems dependent on high chemical inputs.

The Expansion of Monocultures

Today monocultures have increased dramatically worldwide, mainly through the geographical expansion of land devoted to single crops and year-to-year production of the same crop species on the same land. Available data indicate that the amount of crop diversity per unit of arable land has decreased and that croplands have shown a tendency toward concentration. There are political and economic forces influencing the trend to devote large areas to monoculture, and in fact such systems are rewarded by economies of scale and contribute significantly to the ability of national agricultures to serve international markets.

The technologies allowing the shift toward monoculture were mechanization, the improvement of crop varieties, and the development of agrochemicals to fertilize crops and control weeds and pests. Government commodity policies these past several decades encouraged the acceptance and utilization of these technologies. As a result, farms today are fewer, larger, more specialized and more capital intensive. At the regional level, increases in monoculture farming meant that the whole agricultural support infrastructure (i.e. research, extension, suppliers, storage, transport, markets, etc.) has become more specialized.

[2] Conway, G.R. and Pretty, J.N. 1991. *Unwelcome harvest: agriculture and pollution.* Earthscan Publisher, London.

From an ecological perspective, the regional consequences of monoculture specialization are many-fold:

a) Most large-scale agricultural systems exhibit a poorly structured assemblage of farm components, with almost no linkages or complementary relationships between crop enterprises and among soils, crops and animals.

b) Cycles of nutrients, energy, water and wastes have become more open, rather than closed as in a natural ecosystem. Despite the substantial amount of crop residues and manure produced in farms, it is becoming increasingly difficult to recycle nutrients, even within agricultural systems. Animal wastes cannot economically be returned to the land in a nutrient-recycling process because production systems are geographically remote from other systems which would complete the cycle. In many areas, agricultural waste has become a liability rather than a resource. Recycling of nutrients from urban centers back to the fields is similarly difficult.

c) Part of the instability and susceptibility to pests of agroecosystems can be linked to the adoption of vast crop monocultures, which have concentrated resources for specialist crop herbivores and have increased the areas available for immigration of pests. This simplification has also reduced environmental opportunities for natural enemies. Consequently, pest outbreaks often occur when large numbers of immigrant pests, inhibited populations of beneficial insects, favorable weather and vulnerable crop stages happen simultaneously.

d) As specific crops are expanded beyond their «natural» ranges or favorable regions to areas of high pest potential, or with limited water, or low-fertility soils, intensified chemical controls are required to overcome such limiting factors. The assumption is that the human intervention and level of energy inputs that allow these expansions can be sustained indefinitely.

e) Commercial farmers witness a constant parade of new crop varieties as varietal replacement due to biotic stresses and market changes has accelerated to unprecedented levels. A cultivar with improved disease or insect resistance makes a debut, performs well for a few years (typically 5-9 years) and is then succeeded by another variety when yields begin to slip, productivity is threatened, or a more promising cultivar becomes available. A variety's trajectory is characterized by a take-off phase when it is adopted by farmers, a middle stage when the planted area stabilizes and finally a retraction of its acreage. Thus, stability in modern agriculture hinges on a continuous supply of new cultivars rather than a patchwork quilt of many different varieties planted on the same farm.

f) The need to subsidize monocultures requires increases in the use of pesticides and fertilizers, but the efficiency of use of applied inputs is decreasing and crop yields in most key crops are leveling off. In some places, yields are actually in decline. There are different opinions as to the underlying causes of this phenomenon. Some believe that yields are leveling off because the maximum yield potential of current varieties is being approached, and therefore genetic engineering must be applied to the task of redesigning crop. Agroecologists, on the other hand, believe that the leveling off is because of the steady erosion of the productive base of agriculture through unsustainable practices[3].

The First Wave of Environmental Problems

The specialization of production units has led to the image that agriculture is a modern miracle of food production. Evidence indicates, however, that excessive reliance on monoculture farming and agroindustrial inputs, such as capital-intensive technology, pesticides, and chemical fertilizers, has negatively impacted the environment and rural society. Most agriculturalists had assumed that the agroecosystem/natural ecosystem dichotomy need not lead to undesirable consequences, yet, unfortunately, a number of «ecological diseases» have been associated with the

[3] Altieri, M.A. and P.M. Rosset 1995. Agroecology and the conversion of large-scale conventional systems to sustainable management. *International Journal of Environmental Studies* 50: 165-185.

intensification of food production. They may be grouped into two categories: diseases of the ecotope, which include erosion, loss of soil fertility, depletion of nutrient reserves, salinization and alkalinization, pollution of water systems, loss of fertile croplands to urban development, and diseases of the biocoenosis, which include loss of crop, wild plant, and animal genetic resources, elimination of natural enemies, pest resurgence and genetic resistance to pesticides, chemical contamination, and destruction of natural control mechanisms. Under conditions of intensive management, treatment of such «diseases» requires an increase in the external costs to the extent that, in some agricultural systems, the amount of energy invested to produce a desired yield surpasses the energy harvested[4].

The loss of yields due to pests in many crops (reaching about 20-30% in most crops), despite the substantial increase in the use of pesticides (about 500 million kg of active ingredient worldwide) is a symptom of the environmental crisis affecting agriculture. It is well known that cultivated plants grown in genetically homogenous monocultures do not possess the necessary ecological defense mechanisms to tolerate the impact of outbreaking pest populations. Modern agriculturists have selected crops for high yields and high palatability, making them more susceptible to pests by sacrificing natural resistance for productivity. On the other hand, modern agricultural practices negatively affect pest natural enemies, which in turn do not find the necessary environmental resources and opportunities in monocultures to effectively and biologically suppress pests. Due to this lack of natural controls, an investment of about 40 billion dollars in pesticide control is incurred yearly by US farmers, which is estimated to save approximately $6 billion in US crops. However, the indirect costs of pesticide use to the environment and public health have to be balanced against these benefits. Based on the available data, the environmental (impacts on wildlife, pollinators, natural enemies, fisheries, water and development of resistance) and social costs (human poisonings and illnesses) of pesticide use reach about $8 billion each

[4] Gliessman, S.R. 1997. *Agroecology: ecological processes in agriculture.* Ann Arbor Press, Michigan.
[5] Pimentel, D. and H. Lehman 1993. *The pesticide question.* Chapman and Hall, N.Y.

year[5]. What is worrisome is that pesticide use is on the rise. Data from California shows that from 1941 to 1995 pesticide use increased from 161 to 212 million pounds of active ingredient. These increases were not due to increases in planted acreage, as statewide crop acreage remained constant during this period. Crops such as strawberries and grapes account for much of this increased use, which includes toxic pesticides, many of which are linked to cancers[6].

Fertilizers, on the other hand, have been praised as being highly associated with the temporary increase in food production observed in many countries. National average rates of nitrate applied to most arable lands fluctuate between 120-550 kg N/ha. But the bountiful harvests created at least in part through the use of chemical fertilizers, have associated, and often hidden, costs. A primary reason why chemical fertilizers pollute the environment is due to wasteful application and the fact that crops use them inefficiently. The fertilizer that is not recovered by the crop ends up in the environment, mostly in surface water or in ground water. Nitrate contamination of aquifers is widespread and in dangerously high levels in many rural regions of the world. In the US, it is estimated that more than 25% of the drinking water wells contain nitrate levels above the 45 parts per million safety standard. Such nitrate levels are hazardous to human health and studies have linked nitrate uptake to methaemoglobinemia in children and to gastric, bladder and oesophageal cancers in adults[7].

Fertilizer nutrients that enter surface waters (rivers, lakes, bays, etc.) can promote eutrophication, characterized initially by a population explosion of photosynthetic algae. Algal blooms turn the water bright green, prevent light from penetrating beneath surface layers, and therefore killing plants living on the bottom. Such dead vegetation serve as food for other aquatic microorganisms which soon deplete water of its oxygen,

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[6] Liebman, J. 1997. *Rising toxic tide: pesticide use in California, 1991-1995*. Report of Californians for Pesticide Reform and Pesticide Action Network. San Francisco.
[7] Conway, G.R. and Pretty, J.N. 1991. *Unwelcome harvest: agriculture and pollution.* Earthscan Publisher, London.

inhibiting the decomposition of organic residues, which accumulate on the bottom. Eventually, such nutrient enrichment of freshwater ecosystems leads to the destruction of all animal life in the water systems. In the US it is estimated that about 50-70% of all nutrients that reach surface waters is derived from fertilizers.

Chemical fertilizers can also become air pollutants, and have recently been implicated in the destruction of the ozone layer and in global warming. Their excessive use has also been linked to the acidification/ salinization of soils and to a higher incidence of insect pests and diseases through mediation of negative nutritional changes in crop plants[8].

It is clear then that the first wave of environmental problems is deeply rooted in the prevalent socioeconomic system which promotes monocultures and the use of high input technologies and agricultural practices that lead to natural resource degradation. Such degradation is not only an ecological process, but also a social and political-economic process[9]. This is why the problem of agricultural production cannot be regarded only as a technological one, but while agreeing that productivity issues represent part of the problem, attention to social, cultural and economic issues that account for the crisis is crucial. This is particularly true today where the economic and political domination of the rural development agenda by agribusiness has thrived at the expense of the interests of consumers, farmworkers, small family farms, wildlife, the environment, and rural communities[10].

The Second Wave of Environmental Problems

Despite that awareness of the impacts of modern technologies on the environment increased, as we traced pesticides in food chains and crop

[8] Mc Guinnes, H. 1993. *Living soils: sustainable alternatives to chemical fertilizers for developing countries.* Unpublished manuscript, Consumers Policy Institute, New York.
[9] Buttel, F.H. and M.E. Gertler 1982. Agricultural structure, agricultural policy and environmental quality. *Agriculture and Environment* 7: 101-119.
[10] Audirac, Y. 1997. *Rural sustainable development in America.* John Wiley and Sons, N.Y.

nutrients in streams and aquifiers, there are those that confronted to the challenges of the XXI century still argue for further intensification to meet the requirements of agricultural production. It is in this context that supporters of «status-quo agriculture» celebrate the emergence of biotechnology as the latest magic bullet that will revolutionize agriculture with products based on natures' own methods, making farming more environmentally friendly and more profitable for the farmer. Although clearly certain forms of non-transformational biotechnology hold promise for an improved agriculture, given its present orientation and control by multinational corporations, it holds more promise for environmental harm, for the further industrialization of agriculture and for the intrusion of private interests too far into public interest sector research[11].

What is ironic is the fact that the biorevolution is being brought forward by the same interests (Monsanto, Novartis, DuPont, etc.) that promoted the first wave of agrochemically-based agriculture, but this time, by equipping each crop with new «insecticidal genes», they are promising the world safer pesticides, reduction on chemically intensive farming and a more sustainable agriculture.

However, as long as transgenic crops follow closely the pesticide paradigm, such biotechnological products will do nothing but reinforce the pesticide treadmill in agroecosystems, thus legitimizing the concerns that many scientists have expressed regarding the possible environmental risks of genetically engineered organisms.

So far, field research as well as predictions based on ecological theory, indicate that among the major environmental risks associated with the release of genetically engineered crops can be summarized as follows[12]:

[11] Krimsky, S. and R.P. Wrubel 1996. *Agricultural biotechnology and the environment: science, policy and social issues.* University of Illinois Press, Urbana.
[12] Rissler, J. and M. Mellon 1996. *The ecological risks of engineered crops.* MIT Press, Cambridge.

- The trends set forth by corporations is to create broad international markets for a single product, thus creating the conditions for genetic uniformity in rural landscapes. History has repeatedly shown that a huge area planted to a single cultivar is very vulnerable to a new matching strain of a pathogen or pest.
- The spread of transgenic crops threatens crop genetic diversity by simplifying cropping systems and promoting genetic erosion.
- There is potential for the unintended transfer to plant relatives of the «transgenes» and the unpredictable ecological effects. The transfer of genes from herbicide resistant crops (HRCs) to wild or semidomesticated relatives can lead to the creation of super weeds.
- Most probably insect pests will quickly develop resistance to crops with Bt toxin. Several Lepidoptera species have been reported to develop resistance to Bt toxin in both field and laboratory tests, suggesting that major resistance problems are likely to develop in Bt crops which through the continuous expression of the toxin create a strong selection pressure.
- Massive use of Bt toxin in crops can unleash potential negative interactions affecting ecological processes and non-target organisms. Evidence from studies conducted in Scotland suggest that aphids were capable of sequestering the toxin from Bt crops and transferring it to its coccinellid predators, in turn affecting reproduction and longevity of the beneficial beetles.
- Bt toxins can also be incorporated into the soil through leaf materials and litter, where they may persist for 2-3 months, resisting degradation by binding to soil clay particles while maintaining toxic activity, in turn negatively affecting invertebrates and nutrient cycling.
- A potential risk of transgenic plants expressing viral sequences derives from the possibility of new viral genotypes being generated by recombination between the genomic RNA of infecting viruses and RNA transcribed from the transgene.
- Another important environmental concern associated with the large scale cultivation of virus-resistant transgenic crops relates to the

possible transfer of virus-derived transgenes into wild relatives through pollen flow.

Although there are many unanswered questions regarding the impact of the release of transgenic plants and micro-organisms into the environment, it is expected that biotechnology will exacerbate the problems of conventional agriculture and by promoting monocultures will also undermine ecological methods of farming such as rotations and polycultures. Because transgenic crops developed for pest control emphasize the use of a single control mechanism, which has proven to fail over and over again with insects, pathogens and weeds, transgenic crops are likely to increase the use of pesticides and to accelerate the evolution of «super weeds» and resistant insect pest strains. These possibilities are worrisome, especially when considering that during the period 1986-1997, approximately 25,000 transgenic crop field trials were conducted worldwide on more than 60 crops with 10 traits in 45 countries. By 1997 the global area devoted to transgenic crops reached 12.8 million hectares. Seventy-two percent of all transgenic crop field trials were conducted in the USA and Canada, although some were also conducted in descending order in Europe, Latin America and Asia[13]. In most countries biosafety standards to monitor such releases are absent or are inadequate to predict ecological risks. In the industrialized countries from 1986-1992, 57% of all field trials to test transgenic crops involved herbicide tolerance pioneered by 27 corporations including the world's eight largest pesticide companies. As Roundup and other broad spectrum herbicides are increasingly deployed into croplands, the options for farmers for a diversified agriculture will be even more limited.

The Array of Alternatives to Conventional Agriculture

Reduction and, especially, elimination of agrochemical require major changes in management to assure adequate plant nutrients and to control crop pests. As it was done a few decades ago, alternative sources of nutrients to maintain soil fertility include manures, sewage sludge and

[13] James, C. 1997. *Global status of transgenic crops in 1997.* ISAA Briefs, Ithaca, N.Y.

other organic wastes, and legumes in cropping sequences. Rotation benefits are due to biologically fixed nitrogen and from the interruption of weed, disease and insect cycles. A livestock enterprise may be integrated with grain cropping to provide animal manures and to utilize better the forages produced. Maximum benefits of pasture integration can be realized when livestock, crops, animals and other farm resources are assembled in mixed and rotational designs to optimize production efficiency, nutrient cycling and crop protection.

In orchards and vineyards, the use of cover crops improve soil fertility, soil structure and water penetration, prevent soil erosion, modify the microclimate and reduce weed competition. Entomological studies conducted in orchards with ground cover vegetation indicate that these systems exhibit lower incidence of insect pests than clean cultivated orchards. This is due to a higher abundance and efficiency of predators and parasitoids enhanced by the rich floral undergrowth[14].

Increasingly, researchers are showing that it is possible to provide a balanced environment, sustained yields, biologically mediated soil fertility and natural pest regulation through the design of diversified agroecosystems and the use of low-input technologies. Many alternative cropping systems have been tested, such as double cropping, strip cropping, cover cropping and intercropping, and more importantly concrete examples from real farmers show that such systems lead to optimal recycling of nutrients and organic matter turnover, closed energy flows, water and soil conservation and balanced pest-natural enemy populations. Such diversified farming exploit the complementarities that result from the various combinations of crops, trees and animals in spatial and temporal arrangements[15].

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[14] Altieri, M.A. 1992. Agroecological foundations of alternative agriculture in California. *Agriculture, Ecosystems and Environment* 39: 23-53.
[15] Altieri, M.A. 1995. *Agroecology: the science of sustainable agriculture.* Westview Press, Boulder, CO.

In essence, the optimal behavior of agroecosystems depends on the level of interactions between the various biotic and abiotic components. By assembling a functional biodiversity it is possible to initiate synergisms which subsidize agroecosystem processes by providing ecological services such as the activation of soil biology, the recycling of nutrients, the enhancement of beneficial arthropods and antagonists, and so on. Today there is a diverse selection of practices and technologies available, and which vary in effectiveness as well as in strategic value.

The Barriers for the Implementation of Alternatives

The agroecological approach seeks the diversification and revitalization of medium size and small farms and the reshaping of the entire agricultural policy and food system in ways that are economically viable to farmers and consumers. In fact, throughout the world there are hundreds of movements that are pursuing a change toward ecologically sensitive farming systems from a variety of perspectives. Some emphasize the production of organic products for lucrative markets, others land stewardship, while others the empowerment of peasant communities. In general, however, the goals are usually the same: to secure food self-sufficiency, to preserve the natural resource base, and to ensure social equity and economic viability.

What happens is that some well-intentioned groups suffer from «technological determinism», and emphasize as a key strategy only the development and dissemination of low-input or appropriate technologies as if these technologies in themselves have the capability of initiating beneficial social changes. The organic farming school that emphasizes input substitution (i.e. a toxic chemical substituted by a biological insecticide) but leaving the monoculture structure untouched, epitomizes those groups that have a relatively benign view of capitalist agriculture. Such perspective has unfortunately prevented many groups from

[16] Rosset, P.M. and M.A. Altieri 1997. Agroecology versus input substitution: a fundamental contradiction in sustainable agriculture. *Society and Natural Resources* 10: 283-295.

understanding the structural roots of environmental degradation linked to monoculture farming[16].

This narrow acceptance of the present structure of agriculture as a given condition restricts the real possibility of implementing alternatives that challenge such a structure. Thus, options for a diversified agriculture are inhibited among other factors by the present trends in farm size and mechanization. Implementation of such mixed agriculture would only be possible as part of a broader program that includes, among other strategies, land reform and redesign of farm machinery adapted to polycultures. Merely introducing alternative agricultural designs will do little to change the underlying forces that led to monoculture production, farm size expansion, and mechanization in the first place.

Similarly, obstacles to changing cropping systems has been created by the government commodity programs in place these last several decades. In essence, these programs have rewarded those who maintained monocultures on their base feed grain acres by assuring these producers a particular price for their product. Those who failed to plant the allotted acreage of corn and other price-supported crops lost one deficit hectrage from their base. Consequently this created a competitive disadvantage for those who used a crop rotation. Such a disadvantage, of course, exacerbated economic hardship for many producers[17]. Obviously many policy changes are necessary in order to create an economic scenario favorable to alternative cropping practices.

On the other hand, the large influence of multinational companies in promoting sales of agrochemicals cannot be ignored as a barrier to sustainable farming. Most MNCs have taken advantage of existing policies that promote the enhanced participation of the private sector in technology development and delivery, positioning themselves in a powerful position to scale up promotion and marketing of pesticides. Realistically then the future of agriculture will be determined by power relations, and there is no reason why farmers and the public in general, if sufficiently empowered, could not influence the direction of agriculture along sustainability goals.

[17] Mc Isaac, G. and W.R. Edwards 1994. *Sustainable agriculture in the American midwest.* University of Illinois Press, Urbana.

Conclusions

Clearly the nature of modern agricultural structure and contemporary policies have decidedly influenced the context of agricultural technology and production, which in turn has led to environmental problems of a first and second order. In fact, given the realities of the dominant economic milieu, policies discourage resource-conserving practices and in many cases such practices are not privately profitable for farmers. So the expectation that a set of policy changes could be implemented for a renaissance of diversified or small scale farms may be unrealistic, because it negates the existence of scale in agriculture and ignores the political power of agribusiness corporations and current trends set forth by globalization. A more radical transformation of agriculture is needed, one guided by the notion that ecological change in agriculture cannot be promoted without comparable changes in the social, political, cultural and economic arenas that also conform agriculture. In other words, change toward a more socially just, economically viable, and environmentally sound agriculture should be the result of social movements in the rural sector in alliance with urban organizations. This is especially relevant in the case of the new biorevolution, where concerted action is needed so that biotechnology companies feel the impact of environmental, farm labor, animal rights and consumers lobbies, pressuring them to re-orienting their work for the overall benefit of society and nature.

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Chapter 2

Chapter 2

Agroecology: Principles and Strategies for Designing Sustainable Farming Systems

The concept of sustainable agriculture is a relatively recent response to the decline in the quality of the natural resource base associated with modern agriculture (McIsaac and Edwards, 1994). Today, the question of agricultural production has evolved from a purely technical one to a more complex one characterized by social, cultural, political and economic dimensions. The concept of sustainability although controversial and diffuse due to existing conflicting definitions and interpretations of its meaning, is useful because it captures a set of concerns about agriculture which is conceived as the result of the co-evolution of socioeconomic and natural systems (Reijntjes *et al.,* 1992). A wider understanding of the agricultural context requires the study between agriculture, the global environment and social systems given that agricultural development results from the complex interaction of a multitude of factors. It is through this deeper understanding of the ecology of agricultural systems that doors will open to new management options more in tune with the objectives of a truly sustainable agriculture.

The sustainability concept has prompted much discussion and has promoted the need to propose major adjustments in conventional agriculture to make it more environmentally, socially and economically viable and compatible. Several possible solutions to the environmental problems created by capital and technology intensive farming systems have been proposed and research is currently in progress to evaluate alternative systems (Gliessman, 1998). The main focus lies on the reduction or elimination of agrochemical inputs through changes in management to assure adequate plant nutrition and plant protection through organic nutrient sources and integrated pest management, respectively.

Although hundreds of more environmentally prone research projects and technological development attempts have taken place, and many lessons have been learned, the thrust is still highly technological, emphasizing the suppression of limiting factors or the symptoms that mask an ill producing agroecosystem. The prevalent philosophy is that pests, nutrient deficiencies or other factors are the cause of low productivity, as opposed to the view that pests or nutrients only become limiting if conditions in the agroecosystem are not in equilibrium (Carrol *et al.,* 1990). For this reason, there still prevails a narrow view that specific causes affect productivity, and overcoming the limiting factor via new technologies, continues to be the main goal. This view has diverted agriculturists from realizing that limiting factors only represent symptoms of a more systemic disease inherent to unbalances within the agroecosystem and from an appreciation of the context and complexity of agroecological processes thus underestimating the root causes of agricultural limitations (Altieri *et al.,* 1993).

On the other hand, the science of agroecology, which is defined as the application of ecological concepts and principles to the design and management of sustainable agroecosystems, provides a framework to assess the complexity of agroecosystems (Altieri, 1995). The idea of agroecology is to go beyond the use of alternative practices and to develop agroecosystems with the minimal dependence on high agrochemical and energy inputs, emphasizing complex agricultural systems in which ecological interactions and synergisms between biological components provide the mechanisms for the systems to sponsor their own soil fertility, productivity and crop protection (Altieri and Rosset, 1995).

Principles of Agroecology

In the search to reinstate more ecological rationale into agricultural production, scientists and developers have disregarded a key point in the development of a more self-sufficient and sustaining agriculture: a deep understanding of the nature of agroecosystems and the principles by which they function. Given this limitation, agroecology has emerged as the discipline that provides the basic ecological principles for how to study, design and manage agroecosystems that are both productive and natural resource conserving, and that are also culturally sensitive, socially just and economically viable (Altieri, 1995).

Agroecology goes beyond a one-dimensional view of agroecosystems —their genetics, agronomy, edaphology, and so on— to embrace an understanding of ecological and social levels of co-evolution, structure and function. Instead of focusing on one particular component of the agroecosystem, agroecology emphasizes the interrelatedness of all agroecosystem components and the complex dynamics of ecological processes (Vandermeer, 1995).

Agroecosystems are communities of plants and animals interacting with their physical and chemical environments that have been modified by people to produce food, fibre, fuel and other products for human consumption and processing. Agroecology is the holitstic study of agroecosystems, including all environmental and human elements. It focuses on the form, dynamics and functions of their interrelationships and the processes in which they are involved. An area used for agricultural production, e.g. a field is seen as a complex system in which ecological processes found under natural conditions also occur, e.g. nutrient cycling, predator/prey interactions, competition, symbiosis and successional changes. Implicit in agroecological research is the idea that, by understanding these ecological relationships and processes, agroecosystems can be manipulated to improve production and to produce more sustainably, with fewer negative environmental or social impacts and fewer external inputs (Altieri, 1995).

The design of such systems is based on the application of the following ecological principles (Reinjntjes *et al.,* 1992) (see also Table 1):

1. Enhance recycling of biomass and optimizing nutrient availability and balancing nutrient flow.

2. Securing favorable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biotic activity.

3. Minimizing losses due to flows of solar radiation, air and water by way of microclimate management, water harvesting and soil management through increased soil cover.

4. Species and genetic diversification of the agroecosystem in time and space.

5. Enhance beneficial biological interactions and synergisms among agrobiodiversity components thus resulting in the promotion of key ecological processes and services.

These principles can be applied by way of various techniques and strategies. Each of these will have different effects on productivity, stability and resiliency within the farm system, depending on the local opportunities, resource constraints and, in most cases, on the market. The ultimate goal of agroecological design is to integrate components so that overall biological efficiency is improved, biodiversity is preserved, and the agroecosystem productivity and its self-sustaining capacity is maintained. The goal is to design a quilt of agroecosystems within a landscape unit, each mimicking the structure and function of natural ecosystems.

Biodiversification of Agroecosystems

From a management perspective, the agroecological objective is to provide a balanced environments, sustained yields, biologically mediated soil fertility and natural pest regulation through the design of diversified agroecosystems and the use of low-input technologies (Gleissman, 1998). Agroecologists are now recognizing that intercropping, agroforestry and other diversification methods mimic natural ecological processes, and that the sustainability of complex agroecosystems lies in the ecological models they follow. By designing farming systems that mimic nature, optimal use can be made of sunlight, soil nutrients and rainfall (Pretty, 1994).

Agroecological management must lead management to optimal recycling of nutrients and organic matter turnover, closed energy flows, water and soil conservation and balance pest-natural enemy populations. The strategy exploits the complementarities and synergisms that result from the various combinations of crops, tree and animals in spatial and temporal arrangements (Altieri,1994).

In essence, the optimal behavior of agroecosystems depends on the level of interactions between the various biotic and abiotic components. By assembling a functional biodiversity it is possible to initiate synergisms which subsidize agroecosystem processes by providing ecological services such as the activation of soil biology, the recycling of nutrients, the enhancement of beneficial arthropods and antagonists, and so on (Altieri and Nicholls, 1999). Today there is a diverse selection of practices and technologies available, and which vary in effectiveness as well as in strategic value. Key practices are those of a preventative nature and which act by reinforcing the «immunity» of the agroecosystem through a series of mechanisms (Table 2).

Various strategies to restore agricultural diversity in time and space include crop rotations, cover crops, intercropping, crop/livestock mixtures, and so on, which exhibit the following ecological features:

1. *Crop Rotations*. Temporal diversity incorporated into cropping systems, providing crop nutrients and breaking the life cycles of several insect pests, diseases, and weed life cycles (Sumner, 1982).

2. *Polycultures*. Complex cropping systems in which tow or more crop species are planted within sufficient spatial proximity to result in competition or complementation, thus enhancing yields (Francis, 1986; Vandermeer, 1989).

3. *Agroforestry Systems*. An agricultural system where trees are grown together with annual crops and/or animals, resulting in enhanced complementary relations between components increasing multiple use of the agroecosystem (Nair, 1982).

4. *Cover Crops*. The use of pure or mixed stands of legumes or other annual plant species under fruit trees for the purpose of improving soil fertility, enhancing biological control of pests, and modifying the orchard microclimate (Finch and Sharp, 1976).

5. Animal integration in agroecosystems aids in achieving high biomass output and optimal recycling (Pearson and Ison, 1987).

All of the above diversified forms of agroecosystems share in common the following features (Altieri and Rosset, 1995):

a. Maintain vegetative cover as an effective soil and water conserving measure, met through the use of no-till practices, mulch farming, and use of cover crops and other appropriate methods.

b. Provide a regular supply of organic matter through the addition of organic matter (manure, compost, and promotion of soil biotic activity).

c. Enhance nutrient recycling mechanisms through the use of livestock systems based on legumes, etc.

d. Promote pest regulation through enhanced activity of biological control agents achieved by introducing and/or conserving natural enemies and antagonists.

Research on diversified cropping systems underscores the great importance of diversity in an agricultural setting (Francis, 1986, Vandermeer, 1989; Altieri, 1995). Diversity is of value in agroecosystems for a variety of reasons (Altieri, 1994; Gliessman, 1998):

- As diversity increases, so do opportunities for coexistence and beneficial interactions between species that can enhance agroecosystem sustainability.

- Greater diversity often allows better resource-use efficiency in an agroecosystem. There is better system-level adaptation to habitat heterogeneity, leading to complementarity in crop species needs, diversification of niches, overlap of species niches, and partitioning of resources.
- Ecosystems in which plant species are intermingled possess an associated resistance to herbivores as in diverse systems there is a greater abundance and diversity of natural enemies of pest insects keeping in check the populations of individual herbivore species.
- A diverse crop assemblage can create a diversity of microclimates within the cropping system that can be occupied by a range of noncrop organisms —including beneficial predators, parasites, pollinators, soil fauna and antagonists— that are of importance for the entire system.
- Diversity in the agricultural landscape can contribute to the conservation of biodiversity in surrounding natural ecosystems.
- Diversity in the soil performs a variety of ecological services such as nutrient recycling and detoxification of noxious chemicals and regulation of plant growth.
- Diversity reduces risk for farmers, especially in marginal areas with more unpredictable environmental conditions. If one crop does not do well, income from others can compensate.

Agroecology and the Design of Sustainable Agroecosystems

Most people involved in the promotion of sustainable agriculture aim at creating a form of agriculture that maintains productivity in the long term by (Pretty, 1994; Vandermeer, 1995):

- optimizing the use of locally available resources by combining the different components of the farm system, i.e. plants, animals, soil, water, climate and people, so that they complement each other and have the greatest possible synergetic effects;

- reducing the use of off-farm, external and non-renewable inputs with the greatest potential to damage the environment or harm the health of farmers and consumers, and a more targeted use of the remaining inputs used with a view to minimizing variable costs;
- relying mainly on resources within the agroecosystem by replacing external inputs with nutrient cycling, better conservation, and an expanded use of local resources;
- improving the match between cropping patterns and the productive potential and environmental constraints of climate and landscape to ensure long-term sustainability of current production levels;
- working to value and conserve biological diversity, both in the wild and in domesticated landscapes, and making optimal use of the biological and genetic potential of plant and animal species; and
- taking full advantage of local knowledge and practices, including innovative approaches not yet fully understood by scientists although widely adopted by farmers.

Agroecology provides the knowledge and methodology necessary for developing an agriculture that is on the on e hand environmentally sound and on the other hand highly productive, socially equitable and economically viable. Through the application of agroecological principles, the basic challenge for sustainable agriculture to make better use of internal resources can be easily achieved by minimizing the external inputs used, and preferably by regenerating internal resources more effectively through diversification strategies that enhance synergisms among key components of the agroecosystem.

The ultimate goal of agroecological design is to integrate components so that overall biological efficiency is improved, biodiversity is preserved, and the agroecosystem productivity and its self-regulating capacity is maintained. The goal is to design an agroecosystem that mimics the structure and function of local natural ecosystems; that is, a system with high species diversity and a biologically active soil, one that promotes natural pest control, nutrient recycling and high soil cover to prevent resource losses.

Conclusions

Agroecology provides guidelines to develop diversified agroecosystems that take advantage of the effects of the integration of plant and animal biodiversity such integration enhances complex interactions and

Table 1. Ecological processes to optimize in agroecosystems

- Strengthen the immune system (profer functioning of natural pest control).
- Decrease toxicity through elimination of agrochemicals.
- Optimize metabolic function (organic matter decomposition and nutrient cycling.
- Balance regulatory systems (nutrient cycles, water balance, energy flow, population regulation, etc.).
- Enhance conservation and regeneration of soil-water resources and biodiversity.
- Increase and sustain long-term productivity.

Table 2. Mechanisms to improve agroecosystems immunity

- Increase of plant species and genetic diversity in time and space.
- Enhencement of functional biodiversity (natural enemies, antagonists, etc.).
- Enhencement of soil organic matter and biological ability.
- Elimination of toxic inputs and residues.

synergisms and optimizes ecosystem functions and processes, such as biotic regulation of harmful organisms, nutrient recycling, and biomass production and accumulation, thus allowing agroecosystems to sponsor their own functioning. The end result of agroecological design is improved economic and ecological sustainability of the agroecosystem, with the proposed management systems specifically in tune with the local resource base and operational framework of existing environmental and socioeconomic conditions. In an agroecological strategy, management components are directed to highlight the conservation and enhancement of local agricultural resources (germplasm, soil, beneficial fauna, plant biodiversity, etc.) by emphasizing a development methodology that encourages farmer participation, use of traditional knowledge, and adaptation of farm enterprises that fit local needs and socioeconomic and biophysical conditions.

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Chapter 3

Chapter 3

Ten Reasons why Biotechnology will not Ensure Food Security, Protect the Environment and Reduce Poverty in the Developing World

Advocates of biotechnology affirm that the application of genetic engineering to develop transgenic crops will increase world agricultural productivity, enhance food security, and move agriculture away from a dependence on chemical inputs helping to reduce environmental problems. This paper challenges such assertions by first demystifying the Malthusian view that hunger is due to a gap between food production and human population growth. Second, we expose the fact that current bio-engineered crops are not designed to increase yields or for poor small farmers, so that they may not benefit from them. In addition, transgenic crops pose serious environmental risks, continuously underplayed by the biotechnology industry. Finally, it is concluded that there are many other agro-ecological alternatives that can solve the agricultural problems that biotechnology aims at solving, but in a much more socially equitable manner and in a more environmentally harmonious way.

Biotechnology companies often claim that genetically modified organisms (GMOs) —specifically genetically altered seeds— are essential scientific breakthroughs needed to feed the world, protect the environment, and reduce poverty in developing countries. The Consultative Group on International Agricultural Research (CGIAR) and its constellation of international centers around the world charged with research to enhance food security in the developing world echo this view, which rests on two critical assumptions. The first is that hunger is due to a gap between food production and human population density or growth rate. The second is that genetic engineering is the only or best way to increase agricultural production and, thus, meet future food needs.

Our objective is to challenge the notion of biotechnology as a magic bullet solution to all of agriculture's ills, by clarifying misconceptions concerning these underlying assumptions.

1. There is no relationship between the prevalence of hunger in a given country and its population.

For every densely populated and hungry nation like Bangladesh or Haiti, there is a sparsely populated and hungry nation like Brazil and Indonesia. The world today produces more *M.A. Altieri & P. Rosset - Ten Reasons Why Biotechnology Will Not Help the Developing World* food per inhabitant than ever before. Enough food is available to provide 4.3 pounds for every person everyday: 2.5 pounds of grain, beans and nuts, about a pound of meat, milk and eggs and another of fruits and vegetables. The real causes of hunger are poverty, inequality and lack of access to food and land. Too many people are too poor to buy the food that is available (but often poorly distributed) or lack the land and resources to grow it themselves (Lappe, Collins and Rosset, 1998).

2. Most innovations in agricultural biotechnology have been profit-driven rather than needdriven.

The real thrust of the genetic engineering industry is not to make third world agriculture more productive, but rather to generate profits (Busch *et al.*, l990). This is illustrated by reviewing the principle technologies on the market today: (1) herbicide resistant crops, such as Monsanto's «Roundup Ready» soybeans, seeds that are tolerant to Monsanto's herbicide Roundup, and (2) «Bt» (*Bacillus thuringiensis*) crops which are engineered to produce their own insecticide. In the first instance, the goal is to win a greater herbicide market-share for a proprietary product and, in the second, to boost seed sales at the cost of damaging the usefulness of a key pest management product (the *Bacillus thuringiensis* based microbial insecticide) relied upon by many farmers, including most organic farmers, as a powerful alternative to insecticides. These technologies respond to the need of biotechnology companies to intensify farmers' dependence upon seeds protected by so-called «intellectual property rights» which conflict directly with the age-old rights of farmers to reproduce, share or store seeds (Hobbelink, l991). Whenever possible corporations will require farmers to buy a company's brand of inputs and will forbid farmers from keeping or selling seed. By controlling germplasm from seed to sale, and by forcing farmers to pay inflated prices for seed-chemical packages, companies are determined to extract the most profit from their investment (Krimsky and Wrubel, l996).

3. The integration of the seed and chemical industries appears destined to accelerate increases in per acre expenditures for seeds plus chemicals, delivering significantly lower returns to growers.

Companies developing herbicide tolerant crops are trying to shift as much per acre cost as possible from the herbicide onto the seed via seed costs and technology charges. Increasingly price reductions for herbicides will be limited to growers purchasing technology packages. In Illinois, the adoption of herbicide resistant crops makes for the most expensive soybean seedplus- weed management system in modern history —between $40.00 and $60.00 per acre depending on fee rates, weed pressure, and so on. Three years ago, the average seed-plus-weed control costs on Illinois farms was $26 per acre, and represented 23% of variable costs; today they represent 35-40% (Benbrook, l999). Many farmers are willing to pay for the simplicity and robustness of the new weed management system, but such advantages may be short-lived as ecological problems arise.

4. Recent experimental trials have shown that genetically engineered seeds do not increase the yield of crops.

A recent study by the United States Department of Agriculture (USDA) Economic Research Service shows that in 1998 yields were not significantly different in engineered versus non-engineered crops in 12 of 18 crop/region combinations. In the six crop/region combinations where Bt crops or herbicide tolerant crops (HTCs) fared better, they exhibited increased yields between 5-30%. Glyphosphate tolerant cotton showed no significant yield increase in either region where it was surveyed. This was confirmed in another study examining more than 8,000 field trials, where it was found that Roundup Ready soybean seeds produced fewer bushels of soybeans than similar conventionally bred varieties (USDA, l999).

5. Many scientists claim that the ingestion of genetically engineered food is harmless.

Recent evidence, however, shows that there are potential risks of eating such foods as the new proteins produced in such foods could: (1) act themselves as allergens or toxins; (2) alter the metabolism *M.A. Altieri & P. Rosset -Ten Reasons Why Biotechnology Will Not Help the Developing World* of the food producing plant or animal, causing it to produce new allergens or toxins; or (3) reduce its nutritional quality or value. In the case of (3), herbicide resistant soybeans can contain less isoflavones, an important phytoestrogen present in soybeans, believed to protect women from a number of cancers. At present, developing countries are importing soybean and corn from the United States, Argentina, and Brazil. Genetically engineered foods are beginning to flood the markets in the importing countries, yet no one can predict all their health effects on consumers, who are unaware that they are eating such food. Because genetically engineered food remains unlabeled, consumers cannot discriminate between genetically engineered (GE) and non-GE food, and should serious health problems arise, it will be extremely difficult to trace them to their source. Lack of labeling also helps to shield the corporations that could be potentially responsible from liability (Lappe and Bailey, l998).

6. Transgenic plants which produce their own insecticides, closely follow the pesticide paradigm, which is itself rapidly failing due to pest resistance to insecticides.

Instead of the failed «one pest-one chemical» model, genetic engineering emphasizes a «one pest-one gene» approach, shown over and over again in laboratory trials to fail, as pest species rapidly adapt and develop resistance to the insecticide present in the plant (Alstad and Andow, l995).

Not only will the new varieties fail over the short-to-medium term, despite so-called voluntary resistance management schemes (Mallet and Porter, l992), but in the process may render useless the natural Bt-pesticide which is relied upon by organic farmers and others desiring to reduce chemical dependence. Bt crops violate the basic and widely accepted principle of integrated pest management (IPM), which is that reliance on any single pest management technology tends to trigger shifts in pest species or the evolution of resistance through one or more mechanisms (NRC, l996). In general,the greater the selection pressure across time and space, the quicker and more profound the pests evolutionary response. An obvious reason for adopting this principle is that it reduces pest exposure to pesticides, retarding the evolution of resistance. But when the product is engineered into the plant itself, pest exposure leaps from minimal and occasional to massive and continuous exposure, dramatically accelerating resistance (Gould, l994). *Bacillus thuringiensis* will rapidly become useless, both as a feature of the new seeds and as an old standby sprayed when needed by farmers that want out of the pesticide treadmill (Pimentel *et al.*, l989).

7. The global fight for market share is leading companies to massively deploy transgenic crops around the world (more than 30 million hectares in l998) without proper advance testing of shortor long-term impacts on human health and ecosystems.

In the United States, private sector pressure led the White House to decree «no substantial difference» between altered and normal seeds, thus evading normal Food and Drug Administration (FDA) and Environmental Protection Agency (EPA) testing. Confidential documents made public in an on-going class action lawsuit have revealed that the FDA's own scientists do not agree with this determination. One reason is that many scientists are concerned that the large scale use of transgenic crops poses a series of environmental risks that threaten the sustainability of agriculture (Goldberg, l992; Paoletti and Pimentel, l996; Snow and Moran, l997; Rissler and Mellon, l996; Kendall *et al*., l997; Royal Society, l998). These risk areas are as follows:

• The trend to create broad international markets for single products, is simplifying cropping systems and creating genetic uniformity in rural landscapes. History has shown that a huge area planted to a single crop variety is very vulnerable to new matching strains of pathogens or insect pests. Furthermore, the widespread use of homogeneous transgenic varieties will unavoidably lead to «genetic erosion,» as the local varieties used by thousands of farmers in the developing world are replaced by the new seeds (Robinson, l996). *M.A. Altieri & P. Rosset - Ten Reasons Why Biotechnology Will Not Help the Developing World.*

• The use of herbicide resistant crops undermines the possibilities of crop diversification, thus, reducing agrobiodiversity in time and space (Altieri, l994).

• The potential transfer through gene flow of genes from herbicide resistant crops to wild or semidomesticated relatives can lead to the creation of superweeds (Lutman, l999).

• There is potential for herbicide resistant varieties to become serious weeds in other crops (Duke l996; Holt and Le Baron, l990).

• Massive use of Bt crops affects non-target organisms and ecological processes. Recent evidence shows that the Bt toxin can affect beneficial insect predators that feed on insect pests present on Bt crops (Hilbeck *et al.*, l998). In addition, windblown pollen from Bt crops, found on natural vegetation surrounding transgenic fields, can kill non-target insects such as the monarch butterfly (Losey *et al*., l999). Moreover, Bt toxin present in crop foliage plowed under after harvest can adhere to soil colloids for up to 3 months, negatively affecting the soil invertebrate populations that break down organic matter and play other ecological roles (Donnegan *et al*., l995; Palm *et al*., l996).

• There is potential for vector recombination to generate new virulent strains of viruses, especially in transgenic plants engineered for viral resistance with viral genes. In plants containing coat protein genes, there is a possibility that such genes will be taken up by unrelated viruses infecting the plant. In such situations, the foreign gene changes the coat structure of the viruses and may confer properties, such as changed method of transmission between plants. The second potential risk is that recombination between RNA virus and a viral RNA inside the transgenic crop could produce a new pathogen leading to more severe disease problems. Some researchers have shown that recombination occurs in transgenic plants and that under certain conditions it produces a new viral strain with altered host range (Steinbrecher, l996).

Ecological theory predicts that the large-scale landscape homogenization with transgenic crops will exacerbate the ecological problems already associated with monoculture agriculture.

Unquestioned expansion of this technology into developing countries may not be wise or desirable. There is strength in the agricultural diversity of many of these countries, and it should not be inhibited or reduced by extensive monoculture, especially when consequences of doing so results in serious social and environmental problems (Altieri, l996).

Although the ecological risks issue has received some discussion in government, international, and scientific circles, discussions have often been pursued from a narrow perspective that has downplayed the seriousness of the risks (Kendall *et al.*, 1997; Royal Society, 1998). In fact, methods for risk assessment of transgenic crops are not well developed (Kjellsson and Simmsen, 1994) and there is justifiable concern that current field biosafety tests tell little about potential environmental risks associated with commercial-scale production of transgenic crops. A main concern is that international pressures to gain markets and profits is resulting in companies releasing transgenic crops too fast, without proper consideration for the long-term impacts on people or the ecosystem.

8. There are many unanswered ecological questions regarding the impact of transgenic crops.

Many environmental groups have argued for the creation of suitable regulation to mediate the testing and release of transgenic crops to offset environmental risks and demand a much better assessment and understanding of ecological issues associated with genetic engineering. This is M.A. Altieri & P. Rosset - *Ten Reasons Why Biotechnology Will Not Help the Developing World* crucial, as many results emerging from the environmental performance of released transgenic crops suggest that in the development of resistant crops not only is there a need to test direct effects on the target insect or weed, but the indirect effects on the plant. Plant growth, nutrient content, metabolic changes, and effects on the soil and non-target organisms should all be examined. Unfortunately, funds for research on environmental risk assessment are very limited.

For example, the USDA spends only 1% of the funds allocated to biotechnology research on risk assessment, about $1-2 million per year. Given the current level of deployment of genetically engineered plants, such resources are not enough to even discover the «tip of the iceberg». It is a tragedy-in-the-making that so many millions of hectares have been planted without proper biosafety standards. Worldwide such acreage expanded considerably in 1998 with transgenic cotton reaching 6.3 million acres, transgenic corn reaching 20.8 million acres, and transgenic soybean 36.3 million acres. This expansion has been helped along by marketing and distribution agreements entered into by corporations and marketers (i.e. Ciba Seeds with Growmark and Mycogen Plant Sciences with Cargill), and in the absence of regulations in many developing countries. Genetic pollution, unlike oil spills, cannot be controlled by throwing a boom around it.

9. As the private sector has exerted more and more dominance in advancing new biotechnologies.

The public sector has had to invest a growing share of its scarce resources in enhancing biotechnological capacities in public institutions, including the CGIAR, and in evaluating and responding to the challenges posed by incorporating private sector technologies into existing farming systems. Such funds would be much better used to expand support for ecologically based agricultural research, as all the biological problems that biotechnology aims at can be solved using agroecological approaches. The dramatic effects of rotations and intercropping on crop health and productivity, as well as of the use of biological control agents on pest regulation have been confirmed repeatedly by scientific research. The problem is that research at public institutions increasingly reflects the interests of private funders at the expense of public good research, such as biological control, organic production systems and general agroecologicaltechniques. Civil society must request for more research on alternatives to biotechnology by universities and other public organizations (Krimsky and Wrubel, l996). There is also an urgent need to challenge the patent system and intellectual property rights intrinsic to the World Trade Organization (WTO) which not only provide multinational corporations with the right to seize and patent genetic resources, but will also accelerate the rate at which market forces already encourage monocultural cropping with genetically uniform transgenic varieties. Based on history and ecological theory, it is not difficult to predict the negative impacts of such environmental simplification on the health of modern agriculture (Altieri, l996).

10. Much of the needed food can be produced by small farmers located throughout the world using agroecological technologies (Uphoff & Altieri , l999).

In fact, new rural development approaches and low-input technologies spearheaded by farmers and non-governmental organizations (NGOs) around the world are already making a significant contribution to food security at the household, national, and regional levels in Africa, Asia and Latin America (Pretty, l995). Yield increases are being achieved by using technological approaches, based on agroecological principles that emphasize diversity, synergy, recycling and integration; and social processes that emphasize community participation and empowerment (Rosset, l999). When such features are optimized, yield enhancement and stability of production are achieved, as well as a series of ecological services such conservation of biodiversity, soil and water restoration and conservation, improved natural pest regulation mechanisms, and so on (Altieri *et al*., 1998).

These results are a breakthrough for achieving food security and environmental preservation in the developing world, but their potential and further spread depends on investments, policies, institutional support, and attitude changes on the part of policy makers and the scientific community; especially the CGIAR who should devote much of its efforts to the 320 million poor *M.A. Altieri & P. Rosset - Ten Reasons Why Biotechnology Will Not Help the Developing World* farmers living in marginal environments. Failure to promote such people-centered agricultural research and development due to the diversion of funds and expertise towards biotechnology will forego an historical opportunity to raise agricultural productivity in economically viable, environmentally benign, and socially uplifting ways.

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Chapter 4

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The Ecological Impacts of Transgenic Crops

Transgenic crops (GMCs), main products of agricultural biotechnology, are increasingly becoming a dominant feature of the agricultural landscapes of the USA and other countries. Worldwide, the areas planted to transgenic crops jumped more than thirty-fold in the past seven years, from 3 million hectares in 1996 to nearly 58.7 million hectares in 2002 (James, 2002). The increase in area between 2001 and 2002 is 12%, equivalent to 6.1 million has. Despite expectations that transgenic crops will benefit third world agriculture, 99% of the total global GM crop area is still concentrated in four countries: USA, 55% of global total, Argentina, 27%, Canada, 6% and China 4%. Globally the main GM crops soybean occupying 36.5 million has, maize 12.4% has followed by cotton and canola .In the USA, Argentina and Canada, over half of the average for major crops such as soybean, corn and canola are planted in transgenic varieties. Herbicide resistant crops (HRC) and insect resistant crops (Bt crops) have been consistently the dominant traits.

Transnational corporations (TNCs) such as Monsanto, DuPont, Novartis, etc. which are the main proponents of biotechnology argue that carefully planned introduction of these crops should reduce or even eliminate the enormous crop losses due to weeds, insect pests, and pathogens. In fact, they argue that the use of such crops will have added beneficial effects on the environment by significantly reducing the use of agrochemicals (Krimsky and Wrubel, 1996). Several scientists argue that HRCs and Bt crops have been a poor choice of traits to feature this new technology given predicted environmental problems and the issue of resistance evolution. In fact, there is enough evidence to suggest that both these types of crops are not really needed to address the problems they were designed to solve. On the contrary, they tend to reduce the pest management options available to farmers. There are many alternative approaches, (i.e. rotations, polycultures, cover crops, biological control, etc.) that farmers can use to effectively regulate the insect and weed populations that are being targeted by the biotechnology industry. To the extent that transgenic crops further entrench the current monocultural system, they impede farmers from using a plethora of alternative methods (Altieri, 1996).

GM crops further lead to agricultural intensification and ecological theory predicts that as long as transgenic crops follow closely the pesticide paradigm, such biotechnological products will do nothing but reinforce the pesticide treadmill in agroecosystems, thus legitimizing the concerns that many environmentalists and some scientists have expressed regarding the possible environmental risks of genetically engineered organisms. In fact, there are several widely accepted environmental drawbacks associated with the rapid deployment and widespread commercialization of such crops in large monocultures, including (Rissler and Mellon, 1996; Snow and Moran, 1997; Kendall *et al.,* l997; Altieri, 2000):

a) the spread of transgenes to related weeds or conspecifics via crop-weed hybridization;

b) reduction of the fitness of non-target organisms (especially weeds or local varieties) through the acquisition of transgenic traits via hybridization;

c) the rapid evolution of resistance of insect pests such as Lepidoptera to Bt;

d) accumulation of the insecticidal Bt toxin, which remains active in the soil after the crop is ploughed under and binds tightly to clays and humic acids;

e) disruption of natural control of insect pests through intertrophic-level effects of the Bt toxin on natural enemies;

f) unanticipated effects on non-target herbivorous insects (i.e. monarch butterflies) through deposition of transgenic pollen on foliage of surrounding wild vegetation (Losey *et al.,* l999); and

g) vector-mediated horizontal gene transfer and recombination to create new pathogenic organisms

Direct benefits of biodiversity of agriculture lie in the range of environmental services provided by the different biodiversity components such as nutrient cycling, pest regulation and productivity. Any reductions in agroecosystem biodiversity prompted by GM crops is bound to affect such services and thus affect agroecosystem function. This paper focuses on the known and potential effects of the two dominant types of GM crops: HRCs and Bt crops.

Biotechnology and the Loss of Agrobiodiversity

Ninety one percent of the 1.5 billion hectares of cropland are under annual crops worldwide, mostly monocultures of wheat, rice, maize, cotton, and soybeans (Smil, 2000). This process represents an extreme form of simplification of nature's biodiversity, as monocultures in addition to being genetically uniform and species-poor systems, advance at the expense of natural vegetation, a key landscape component that provides important ecological services to agriculture such as natural mechanisms of crop protection (Altieri, 1999). Since the onset of agricultural modernization, farmers and researchers have been faced with a main ecological dilemma arising from the homogenization of agricultural systems: an increased vulnerability of crops to insect pests and diseases, which can be devastating when infesting uniform crop, large scale monocultures (Adams *et al.,* l971; Altieri and Letourneau, l982, l984). Monocultures may have temporary economic advantages for farmers, but in the long term they do not represent an ecological optimum. Rather, the drastic narrowing of cultivated plant diversity has put the world's food production in greater peril (NAS, l972; Robinson, 1996).

The rapid spread of transgenic crops further threatens crop diversity by promoting large monocultures in a rapid scale leading to further environmental simplification and genetic uniformity History has repeatedly shown that uniformity characterizing agricultural areas sown to a smaller number of varieties as in the case of GM crops, is a source of increased risk for farmers, as the genetically homogeneous fields tend to be more vulnerable to disease and pest attack (Robinson, 1996). Examples of disease epidemics associated with homogeneous crops abound in the literature, including the $1 billion loss of maize in the USA in 1970 and the 18 million citrus trees destroyed by pathogens in Florida in 1984 (Thrupp, 1998).

Proponents of the biotech revolution are the same as those that rpomoted the Green Revolution in the developing world. These people assume progress and achieving development in traditional agriculture as inevitably requiring the replacement of local crop varieties for improved ones, and that the economic and technological integration of traditional farming systems into the global system is a positive step that enables increased production, income and commonly well being (Wilkes and Wilkes, 1972). But as evinced by the Green Revolution integration brought in addition several negative impacts (Tripp, 1996; Lappe *et al.,* 1998):

- The Green Revolution involved the promotion of a package that included modern varieties (MVs), fertilizer and irrigation, marginalizing a great number of resource-poor farmers who could not afford the technology.
- In areas where farmers adopted the package stimulated by government extension and credit programs, the spread of MVs greatly increased the use of pesticides, often with serious health and environmental consequences.
- Enhanceded uniformity caused by sowing large areas to a few MVs increased risk for farmers. Genetically uniform crops proved more

susceptible to pests and diseases, and also improved varieties did not perform well in marginal environments where the poor live.

- Diversity is an important nutritional resource of poor communities, but the spread of MVs was accompanied by a simplification of traditional agroecosystems and a trend toward monoculture which affected dietary diversity thus raising considerable nutritional concerns.
- The replacement of folk varieties also represents a loss of cultural diversity, as many varieties are integral to religious or community ceremonies. Given this, several authors have argued that the conservation and management of agrobiodiversity may not be possible without the preservation of cultural diversity.

Concerns have been raised about weather the introduction of transgenic crops may replicate or further aggravate the effects of MVs on the genetic diversity of landraces and wild relatives in areas of crop origin and diversification and therefore affect the cultural thread of communities. The debate was prompted by Nature's controversial article reporting the presence of introgressed transgenic DNA constructs in native maize landraces grown in remote mountains in Oaxaca, Mexico (Quist and Chapela, 2001). Although there is a high probability that the introduction of transgenic crops will further accelerate the loss of genetic diversity and of indigenous knowledge and culture, through mechanisms similar to those of the Green revolution, there are some fundamental differences in the magnitude of the impacts. The Green Revolution increased the rate at which modern varieties replaced folk varieties, without necessarily changing the genetic integrity of local varieties. Genetic erosion involves a loss of local varieties but it can be slowed and even reversed through in-situ conservation efforts which conserve not only landraces and wild-weedy relatives, but also agroecological and cultural relationships of crop evolution and management in specific localities. Examples of successful in-situ conservation have been widely documented.

The problem with introductions of transgenic crops into diversity regions is that the spread of characteristics of genetically altered grain to local varieties favored by small farmers could dilute the natural sustainability of these races.

Although many proponents of biotechnology believe that unwanted gene flow from GM maize may not compromise maize biodiversity (and therefore the associated systems of agricultural knowledge and practice along with the ecological and evolutionary processes involved) and may pose no worse a threat than cross-pollination from conventional (non GM) seed. In fact some industry researchers believe that DNA from engineered maize is unlikely to have an evolutionary advantage, but if transgenes do persist they may actually prove advantageous to Mexican farmers and crop diversity. But here a key question arises: Can genetically engineered plants actually increase crop production and, at the same time repel pest, resist herbicides, and confer adaptation to stressful factors commonly faced by small farmers? Thermodynamic considerations suggest they cannot; traits important to indigenous farmers (resistance to drought, food or fodder quality, maturity, competitive ability, performance on intercrops, storage quality, taste or cooking properties, compatibility with household labor conditions, etc) could be traded for transgenic qualities which may not be important to farmers (Jordan, 2001). Under this scenario risk will increase and farmers will lose their ability to adapt to changing biophysical environments and produce relatively stable yields with a minimum of external inputs while supporting their communities' food security (Altieri, 2003).

Most scientists agree that teosinte and maize interbreed. One problematic result from a transgenic maize-teosintle cross would be if the crop-wild relative hybrids would be more successful by acquiring tolerance to pests (Ellstrand, 2001). Such hybrids could become problem weed upsetting farmers management but also out-competing wild relatives. Another potential problem derived from transgenic crop – to – wild gene flow is that it can lead to extinction of wild plants via swamping and outbreeding depression (Stabinsky and Sarno, 2001).

Ecological Effects of HRCs Gene Flow: Super Weeds and Herbicide Resistance

Just as it occurs between traditionally improved crops and wild relatives, pollen mediated gene flow occurs between GMCs and wild relatives or conspecifics despite all possible efforts to reduce it. The main concern with trangenes that confer significant biological advantages is that they may transform wild/weed plants into new or worse weeds. In the cases of hybridization of HRCs with populations of free living relatives will make these plants increasingly difficult to control, especially if they are already recognized as agricultural weeds and if they acquire resistance to widely used herbicides. Snow and Palma (1997) argue that widespread cultivation of HRCs could exacerbate the problem of gene flow from cultivated plants enhancing the fitness of sexually compatible wild relatives. In fact, the flow of herbicide resistant transgenes has already become a problem in Canadian farmers' fields where volunteer canola resistant to three herbicides (glyphosate, imidazolinone and gufosinate) has been detected, a case of «stacked» or resistance to multiple herbicides (Hall *et al.,* 2000). The Royal Society of Canada (2001) reports that herbicide-resistant volunteer canola plants ae beginning to develop into a major weed problem in some parts of the Paririe Provinces of Canada. Transgenic resistance to glufosinate is capable of introgressing from Brassica napus into populations of weedy Brassica napa, and to persist under natural conditions (Snow and Moran 1997). In Europe there is a major concern about the possibility of pollen transfer of herbicide tolerant genes from Brassica oilseeds to Brassica nigra and Sinapis arvensis (Goldberg, 1992).

Transgenic herbicide resistance in crop plants simplifies chemically based weed management because it typically involves compounds that are active on a very broad spectrum of weed species. Post-emergence application timing for these materials fits well with reduced or zero-tillage production methods, which can conserve soil and reduce fuel and tillage costs (Duke, l996). Reliance on HRCs however perpetuates the weed resistance problems and species shifts that are common to conventional herbicide based approaches. Herbicide resistance becomes more of a problem as the number of herbicide modes of action to which weeds are exposed becomes fewer and fewer, a trend that HRCs may exacerbate due to market forces. Given industry pressures to increase herbicide sales, acreage treated with broad-spectrum herbicides will expand, exacerbating the resistance problem. For example, it has been projected that the acreage treated with glyphosate will increase to nearly 150 million acres. Although glyphosate is considered less prone to weed resistance, the increased use of the herbicide will result in weed resistance, even if more slowly, as it has been already documented with Australian populations of annual ryegrass, quackgrass, birdsfoot trefoil and *Cirsium arvense* (Gill, 1995). In Iowa, *Amaranthus rudis* populations showed delayed germination thus «avoiding» planned glyphosate applications and velvetleaf demonstrated greater tolerance to glyphosate (Owens, 1997). Conyza canadensis (horseweed) has been found resistant to glyphpsate in Delaware (VanGessel and Glasgow, 2001).

Perhaps the greatest problem of using HRCs to solve weed problems is that they steer efforts away from alternatives such crop rotation or cover crops and help to maintain cropping systems dominated by one or two annual species. Crop rotation not only reduces the need for herbicides, but also improves soil and water quality, minimize requirements for synthetic nitrogen fertilizer, regulate insect pest and pathogen populations, increase crop yields, and reduce yield variance. Thus, to the extent that transgenic HRCs inhibit the adoption of rotational crops and cover crops they hinder the development of sustainable agriculture.

HRCs and the Consequences of Total Weed Removal

The presence of weeds within or around crop fields influences the dynamics of the crop and associated biotic communities. Stud-ies over the past 30 years have produced a great deal of evidence that the manipulation of a specific weed species, a particular weed control practice, or a cropping system can affect the ecology of insect pests and associated natural enemies (Altieri *et al.;* Doll, 1977).

Many weeds are important components of agroecosystems be-cause they positively affect the biology and dynamics of beneficial insects.

Weeds offer many important requisites for natural enemies such as alternative prey/hosts, pollen, or nectar as well as microhab-itats that are not available in weedfree monocultures (Altieri and Whitcomb, 1979). Many insect pests are not continuously present in annual crops, and their predators and parasitoids must survive elsewhere during their absence. Weeds usually provide such resources (alternate host or pollen-nectar) thus aiding in the survival of viable natural enemy populations. In the last 20 years, research has shown that outbreaks of certain types of crop pests are less likely to occur in weeddiversified crop systems than in weedfree fields, mainly due to increased mortality imposed by natural enemies. Crop fields with a dense weed cover and high diversity usually have more predaceous ar-thropods than do weedfree fields. The successful establishment of several parasitoids usually depend on the presence of weeds that provide nectar for the adult female wasps. Relevant examples of cropping systems in which the presence of specific weeds has enhanced the biological control of particular pests have been reviewed by Altieri (1994). A literature survey by Baliddawa (1985) showed that population densities of 27 insect pest species were reduced in weedy crops compared to weed-free crops. Obviously, total elimination of weeds as it is common practice under HRC crops, can have major ecological implications for insect pest management.

Recent studies conducted in UK, showed that reduction of weed biomass, flowering and seeding of plants under HRCs management within and in margins of beet and spring oilseed rape involved changes on resource availability with knock-on effects on higher trophic levels reducing abundance of relatively sedentary and host specific herbivores including Heteroptera, butterflies and bees. Counts of predaceous carabid beetles that feed on weed seeds where also smaller in HRC fields (Hawes *et al.,* 2003). Data showed that in beet and oilseed rape, weed densities were lower in the HRCs compared to its conventional cousins while the biomass in GM beet and oilseed rape was one-sixth and about one-third, respectively, of that in conventional plots. Researchers also recorded lower biomass for many species of weeds among the two HR crops which led them to conclude that these «differences compounded over time would result in large decreases in population densities of arable weeds». And, «With a few exceptions, weed species in beet and spring oilseed rape were negatively affected by the GMHT treatment». The abundance of invertebrates, which are food for mammals, birds and other invertebrates, and important for controlling pests or recycling nutrients within the soil, was also found to be generally lower in GMHT beet and oilseed rape.

These reductions are an underestimate as comparisons were made between conventional and biotech plots. Because organic systems were not included in the comparisons the full spectrum of impacts on biodiversity were not captured. Also the studies did not address what effects if any did biodiversity reductions have on agroecosystem processes such as nutrient cycling or pest regulation.

Ecological Risks of Bt Crops: Pest Resistance

Based on the fact that more than 500 species of pests have already evolved resistance to conventional insecticides, pests can also evolve resistance to Bt toxins present in transgenic crops (Gold, l994). No one questions if Bt resistance will develop, the question is now how fast it will develop. Susceptibility to Bt toxins can therefore be viewed as a natural resource that could be quickly depleted by inappropriate use of Bt crops (Mellon and Rissler, l998). However, cautiously restricted use of these crops should substantially delay the evolution of resistance. The question is whether cautious use of Bt crops is possible given commercial pressures that have resulted in a rapid roll-out of Bt crops reaching 7.6 million hectares worldwide in 2002.

Like conventional pesticides, transgenic technologies represent a single-intervention approach where in ecological factors are manipulated through the destruction of the pest. This approach disturbs the ecology of farms, causing ripple effects through the agroecosystem. Pest populations are selected, typically resulting in resistance to the control, and pest predators are harmed either directly or through deprivation of their prey. To move beyond the «pesticide paradigm» followed by Bt crops, technologies should be designed to induce pest damage tolerance rather than resistance to pests. Tolerance does not rely on toxicity to kill pests and therefore does not negatively impact non-target organisms or promote resistance development (Welsh *et al.,* 2002).

In order to delay the inevitable development of resistance by insects to Bt crops, bioengineers are preparing resistance management plans, which consist of patchworks of transgenic and nontransgenic (called refuges) to delay the evolution of resistance by providing susceptible insects for mating with resistant insects. Although refuges should be in size at least 30 percent of the crop area, according to members of the Campaign for Food Safety, Monsanto's new plan calls for only 20 percent refuges even when insecticides are to be used. Moreover, the plan offers no details whether the refuges must be planted alongside the transgenic crops, or at some distance away, where studies suggest they would be less effective (Mallet and Porter, 1992). In addition to refuges requiring the difficult goal of regional coordination between farmers, it is unrealistic to expect most small and medium sized farmers to devote up to 30 to 40 percent of their crop area to refuges, especially if crops in these areas are to sustain heavy pest damage. In one of the few field studies assessing resistance development to BT crops, Tabashnik *et al.* (2001) found in 1997 that approximately 3.2 % of pink bollworm larvae collected from Arizona Bt cotton fields exhibited resistance.

The farmers that face the greatest risk from the development of insect resistance to Bt are neighboring organic farmers who grow corn and soybeans without agrochemicals. Once resistance appears in insect populations, organic farmers will not be able to use *Bacillus thuringiensis* in its microbial insecticide form to control the lepidopteran pests that move in from adjacent neighboring transgenic fields. In addition, genetic pollution of organic crops resulting from gene flow (pollen) from transgenic crops can jeopardize the certification of organic crops forcing organic farmers to lose premium markets. Who will compensate the farmers for such losses?

BT Crops and Beneficial Insects

Bacillus thuringiensis proteins are becoming ubiquitous, highly bioactive substances in agroecosystems present for many months. Most, if not all, non-target herbivores colonizing Bt crops in the field, although not lethally affected, ingest plant tissue containing Bt protein which they can pass on to their natural enemies in a more or less processed form. Polyphagous natural enemies that move between crop cultures are found to frequently encounter Bt containing non-target herbivorous prey in more that one crop during the entire season. According to Groot and Dicke (2002) natural enemies may come in contact more often with Bt toxins via non-target herbivores, because the toxins do not bind to receptors on the midgut membrane in the non-target herbivores. This is a major ecological concern given previous studies that documented that Cry1 Ab adversely affected the predaceous lacewing *Chrysoperla carnea* reared on Bt corn-fed prey larvae (Hilbeck, l998). In another study feeding three different herbivore species exposed to Bt-maize to *C. carnea,* showed a significant increase in mortality and a delay in development when predators were fed *Spodoptora littoralis* reared on Bt-maize. A combined interaction of poor prey quality and Cry 1Ab toxin may account for the negative effects on *C. carnea*. Apparently the fitness of parasitoids and predators is indirectly affected by Bt toxins exposed in GM crops by feeding from suboptimal food or because of host death and scarcity (Groot and Dicke, 2002). Because of the development of a new generation of Bt crops with much higher expression levels, the effects on natural enemies reported so far are likely to be an under-estimate.

These findings are problematic for small farmers in developing countries who rely for insect pest control, on the rich complex of predators and parasites associated with their mixed cropping systems (Altieri, 1994). Research results showing that natural enemies can be affected directly through inter-trophic level effects of the toxin present in Bt crops raises serious concerns about the potential disruption of natural pest control, as polyphagous predators that move within and between crop cultivars will encounter Bt-containing, non-target prey throughout the crop season.

Disrupted biocontrol mechanisms will likely result in increased crop losses due to pests or to increased use of pesticides by farmers with consequent health and environmental hazards.

Effects on the Soil Ecosystem

The possibilities for soil biota to be exposed to transgenic products are very high. The little research conducted in this area has already demonstrated long term persistence of insecticidal products (Bt and proteinase inhibitors) in soil after exposure to decomposing microbes (Donegan and Seidler, 1999). The insecticidal toxin produced by *Bacillus thuringiensis* subsp. *kurskatki* remain active in the soil, where it binds rapidly and tightly to clays and humic acids. The bound toxin retains its insecticidal properties and is protected against microbial degradation by being bound to soil particles, persisting in various soils for at least 234 days (Palm *et al.,* l996). Palm *et al.,* (1996) found that 25-30 % of the Cry1A proteins produced by Bt cotton leaves remained bound in the soil even after 140 days. In another study researchers confirmed the presence of the toxin in exudates from Bt corn and verified that it was active in an insecticidal bioassay using larvae of the tobacco hornworm (Saxena *et al.,* l999). In a recent study, after 200 days of exposure, *Lombricus terrestris* adults experienced a significant weight loss when fed Bt corn litter when compared to earthworms fed on non-Bt corn litter (Zwahlen *et al.*, 2003). Potentially these earthworms may serve as intermediaries through which Bt toxins may be posed or to organisms feeding of these earthworms. Given the persistence and the possible presence of exudates, there is potential for prolonged exposure of the microbial and invertebrate community to such toxins, and therefore studies should evaluate the effects of transgenic plants on both microbial and invertebrate communities and the ecological processes they mediate (Altieri, 2000).

If transgenic crops substantially alter soil biota and affect processes such as soil organic matter decomposition and mineralization, this would be of serious concern to organic farmers and most poor farmers in the developing world who cannot purchase or do not want to use expensive chemical fertilizers, and that rely instead on local residues, organic matter and especially soil organisms for soil fertility (i.e. key invertebrate, fungal or bacterial species) which can be affected by the soil bound toxin. Soil fertility could be dramatically reduced if crop leachates inhibit the activity of the soil biota and slow down natural rates of decomposition and nutrient release. Due to accumulation of toxins over time during degradation of plant biomass, the doses of Bt toxin to which these soil organisms are exposed may increase with time, so impacts on soil biology could be worse and longer term.

HCs can also indirectly soil biota through effects of glyphosate which appears to act as antibiotic in the soil inhibiting mycorrizae, antagonists and nitrogen fixing bacteria. Scientists have shown that root development, nodulation and nitrogen fixation is impaired in some HR soybean varieties which exhibit lower yields and that effects are worse under drought stress or infertile soils (Benbrook, 2001).

Conclusions

The available, independently generated scientific information suggests that the massive use of transgenic crops pose substantial potential risks from an ecological point of view. The environmental effects are not limited to pest resistance and creation of new weeds or virus strains (Kendall *et al.,* l997). As argued herein, transgenic crops can produce environmental toxins that move through the food chain and also end up in the soil where they bind to colloids and retain their toxicity affecting invertebrates and possibly nutrient cycling (Altieri, 2000). No one can really predict the long-term impacts on agrobiodiversity and the processes they mediate from the massive deployment of such crops.

Not enough research has been done to evaluate the environmental and health risks of transgenic crops, an unfortunate trend, as most scientists feel that such knowledge was crucial to have before biotechnological innovations were upscaled to actual levels. There is a clear need to further assess the severity, magnitude and scope of risks associated with the massive field release of transgenic crops. Much of the evaluation of risks must move beyond comparing GMC fields and conventionally managed systems to include alternative cropping systems featuring crop diversity and low-external input approaches. These systems express higher levels of biological diversity and thus allow scientists to capture the full range of impacts on biodiversity and agroecosystem processes.

Moreover, the large-scale landscape homogenization with transgenic crops will exacerbate the ecological problems already associated with monoculture agriculture (Altieri, 2000). Unquestioned expansion of this technology in to developing countries may not be wise or desirable. There is strength in the agricultural diversity of many of these countries, and it should not be inhibited or reduced by extensive monoculture, especially when consequences of doing so results in serious social and environmental problems (Altieri, 1996).

The repeated use of transgenic crops in an area may result in cumulative effects such as those resulting from the buildup of toxins in soils. For this reason, risk assessment studies not only have to be of an ecological nature in order to capture effects on ecosystem processes, but also of sufficient duration so that probable accumulative effects can be detected. A decade of carefully ecologically monitored field and larger scale results are necessary to assess the full potential for risks from GM crops to the environment. Decreases in pesticide use are not acceptable as proxies for environmental benefits. The application of multiple diagnostic methods to assess multitrophic effects and impacts on agroecosystem function will provide the most sensitive and comprehensive assessment of the potential ecological impact of transgenic crops.

Until these studies are completed a moratorium on transgenic crops based on the precautionary principle should be imposed in the USA and other regions. This principle advises that instead of using the criterion the «absence of evidence» of serious environmental damage, the proper decision criterion should be the» evidence of absence», in other words avoiding «type II» statistical error: the error of assuming that no significant environmental risk is present when in fact risk exists.

Although biotechnology maybe an important tool, at this point alternative solutions exist to address the problems that current GMCs, developed mostly by profit motives, are designed to solve. A recent study conducted by scientists at ICIPE in Africa highlight the dramatic positive effects of rotations, multiple cropping, and biological control on crop health, environmental quality and agricultural productivity confirmed by scientific research in many parts of the world (Altieri, l995). ICIPE scientists developed a habitat management system to control Lepidoptera stemborers, potential primary targets to be controlled via Bt crops. The push-pull system uses plants in the borders of maize fields which act as trap crops (Napier grass and Sudan grass) attracting stemborer colonization away from maize (the push) and two plants intercropped with maize (molasses grass and silverleaf) that repel the stemborers (the pull) (Khan *et al.,* 1998). Border grasses also enhance the parasitization of stemborers by the wasp *Cotesia semamiae*, and are important fodder plants. The leguminous silverleaf (*Desmodium uncinatum*) suppresses the parasitic weed Striga by a factor of 40 when compared with maize monocrop. *Desmodium's* N-fixing ability increases soil fertility; and it is an excellent forage. As an added bonus, sale of *Desmodium* seed is proving to be a new income-generating opportunity for women in the project areas. The push-pull system has been tested on over 450 farms in two districts of Kenya and has now been released for uptake by the national extension systems in East Africa. Participating farmers in the breadbasket of Trans Nzoia are reporting a 15-20 percent increase in maize yield. In the semi-arid Suba district —plagued by both stemborers and striga— a substantial increase in milk yield has occurred in the last four years, with farmers now being able to support increased numbers of dairy cows on the fodder produced. When farmers plant maize together with the push-pull plants, a return of US $2.30 for every dollar invested is made, as compared to only $1.40 obtained by planting maize as a monocrop. (Khan *et al.,* 1998)

Although biotechnology could be considered as one more tool that can be used to manage agroecosystems, in its present form is totally incompatible with more agroecological approaches given its cascading effects on agroecosystem function. Moreover, this technology is under corporate control, leaving it out of the realm of the international public goods, a major barrier when it comes to promoting socially equitable and accessible agricultural technologies

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Chapter 5

Chapter 5

A Dialogue of Wisdoms: Linking Ecologists and Traditional Farmers in the Search for a Truly Sustainable Agriculture

Throughout centuries, generations of farmers have developed complex, diverse and locally adapted agricultural systems, managed with time-tested ingenious practices that often lead to community food security and the conservation of natural resources and biodiversity. This peasant strategy of minimizing risk, stabilizes yields over the long term, promotes diet diversity, and maximizes returns under low levels of technology and limited resources. These microcosms of agricultural heritage can still be found throughout the developing world covering no less than 10 million hectares, providing a series of cultural and ecological services to rural inhabitants but also to humankind such as the preservation of traditional forms of farming knowledge, local crop and animal varieties and autochthonous forms of socio-cultural organization. By studying these systems ecologists can enhance their learning about the dynamics of complex systems, especially the relationship between biodiversity and ecosystem functioning, thus enriching ecological theory. Moreover, principles can de derived for practical application in the design of more sustainable farming systems appropriate to small farmers in the developing world. In fact several advances in modern agroecology have already accrued from the study of traditional agroecosystems and a series of novel agroecosystem designs have been modeled after successful traditional farming systems.

Ecological Diversity in Traditional Agriculture

The great majority of farmers in Latin America, Africa and Asia are peasants who still farm small plots of land, usually in marginal environments utilizing indigenous and subsistence agricultural methods. One of the salient features of these still prevalent traditional farming systems is their high degree of biodiversity. Polycultures are prevalent among peasants and cover at least 80% of the cultivated area of West Africa and in Latin American more than 40 percent of the cassava, 60 percent of the maize and 80 percent of the beans (photo 1) are grown intercropped with other crops (Francis, l986). These diversified agroeco-systems have emer-ged over centuries of cultural and biological evolution and represent accumulated expe-riences of peasants interacting with the environment without access to external in-puts, capital, or scientific knowledge (Wilson, 1999). Using inventive selfreliance, expe-riential knowledge, and locally available resources, peasants have often developed farming systems adapted to the local conditions enabling farmers to generate sustained yields meeting their subsistence needs, despite marginal land endowments and low use of external inputs (Wilken, 1987; Denevan 1995). Part of this performance is linked to the high levels of agrobiodiversity exhibited by traditional agroecosystems which in turn positively influences agroecosystem function (Vandermeer, 2001).


Photo 1

The persistence of millions of hectares under traditional agriculture in the form of raised fields, terraces (photo 2, next page), polycultures, agroforestry systems, etc., document a successful indigenous agricultural adaptation strategy to difficult environments and comprises a tribute to the «creativity» of peasants throughout the developing world (Altieri, 1999). These micro-cosms of traditional agricu-lture offer promising models for other areas as they promo-te biodiversity, thrive without agroche-micals, and sustain year-round yields (Denevan, 1995). Un-doubtedly, the en-semble of traditional crop management practices used by many resource-poor farmers throughout the developing world represent a rich resource for ecologists interested in understanding the mechanisms at work in complex agroecosystems, such as the interactions between biodiversity and ecosystem function or the use of natural succession as templates for agroecosystem design. Until only recently have applied ecologists recognized the virtues of diversified traditional agroecosystems whose sustainability lies in the complex ecological models they follow. The study of traditional agroecosystems and the ways in which peasants maintain and use biodiversity can also considerably speed the emergence of agroecological principles, which are urgently needed to develop more sustainable agroecosystems and agrobiodiversity conservation strategies both in the industrial and developing countries. In fact, such studies have already helped some agroecologists to create novel farm designs well adapted to the local agroecological and socioeconomic circumstances of peasants (Altieri, 2002). A key challenge has involved the translation of such principles into practical strategies of natural resource management. Nevertheless, more research must take place urgently, before this Neolithic ecological legacy is lost forever, victim of industrial agricultural development. This may indeed be one of the most important tasks for ecologists in the twentieth-first century.

Photo 2

The Extent and Significance of Traditional Agriculture

Despite the increasing industrialization of agriculture, the great majority of farmers are peasants, or small producers, dotting the rural landscapes with small scale, complex and diverse agricultural systems (Beets, 1990; Netting, 1993). It is estimated that there are some 960 million hectares of land under cultivation (arable and permanent crops) in Africa, Asia and Latin America, of which 10-15% is managed by traditional farmers (see Table 3 next page.)

In Latin America the peasant population includes 75 million people representing almost two thirds of the Latin America's total rural population. Average farm size of their units is about 1.8 hectares, but their contribution to the general food supply in the region is significant. In the 1980s it reached approximately 41% of the agricultural output for domestic consumption, and is responsible for producing at the regional level 51% of the maize, 77% of the beans, and 61% of the potatoes (Browder, 1989). About two million people from various indigenous groups live in the Amazon and southern Mexico featuring integrated agriculture-forestry systems with production aimed at subsistence and local-regional markets (Toledo, 2000).

In Africa the majority of farmers (many of them women) are smallholders with 2/3 of all farms below 2 hectares and 90% of farms below 10 hectares. Most small farmers practice «low-resource» agriculture based primarily on the use of local resources, but some make modest use of external inputs. Low-resource agriculture produces the majority of grain; almost all root, tuber and plantain crops, and the majority of legumes. Most basic food crops are grown by small farmers with virtually no or little use of fertilizers and improved seed. This situation however has changed in the last two decades as food production per capita has declined and Africa, once self-sufficient in cereals, now has to import millions of tons to fill the gap. Despite this increase in imports small farmers still produce most of Africa's food (Asenso-Okyere and Benneh, 1997). The majority of the more than 200 million rice farmers

Table 3. Partial distribution and extent of traditional agriculture in the developing world

Region	Number of farmers	Area (hectares or %)	Contribution to food security
Latin America	a. 16 million peasant units b. 50 million indigenous people	38% of total land devoted to agriculture, about 60.5 million hectares	a. 41% of food crop consumed domestically b. Half of humid tropics in Mexico and Amazon
Brazil	4.8 million family farmers	30% of total agricultural land	50% of land devoted to food crops
Cuba	1612 cooperatives and individual peasants	1.5 million hectares	10% of all food crops
Africa	a. 60-80% labor force involved in agriculture b. 70% of population living in rural areas (about 375 million) of Sub-Saharan Africa	100-150 million hectares	80% of cereals 95% of meat
Asia	200 million small scale rice farmers	a. 7.3 million hectares of upland rice b. 20.5 million hectares of rainfed rice	250 million rural people supported by upland shifting cultivation
Global estimate for developing world	50-100 million small holder family units	50-100 million hectares	30-50% of basic food crops

who live in Asia, a few farm more than 2 ha of rice. In China alone there are probably 75 million rice farmers who still practice farming methods similar to those used more than one thousand years ago (Hanks, 1992). Local cultivars, grown mostly on upland ecosystems and/or under rainfed conditions make up the bulk of the rice eaten by the rural poor; the large areas of modern, semi-dwarf varieties supply most of the rice to the urban centers.

The Complex Nature of Indigenous Knowledge

The species and genetic diversity of indigenous farming systems is not the result of a random adaptive process. Traditional agroecosystems are the result of a complex coevolutionary process between natural and social systems, which resulted in ingenious strategies of ecosystem appropriation. In most cases the indigenous knowledge behind the agricultural modification of the physical environment is very detailed (Brokenshaw *et al.,* 1980). Ethnobotanies are the most commonly documented folk taxonomies; in Mexico the Tzeltal, P'urepecha, and Yucatan Mayans can recognize more that 1200, 900 and 500 plant species, respectively (Alcorn, 1984). Soil types, degrees of soil fertility, and land-use categories are also discriminated in detail by farmers. Soil types are usually distinguished by color, texture, and even taste. Shifting cultivators usually classify their soils based on vegetation cover (Williams and Ortiz Solorio, 1981).

Information is extracted from the environment by special cognition and perception systems that select for the most adaptive or useful information and successful adaptations are preserved and passed from generation to generation through oral or experimental means. Indigenous peoples knowledge about ecosystems usually result in multidimensional productive strategies (i.e. multiple use ecosystems with multiple species), and these strategies generate (within certain ecological and technical limits) the food self-sufficiency of farmers in a region (Wilken, 1987).

Most traditional agriculture is place specific, evolving in time in a particular habitat and culture, and this is where and why it tends to be successful. Transfers of specific technologies to other places and contexts may fail, if soils, tools and social organization are different. This is why agroecologists do not focus on specific technologies, but rather in the principles used by traditional agriculturalists to meet the environmental requirements of their food-producing systems. In fact despite the myriad of agricultural systems most traditional agroecosystems share the following structural and functional commonalities (Gliessman, 1998):

- They combine high species numbers and structural diversity in time and space (both through vertical and horizontal organization of crops).
- They exploit the full range of microenvironments (which differ in soil, water, temperature, altitude, slope, fertility, etc.) within a field or region.
- They maintain closed cycles of materials and wastes through effective recycling practices.
- They rely on a complexity of biological interdependencies, resulting in high levels of biological pest suppression.
- They rely on local resources plus human and animal energy, thereby using low levels of input technology and exhibiting positive energy efficiency ratios.
- They rely on local varieties of crops and incorporate the use of wild plants and animals. Production is usually for local consumption. The level of income is low; thus, the influence of noneconomic factors on decision making is substantial.

The strength of rural people's knowledge is that it is based not only on acute observation but also on experimental learning. The experimental approach is very apparent in the selection of seed varieties for specific environments, but it is also implicit in the testing of new cultivation methods to overcome particular biological or socioeconomic constraints. Most local farmers have intimate knowledge about the ecological forces that surround them, however their experience is limited to a relatively small geographical and cultural setting. Such intimate local experience, cannot be matched by generalized knowledge of the ecologist, yet sophisticated training of the ecologist cannot be matched by the experiential knowledge of local farmers, despite the fact that ecologists may be unable to appreciate the rich texture that comes from detailed knowledge of local farmers (Vandermeer, 2003). This is why a «dialogue of wisdoms» is necessary among ecologists and traditional farmers. In fact it is an essential prerequisite to the development of a truly ecological agriculture, in which the people who own the knowledge must be part of the planning process. Local skills can be mobilized through participatory development approaches, combining local farmer knowledge and skills with those of external agents in the design and diffusion of appropriate farming techniques (Richards, 1985).

What Have Ecologists Learned from Traditional Farmers?

In traditional agroecosystems the prevalence of complex and diversified cropping systems is of key importance to peasants, as interactions between crops, animals and trees result in beneficial synergisms that usually allow agroecosystems to sponsor their own soil fertility, pest control and productivity (Altieri, 1985; Reinjtjes *et al.,* 1992).

By studying these systems ecologists can learn more about the dynamics of complex systems, especially the links between biodiversity and ecosystem function (Tilman *et al.,* l996), thus enriching ecological theory, as well as deriving principles for practical application in the design of more sustainable farming systems. There is no doubt that much can be learned from research on traditional agriculture. For example, deciphering how by interplanting, farmers take advantage of the ability of cropping systems to reuse their own stored nutrients can improve the ways in which modern farmers manage soil fertility. Similarly, by determining which biological mechanisms are at play within the complex structure of traditional agroecosystems which minimize crop losses due to insect pests, diseases and weeds, much progress can be made in pest management (Altieri, 1994). In fact several advances in modern agroecology have already accrued from the study of traditional agroecosystems and a series of novel agroecosystem designs have been modeled after successful traditional farming systems. A few examples follow:

Mimicking Nature

At the heart of the agroecology strategy is the idea that an agroecosystem should mimic the functioning of local ecosystems thus exhibiting tight nutrient cycling, complex structure, and enhanced biodiversity. The expectation is that such agricultural mimics, like their natural models, can be productive, pest resistant and conservative of nutrients (Ewel, 1999). This idea is nothing new for tropical small farmers who for centuries have designed home gardens which entail a highly efficient form of land use, incorporating a variety of crops with different growth habits. The result is a structure similar to tropical forests, with agroforests exhibiting diverse species on a multi-layered configuration (Denevan, 1995). Such systems yield enough to secure household food security plus a surplus for local markets. In such «forest-like» agricultural systems, nutrient cycles are tight and closed, as in the case of the traditional coffee under shade, where the system amply compensates the nitrogen loss by harvest with a subsidy from the shade trees. In highly co-evolved systems, researchers have found evidence of synchrony between the peaks of nitrogen transfer to the soil by decomposing litter and the periods of high nitrogen demand by flowering and fruiting coffee plants (Wilken, 1987).

Ewel (1986) termed this strategy the succession analog method, which requires a detailed description of a natural ecosystem in a specific environment and the botanical characterization of all potential crop components. When this information is available, the first step is to find crop plants that are structurally and functionally similar to the plants of the natural ecosystem. The spatial and chronological arrangements of the plants in the natural ecosystem are then used to design an analogous crop system, and researchers conduct spatial and temporal replacements of wild species by botanically/structurally/ecologically similar cultivars (Ewel, 1986, photo 3).

According to Ewel (1999), the only region where it would be advantageous to imitate natural ecosystems rather than struggle to impose simplicity through high inputs in ecosystems that are inherently complex, is the humid tropical lowlands. This area epitomizes environments of low abiotic stress but overwhelming biotic intricacy. The keys to agricultural success in this region are to (i) channel productivity into outputs of nutritional and economic importance, (ii) maintain adequate vegetational diversity to compensate for losses in a system simple enough to be horticulturally manageable, (iii) manage plants and herbivores to facilitate associational resistance, and (iv) use perennial

Photo 3

plants to maintain soil fertility, guard against erosion, and make full use of resources.

Understanding the Mechanisms Underlying the Productivity of Multi-Species Agroecosystems

In most multiple cropping systems developed by smallholders, productivity in terms of harvestable products per unit area is higher than under sole cropping with the same level of management. Yield advantages can range from 20 percent to 60 percent. These differences can be explained by a combination of factors which include the reduction of losses due to weeds, insects and diseases and a more efficient use of the available resources of water, light and nutrients (Vandermeer, 1989).

In Mexico, 1.73 hectares of land has to be planted with maize to produce as much food as one hectare planted with a mixture of maize, squash, and beans. In addition, a maize-squash-bean polyculture can produce up to four tons per hectare of dry matter for plowing into the soil, compared with two tons in a maize monoculture. In drier environments, maize is replaced by sorghum in the intercropping without affecting the productive capacity of cowpeas or beans and yielding LER values of 1.25-1.58. This system exhibits a greater stability of production as sorghum is more tolerant to drought (Francis, 1986).

The mechanisms that result in higher productivity in diverse agroecosystems are embedded in the process of facilitation. Facilitation occurs when one crop modifies the environment in a way that benefits a second crop, for example, by lowering the population of a critical herbivore, or by releasing nutrients that can be taken up by the second crop (Vandermeer, 1989). Facilitation may result in overyielding even where direct competition between crops is substantial. For example polycultures exhibit greater yield stability and less productivity declines during a drought than in the case of monocultures. Natarajan and Willey (1986) examined the effect of drought on enhanced yields with polycultures by manipulating water stress on intercrops of sorghum

(*Sorghum bicolor*) and peanut (*Arachis* spp.), millet (*Panicum* spp.) and peanut, and sorghum and millet. All the intercrops overyielded consistently at five levels of moisture availability, ranging from 297 to 584 mm of water applied over the cropping season. Quite interestingly, the rate of overyielding actually increased with water stress, such that the relative differences in productivity between monocultures and polycultures became more accentuated as stress increased.

Vegetational Diversity and Pest Outbreaks

Researchers have shown that field populations of insect herbivores are less abundant on crop wild relatives and ancestors than on domesticated plants (Rosenthal and Dirzo, 1997). It is only when traditional systems are modernized, reducing their plant diversity, that herbivore abundance increases to pest levels, compounded by changes brought about modern plant breeding and agronomy. In fact, although traditional farmers may be aware that insects can exert crop damage, they rarely consider them pests, as experienced by Morales and Perfecto (2000) when studying traditional methods of pest control among the highland Maya of Guatemala. Influenced by Mayan attitudes, these western scientists rapidly reformulated their research questions and rather than study how Mayan farmers control pest problems, they focused on why farmers do not have pest problems. This line of inquiry proved more productive as it allowed researchers to understand how farmers designed and managed pest resilient cropping systems and to explore the mechanisms underlying agroecosystem health.

Research along this line has concentrated in understanding how the intercropping of diverse plant species helps prevent insect pest buildup in traditional agroecosystems. In some cases one crop may be planted as a diversionary host, protecting other more susceptible or more economically valuable crops from serious damage. In other cases, crops grown simultaneously enhance the abundance of predators and parasites which provide biological suppression of pest densities, thus minimizing the need to use expensive and dangerous chemical insecticides (Altieri, 1994).

Throughout the years many ecologists have conducted experiments testing the theory that decreased plant diversity in agroecosystems leads to enhanced herbivorous insect abundance (Andow, 1991). Many of these experiments have shown that mixing certain plant species with the primary host of a specialized herbivore gives a fairly consistent result: specialized insect pest species usually exhibit higher abundance in monoculture than in diversified crop systems (Altieri, 1994). Insect communities in agroecosystems can be stabilized by constructing vegetational architectures that support natural enemies and/or directly inhibit pest attack (Smith and McSorely, 2000). The literature is full of examples of experiments documenting that diversification of cropping systems often leads to reduced pest populations and that differences in pest abundance between diverse and simple annual cropping systems can be explained by both differences in the movement, colonization and reproductive behavior of herbivores and by the activities of natural enemies (Altieri and Nicholls, 1999) (Andow, l99l; Altieri and Nicholls, 1999; Landis *et al.,* 2000, photo 4).

Photo 4

Many of these studies have transcended the research phase and have found applicability to control specific pests such as Lepidopteran stemborers in Africa. Scientists at the International Center of Insect Physiology and Ecology (ICIPE) developed a habitat management system which uses plants in the borders of maize fields which act as trap crops (Napier grass and Sudan grass) attracting stemborer colonization away from maize (the push) and two plants intercropped with maize (molasses grass and silverleaf) that repel the stemborers (the pull) (Khan *et al.,* 1998). Border grasses also enhance the parasitization of stemboreres by the wasp *Cotesia semamiae*, and are important fodder plants. The leguminous silverleaf (*Desmodium uncinatum*) suppresses the pariastic weed Striga by a factor of 40 when compared with maize monocrop. *Desmodium's* N-fixing ability increases soil fertility; and it is an excellent forage. As an added bonus, sale of *Desmodium* seed is proving to be a new income-generating opportunity for women in the project areas. The push-pull system has been tested on over 450 farms in two districts of Kenya and has now been released for uptake by the national extension systems in East Africa. Participating farmers in the breadbasket of Trans Nzoia are reporting a 15-20 percent increase in maize yield. In the semi-arid Suba district —plagued by both stemborers and striga— a substantial increase in milk yield has occurred in the last four years, with farmers now being able to support increased numbers of dairy cows on the fodder produced. When farmers plant maize together with the push-pull plants, a return of US $2.30 for every dollar invested is made, as compared to only $1.40 obtained by planting maize as a monocrop (Khan *et al.,* 1998).

More research along these lines is crucial to a vast majority of small farmers who rely on the rich complex of predators and parasites associated with their mixed cropping systems for insect pest control. Major changes on the levels of plant diversity in such systems have the potential to disrupt of natural pest control mechanisms, making farmers more dependent on pesticides.

Genetic Diversity and Disease Incidence

In general, traditional agroecosystems are less vulnerable to catastrophic loss because they grow a wide variety of cultivars (photo 5). Many of these plants are landraces grown from seed passed down from generation to generation and selected over the years to produce desired production characteristics. Landraces are genetically more heterogeneous than modern cultivars and can offer a variety of defenses against vulnerability (Thurston, 1991). As many traditional agroecosystems are located in centers of crop diversity, they also contain populations of wild and weedy relatives of crops which also enrich genetic diversity. Clawson (1985) described several systems in which tropical farmers plant multiple varieties of each crop, providing interspecific diversity, thus enhancing harvest security. The resulting genetic diversity heightens resistance to disease that attack particular strains of the crop, and enables farmers to exploit different microclimates and derive multiple nutritional and other uses from genetic variation within species.


Photo 5

Studies by plant pathologists provide evidence suggesting that indeed genetic heterogeneity reduces the vulnerability of monocultured crops to disease. Mixing of crop species and or varieties can delay the onset of diseases by reducing the spread of disease carrying spores, and by modifying environmental conditions so that they are less favorable to the spread of certain pathogens. Recent research in China, where four different mixtures of rice varieties grown by farmers from fifteen different townships over 3,000 hectares, suffered 44% less blast incidence and exhibited 89% greater yield than homogeneous fields without the need to use fungicides (Zhu *et al.,* 2000). More studies along these lines are needed to validate the peasant strategy of genetic diversification, allowing more precise planning of cropping designs for optimal pest and disease regulation.

Clearly, the existence of such genetic diversity has special significance for the maintenance and enhancement of productivity of small farming systems, as diversity provides security to farmers against diseases, pests, droughts and other stresses and also allows farmers to exploit the full range of agroecosystems existing in each region. It is here where ecological research can be of great significance in assessing the potential impacts of introductions of transgenic crops into regions comprising centers of crop diversity. Many proponents of biotechnology believe that unwanted gene flow from GM maize may not compromise maize biodiversity (and therefore the associated systems of agricultural knowledge and practice along with the ecological and evolutionary processes involved) and may pose no worse a threat than cross-pollination from conventional (non GM) seed. In fact some researchers believe that DNA from engineered maize is unlikely to have an evolutionary advantage, but if transgenes do persist they may actually prove advantageous to farmers and crop diversity (Murray, 2003). Others disagree (Quist and Chapela, 2001) and pose a key question: Can genetically engineered plants actually increase crop production and, at the same time repel pest, resist herbicides, and confer adaptation to stressful factors commonly faced by small farmers? At issue is the possibility that traits important to indigenous farmers (resistance to drought, competitive ability, performance on intercrops, storage quality, etc.) could be traded for transgenic qualities which may not be important to farmers (Jordan, 2001). Under this scenario risk could increase and farmers would lose their ability to adapt to changing biophysical environments and produce relatively stable yields with a minimum of external inputs while supporting their communities food security.

A challenge for agroecologists is to assist farmers in the design of on- farm conservation strategies for a wide variety of plant species which represent an important resource for subsistence farming communities as they form the foundation to sustain current production systems essential for the livelihoods of local communities (Brush, 2000). At the same time conservation of folk varieties is extremely important for industrial agriculture because they contain a vast amount of genetic diversity, including traits needed to adapt to evolving pests, and changing climates and soils, as well as for sustainable forms of agriculture that maintain yields while reducing external inputs which usually cause environmental degradation.

Optimizing Traditional Agriculture through Agroecological Research

Undoubtedly, the ensemble of traditional crop management practices used by many resource-poor farmers represent a rich resource for modern workers seeking to create novel agroecosystems well adapted to the local agroecological and socioeconomic circumstances of peasants (DeWalt, 1994). Peasants use a diversity of techniques which tend to be knowledge-intensive rather than input- intensive, but clearly not all are effective or applicable, therefore modifications and adaptations may be necessary. The challenge is to maintain the foundations of such modifications grounded on peasants' rationale and knowledge.

«Slash and burn» or «milpa» is perhaps one of the best examples of an indigenous ecological strategy to manage agriculture in the tropics. By maintaining a mosaic of plots under cropping and some in fallow, farmers capture the essence of natural processes of soil regeneration typical of any ecological succession. By understanding the rationale of the «milpa», a contemporary discovery, the use of «green manures», has provided an ecological pathway to the intensification of the milpa, in areas where long fallows are not possible anymore due to population growth or conversion of forest to pasture (Buckles *et al.,* 1998). Experiences in Central America show that velvetbean, «mucuna» (*Mucuna pruriens*), based maize systems are fairly stable allowing respectable yield levels (usually 2-4 mg ha^{-1}) every year (Buckles *et al.,* 1998). In particular, the system appears to greatly diminish drought stress because the mulch layer left by mucuna helps conserve water in the soil profile. With enough water around, nutrients are made readily available, in good synchronization with major crop uptake. In addition, the mucuna suppresses most weeds, either because velvetbean physically prevents them from germinating and emerging or from surviving very long during the velvetbean cycle, or because a shallow rooting of weeds in the litter layer-soil interface makes them easier to control. Data shows that this system grounded in farmers knowledge, involving the continuous annual rotation of velvetbean and maize, can be sustained for at least fifteen years at a reasonably high level of productivity, without any apparent decline in the natural resource base (Buckles *et al.,* 1998).

Surveys conducted in hillsides after Hurricane Mitch in Central America showed that farmers using sustainable practices such as «mucuna» cover crops, intercropping and agroforestry suffered less «damage» than their conventional neighbors. The survey, spearheaded by the Campesino a Campesino movement, mobilized 100 farmer-technician teams and 1,743 farmers to carry out paired observations of specific agroecological indicators on 1,804 neighboring, sustainable and conventional farms. The study spanned 360 communities and 24 departments in Nicaragua, Honduras and Guatemala. Sustainable plots had 20% to 40% more topsoil, greater soil moisture, less erosion and experienced lower economic losses than their conventional neighbors (Holt-Gimenez, 2001). These data are of great significance to resource-poor farmers living in marginal environments, and should provide the basis for a natural resource management strategy that privileges the diversification of cropping systems as this leads to higher productivity and likely to greater resiliency in the face of climatic variability.

As illustrated with the «mucuna», an increased understanding of the agroecology and ethnoecology of traditional farming systems is necessary to continue developing contemporary systems. As adaptation and innovation at local scales are typically facilitated by a learning-by-doing approach based on experiential knowledge and generational sharing, rather than knowledge gained through structured scientific research. Ecologists will require a framework which summarizes the range of traditional strategies, socio-cultural processes and associated belief systems that foster adpative natural resource management at each site. Two dimensions are of greatest relevance: (1) traditional management practices based on ecological knowledge, and (2) social mechanisms (rituals, folklore, and ceremonies) that support those management practices. Traditional resource management practices and the knowledge of ecosystem processes upon which they are based, are embedded in often elaborate social institutions. A major task then is to identify and assess the traditional knowledge framework and resource management practices used by individuals and communities, illustrating their value as a basis for the sustainable management of local agricultural systems. This can only occur from integrative studies using agroecological and ethnoecological methodologies, which when used combined can help determine the myriad of factors that condition how farmers perceive their environment and subsequently how they modify it, to later translate such information into practical management schemes that promote the dynamic conservation of indigenous agroecosystems.

CONCLUSIONS

A salient feature of traditional farming systems is their high levels of agrobidoversity arranged in the form of polycultures and/or agroforestry patterns (Thrupp, 1998). Diverse agricultural systems that confer high levels of tolerance to changing socio-economic and environmental conditions are extremely valuable to poor farmers, as diverse systems buffer against natural or human-induced variations in production conditions (Altieri, 2002).

Much of the anthropological and ecological research conducted on traditional agriculture has shown that when not disrupted by economic or political forces, most indigenous modes of production generally have a strong ecological basis and lead to regeneration and preservation of biodiversity and natural resources (Denevan, 2001). Traditional methods are particularly instructive because they provide long-term perspective on successful agricultural management. A few key principles seem to underlie the sustainability of such systems:

- species and genetic diversification in time and space;
- animal integration;
- enhanced recycling of biomass and nutrients;
- organic matter accumulation;

- minimization of resource losses through soil cover, water harvesting;
- maintenance of high levels of functional biodiversity.

The challenge for ecologists is to assist resource-poor farmers in translating such principles into a variety of practical techniques and strategies to enhance production, stability and resiliency, depending on the local opportunities, resource constraints and the market. This will require redirecting ecological research to be more problem solving and more participatory so that it is relevant to rural people. Understanding the ecological mechanisms underlying the sustainability of traditional farming systems and then translating them into principles that take various locally available and appropriate technological forms applicable to a massive number of farmers will be a key task. Ecologists will also have to take a more proactive role in cautioning against agricultural modernization efforts that ignore the virtues of traditional agriculture. It is not a matter of romanticizing subsistence agriculture or to consider development per se as detrimental, but if the interest lies in «improving» traditional agriculture, researchers must first understand and build on that agriculture that is to be changed, rather than simply replace it. It is important to highlight the role of traditional agriculture as a source of genetic material and regenerative farming techniques which constitutes the foundation of a sustainable rural development strategy directed at resource-poor farmers (Toledo, 2000).

Due partly to a lack of ecological guidance, agricultural modernization promotes monocultures, new and fewer varieties and agrochemical packages, all perceived as a critical prerequisite for increasing yields, labor efficiency and farm incomes. Strong pressures at play push conversion from subsistence to cash agricultural economy, and as this occurs, the loss of biodiversity in many rural societies is progressing at an alarming rate. In areas characterized by adoption of modern varieties and agrochemical packages, traditional patterns have often been disrupted and landraces and wild relatives along with indigenous technical knowledge are progressively abandoned, becoming relics or extinct (Brush, 1986). This situation could be aggravated by the technological evolution of agriculture based on emerging biotechnologies which is leading towards increased agricultural uniformity (Jordan, 2001). The social and environmental impacts of local crop shortfalls, resulting from such uniformity or changes in the genetic integrity of local varieties due to genetic pollution, can be considerable in the margins of the developing world. A potential problem with introductions of transgenic crops into diversity regions is that the spread of characteristics of genetically altered grain to local varieties favored by small farmers could dilute the natural sustainability of these races (Altieri, 2000). In the extreme periphery, crop losses often mean ongoing ecological degradation, poverty, hunger and even famine. It is under these conditions of marginality that traditional skills and resources associated with biological and cultural diversity should be available to rural populations to maintain or recover their production processes. Ecologists linked to participatory development projects can be of great assistance in this regard. Of course, major changes must be made in policies that are biased against small farmers, and ecologists can play a role in suggesting alternative policy scenarios that promote alternative technologies through social learning and participatory approaches, improve access to resources and fair markets and increase public investments to improve infrastructure and services for the poor.

Under conditions of poverty, marginalized rural populations have no option but to maintain low-risk agroecosystems that are primarily structured to ensure local food security. Farmers in the margins must continue to produce food for their local communities in the absence of modern inputs, and this can be reached by preserving in-situ ecologically intact locally adapted agrobiodiversity. For this, it may be necessary to maintain geographically isolated areas of traditional agroecosystems and pools of genetic diverse material as these islands of traditional agriculture can act as extant safeguards against the potential ecological failure derived from inappropriate agricultural modernization schemes. It is precisely the ability to generate and maintain diverse crop genetic resources that offer «unique» niche possibilties to marginal farmers that cannot be replicated by other farmers with uniform cultivars in the more favorable lands. This «difference» inherent to traditional systems, can be strategically utilized by exploiting unlimited opportunities that exist for linking traditional agrobiodiversity with local/national/international markets, as long as these activities are carefully planned and remain under grassroots control. Ecologists have a major role in this process, especially by helping in the design of a rural development strategy based on traditional farming and ethnobotanical knowledge, as this not only assures continual use and maintenance of valuable genetic resources but also allows for the diversification of peasant subsistence strategies, a crucial issue in times of economic uncertainty (Uphoff, 2002). In addition, the study of traditional agroecosystems and the ways in which peasants maintain and use biodiversity can provide cues on how to reverse the unsustainable trends that characterize industrial agriculture.

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Chapter 6

Chapter 6

Agroecology: The Science of Natural Resource Management for Poor Farmers in Marginal Environments

Throughout the developing world, resource-poor farmers (about 1.4 billion people) located in risk prone, marginal environments, remain untouched by modern agricultural technology. A new approach to Natural Resource Management must be developed so that new management systems can be tailored and adapted in a site-specific way to highly variable and diverse farm conditions typical of resource-poor farmers. Agroecology provides the scientific basis to address the production by a biodiverse agroecosystem able to sponsor its own functioning. The latest advances in agroecological research are reviewed in order to better define elements of a research agenda in natural resource management that is compatible with the needs and aspirations of peasants. Obviously, a relevant research agenda setting should involve the full participation of farmers with other institutions serving a facilitating role. The implementation of the agenda will also imply major institutional and policy changes.

Introduction

Perhaps the most significant realization at the beginning of the XXI century is the fact that the areas in the developing world, characterized by traditional/subsistence agriculture, remain poorly served by the top-down transfer-of-technology approach, due to its bias in favor of modern scientific knowledge and its neglect of local participation and traditional knowledge. For the most part, resource-poor farmers gained very little from the Green Revolution (Pearse, 1980). Many analysts have pointed out that the new technologies were not scale-neutral. The farmers with the larger and better-endowed lands gained the most, whereas farmers with fewer resources often lost, and income disparities were often accentuated (Shiva, 1991). Not only were technologies inappropriate for poor farmers, but peasants were excluded from access to credit, information, technical support and other services that would have helped them use and adapt these new inputs if they so desired (Pingali *et al.,* l997). Although subsequent studies have shown that the spread of high-yielding varieties among small farmers occurred in Green Revolution areas where they had access to irrigation and subsidized agrochemicals, inequities remain (Lipton and Longhurst, 1989).

Clearly, the historical challenge of the publicly funded international agricultural research community is to refocus its efforts on marginalized farmers and agroecosystems and assume responsibility for the welfare of their agriculture. In fact many analysts (Conway, 1997; Blavert and Bodek, 1998) agree that in order to enhance food security in the developing world, the additional food production will have to come from agricultural systems located in countries where the additional people will live in, and especially where the majority of the poor people are concentrated (Pinstrup, Andersen and Colen, 2000). Even this approach may not be enough, as current World Trade Organization (WTO) policies force developing countries to open markets, which allows rich countries to jettison their overproduction at prices that are disincentives to local producers (Mander and Goldsmith, 1996).

An estimated 1.4 billion people live and work in the vast, diverse and risk-prone rainfed areas in the south, where their farming operations cannot benefit much from mainstream agricultural technologies. Their systems are usually located in heterogeneous environments too marginal for intensive agriculture and remote from markets and institutions (Wolf, 1986). In order to benefit the poor more directly, a Natural Resource

Management (NRM) approach must directly and simultaneously tackle the following objectives:

- poverty alleviation;
- food security and self reliance;
- fcological management of productive resources;
- empowerment of rural communities;
- establishment of supportive policies.

The NRM strategy must be applicable under the highly heterogeneous and diverse conditions in which smallholders live, it must be environmentally sustainable and based on the use of local resources and indigenous knowledge (Table 1). The emphasis should be on improving whole farming systems at the field or watershed level rather than the yield of specific commodities. Technological generation should be a demand driven process meaning that research priorities should be based on the socio-economic needs and environmental circumstances of resource-poor farmers (Blauert and Zadek, 1998).

The urgent need to combat rural poverty and to conserve and regenerate the deteriorated resource base of small farms requires an active search for new kinds of agricultural research and resource management strategies. Non-government organizations (NGOs) have long argued that a sustainable agricultural development strategy that is environmentally enhancing must be based on agroecological principles and on a more participatory approach for technology development and dissemination, as many agree that this may be the most sensible avenue for solving the problems of poverty, food insecurity and environmental degradation (Altieri *et al.,* 1998).

To be of benefit to the rural poor, agricultural research and development should operate on the basis of a «bottom-up» approach, using and building upon the resources already available: local people, their knowledge and their autochthonous natural resources. It must also seriously take into consideration, through participatory approaches, the needs, aspirations and circumstances of smallholders (Richards, 1985). The main objective of this paper is to analyze the latest advances in agroecological research and examine whether ecological approaches to agriculture can provide clear guidelines for addressing the technical and production needs of poor farmers living in marginal environments throughout the developing world.

Building on Traditional Knowledge

Many agricultural scientists have argued that the starting point in the development of new pro-poor agricultural development approaches are the very systems that traditional farmers have developed and/or inherited throughout centuries (Chambers, 1983). Such complex farming systems, adapted to the local conditions, have helped small farmers to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science (Denevan, 1995). Although many of these systems have collapsed or disappeared in many parts of the Third World, the stubborn persistence of millions of hectares under traditional agriculture in the form of raised fields, terraces, polycultures, agroforestry systems, etc., are living proof of a successful indigenous agricultural strategy and comprises a tribute to the «creativity» of small farmers throughout the developing world (Wilken, 1997). These microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain year-round yields. It is estimated that about 50 million individuals belonging to about 700 different ethnic indigenous groups live and utilize the humid tropical regions of the world. About two million of these live in the Amazon and southern Mexico (Toledo, 2000). In Mexico, half of the humid tropics is utilized by indigenous communities and «ejidos» featuring integrated agriculture-forestry systems aimed at subsistence and local-regional markets.

Traditional farming systems commonly support a high degree of plant diversity in the form of polycultures and/or agroforestry patterns

(Gliessman, 1998). This strategy of minimizing risks by planting several species of plants and varieties of crops stabilizes yields over the long term, promotes diet diversity and maximizes returns even under low levels of technology and limited resources (Harwood, 1979).

Most peasant systems are productive despite their low use of chemical inputs (Brookfield and Padoch, 1994). Generally, agricultural labor has a high return per unit of input. The energy return to labor expended in a typical peasant farm is high enough to ensure continuation of the present system. Also in these systems, favorable rates of return between inputs and outputs in energy terms are realized. For example, on Mexican hillsides, maize (*Zea mays*) yields in hand-labor dependent swidden systems are about 1940 kg ha^{-1}, exhibiting an output/input ratio of 11:1. In Guatemala, similar systems yield about 1,066 kg ha^{-1} of maize, with an energy efficiency ratio of 4.84. When animal traction is utilized, yields do not necessarily increase but the energy efficiency drops to values ranging from 3.11-4.34. When fertilizers and other agrochemicals are utilized yields can increase to levels of 5-7 mg ha^{-1}, but energy ratios start exhibiting inefficient values (less than 2.0) (Netting, 1993).

In most multiple cropping systems developed by smallholders, productivity in terms of harvestable products per unit area is higher than under sole cropping with the same level of management (Francis, 1986). Yield advantages can range from 20 to 60% and accrue due to reduction of pest incidence and more efficient use of nutrients, water and solar radiation.

Undoubtedly, the ensemble of traditional crop management practices used by many resource-poor farmers represent a rich resource for modern workers seeking to create novel agroecosystems well adapted to the local agroecological and socioeconomic circumstances of peasants. Peasants use a diversity of techniques, many of which fit well to local conditions and can lead to the conservation and regeneration of the natural resource base, as illustrated by the study of Reij *et al.* (1996) of indigenous soil and water management practices in Africa. The techniques tend to be knowledge-intensive rather than input- intensive, but clearly not all are effective or applicable, therefore modifications and adaptations may be necessary. The challenge is to maintain the foundations of such modifications grounded on peasants' rationale and knowledge.

«Slash and burn» or «milpa» is perhaps one of the best examples of an ecological strategy to manage agriculture in the tropics. By maintaining a mosaic of plots under cropping and some in fallow, farmers capture the essence of natural processes of soil regeneration typical of any ecological succession. By understanding the rationale of the «milpa», a contemporary discovery, the use of «green manures», has provided an ecological pathway to the intensification of the milpa, in areas where long fallows are not possible anymore due to population growth or conversion of forest to pasture (Flores, 1989).

Experiences in Central America show that velvetbean, «mucuna» (*Mucuna pruriens*), based maize systems are fairly stable allowing respectable yield levels (usually 2-4 mg ha^{-1}) every year (Buckles *et al.,* 1998). In particular, the system appears to greatly diminish drought stress because the mulch layer left by mucuna helps conserve water in the soil profile. With enough water around, nutrients are made readily available, in good synchronization with major crop uptake. In addition, the mucuna suppresses weeds (with a notable exception of one weed species, *Rottboellia cochinchinensis*), either because velvetbean physically prevents them from germinating and emerging or from surviving very long during the velvetbean cycle, or because a shallow rooting of weeds in the litter layer-soil interface makes them easier to control. Data shows that this system grounded in farmers knowledge, involving the continuous annual rotation of velvetbean and maize, can be sustained for at least fifteen years at a reasonably high level of productivity, without any apparent decline in the natural resource base (Buckles *et al.,* 1998).

As illustrated with the «mucuna» system, an increased understanding of the agroecology and ethnoecology of traditional farming systems is necessary to continue developing contemporary systems. This can only occur from integrative studies that determine the myriad of

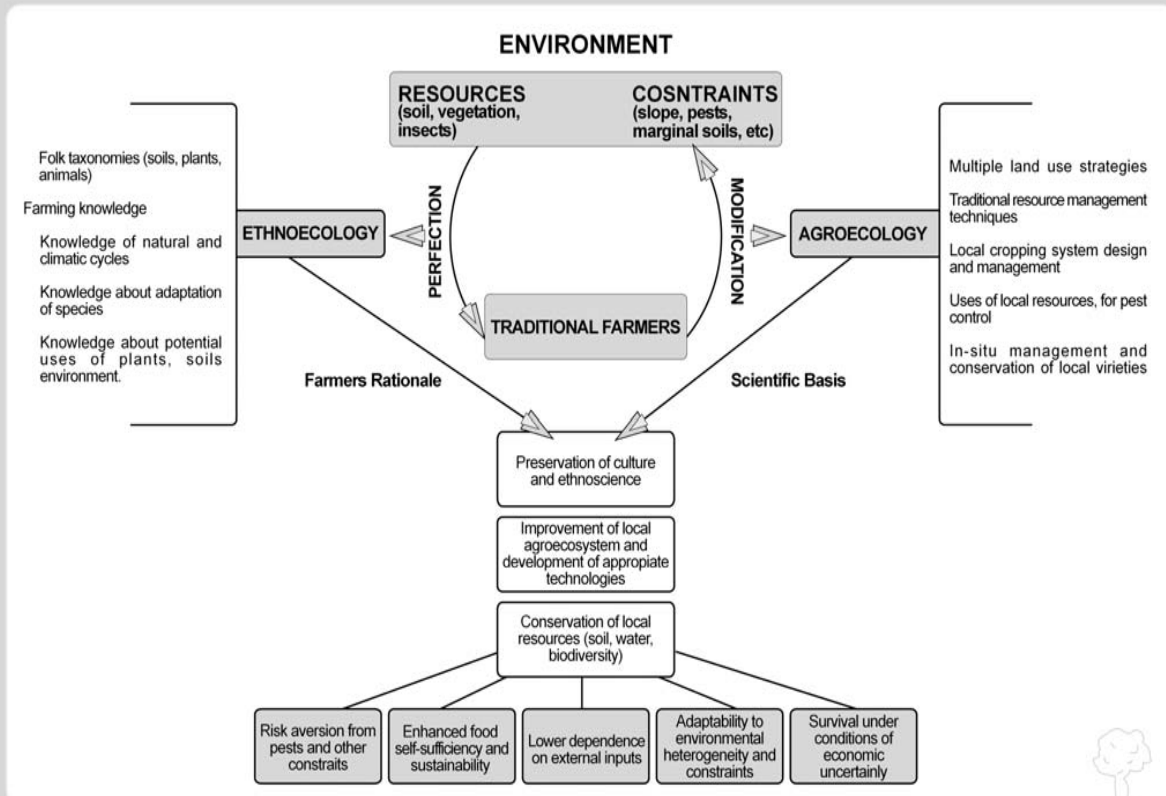

Fig. 1 The role of agroecology and ethnoecology in the retrieval of traditional farming knowledge and the development of sustainable agroecosystems, including appropriate innovations in pest management

factors that condition how farmers perceive their environment and subsequently how they modify it to later translate such information to modern scientific terms (Figure 1).

Defining the Target Population of a Pro-Poor NRM Strategy

Although estimates of the number and location of resource-poor farmers vary considerably, it is estimated that about 1.9 to 2.2 billion people remain directly or indirectly untouched by modern agricultural technology (Pretty, 1995). In Latin America, the rural population is projected to remain stable at 125 million until the year 2000, but over 61% of this population are poor and are expected to increase. The projections for Africa are even more dramatic. The majority of the world's rural poor (about 370 million of the poorest) live in areas that are resource-poor, highly heterogeneous and risk prone. Despite the increasing industrialization of agriculture, the great

Table 2. some features and constrainsof peasant farming systems and poor rural households

Characteriscs of poor smallholders	Constrains to wich poor farmers are exposed
• Meager holdings or access to land	• Heterogeneus and erratic environments
• Little or no capital	• Market failures
• Few off-farm employment opportunities	• Institutional gaps
• Income strategies are varied and complex	• Public good biases
• Complex and diverse farming systems in fragile environments	• Low access to land and other resources inappropiate technologies

majority of the farmers are peasants, or small producers, who still farm the valleys and slopes of rural landscapes with traditional and subsistence methods. Their agricultural systems are small scale, complex and diverse and peasants are confronted to many constraints (Table 2). The worst poverty is often located in arid or semi-arid zones, and in mountains and hills that are ecologically vulnerable (Conway, 1997). These areas are remote from services and roads and agricultural productivity is often low on a crop by crop basis, although total farm output can be significant.

Such resource-poor farmers and their complex systems pose special research challenges and demand appropriate technologies (Netting, 1993).

Shifting the Research Focus

Natural resource problems experienced by poor farmers are not amenable to the research approaches previously used by the international research community. In most organisations, including the 16 international agricultural research centers associated to the Consultative Group on International Agricultural Research (CGIAR), research has been commodity oriented with the goal of improving yields of particular food crops and livestock, but generally without adequately understanding the needs and options of the poor, nor the ecological context of the systems being addressed.

Most scientists use a disciplinary approach, often resulting in recommendations for specific domains and failing to equip farmers with appropriate technologies or empower them to make informed choices between available options. This situation is changing however as one of the Inter-Center Initiatives of the CGIAR is advocating a new approach to Integrated Natural Resource Management (INRM). The idea is to generate a new research approach that considers the interactive effects of ecosystems and socio-economic systems at the ecoregional level (CGIAR, 2000). During a recent INRM workshop CGIAR scientists arrived at two major definitions of NRM (CGIAR, 2000):

a) Responsible and broad based management of land, water, forest and biological resource base (including genes) needed to sustain agricultural productivity and avert degradation of potential productivity.

b) Management of the biogeochemical processes that regulate the ecosystems within which agricultural systems function. NRM methods are those of system science, a system that embraces the interaction of humans with their natural resources.

Despite these new interdisciplinary efforts and the significant advances in understanding the links between components of the biotic community and agricultural productivity, agrobiodiversity is still treated as a «black-box» in agricultural research (Swift and Anderson, 1993). This calls for the need that crop, soil, water and pest management aspects be addressed simultaneously at the field or watershed level in order to match elements for production with forms of agroecosystem management that are sensitive to maintaining and/or enhancing biodiversity. Such integrated approach to agroecosystem management can allow the definition of a range of different strategies that can potentially offer farmers (especially those most reliant on the functions of agrobiodiversity) a choice of options or capacity to manipulate their systems according to their socio-economic constraints and requirements (Blavert and Zadek, 1998).

A case in point has been the evolution of integrated pest management (IPM) and integrated soil fertility management (ISFM) which have proceeded separately without realising that low-input agroecosystems rely on synergies of plant diversity and the continuing function of the soil microbial community, and its relationship with organic matter to maintain the integrity of the agroecosystem (Deugd *et al.,* 1998). It is crucial for scientists to understand that most pest management methods used by farmers can also be considered soil fertility

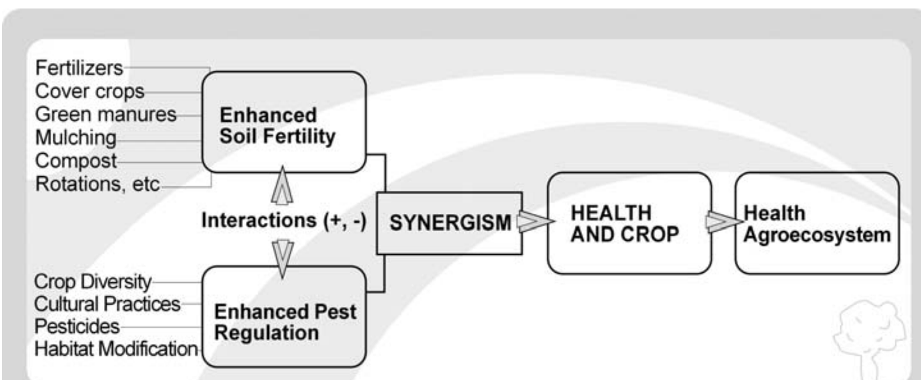

Figure 2. Interactions of soil and pest management practices used by farmers, some of which may result in synergism leading to healthy and productive crops

management strategies and that there are positive interactions between soils and pests that once identified, can provide guidelines for optimising total agroecosystem function (Figure 2). Increasingly, research is showing that the ability of a crop plant to resist or tolerate insect pests and diseases is tied to optimal physical, chemical and mainly biological properties of soils (Luna, 1988). Soils with high organic matter and active soil biological activity generally exhibit good soil fertility as well as complex food webs and beneficial organisms that prevent infection. On the other hand, farming practices that cause nutrition imbalances can lower pest resistance (Magdoff and van Es, 2000).

Table 3.
Examples of research themes for the lower-potencial lands (Conway, 1997)

- Improving understanding of select critical agroecosystems such as the highland valleys of northern South Asia.
- New varieties produced through conventional breeding and genetic engineering that deliver higher yields in the face of environmental stress.
- Thechnologies for drought – and subemergence-prone rain-fed rice cultivation.
- Small-scale, community-managed irrigation and water-conservation systems.
- More productive cereal-based farming systems in Eastern and Southern Africa.
- Improved agroeconomic systems appropiate to specific acid —and mineral— deficient soils in the savannahs of Latin America.
- Symergetic cropping and crop-livestock systems providing higher, more stable yields in the highlands of West Asia.
- Productive and sustainable agroforestry alternatives to shifting cultivation.
- Sustainable income – and employment-generating explotation of forest, fishireis and natural resources.

During the various INRM workshops CGIAR scientists have been able to come up with a list of research themes relevant to less favourable areas (Table 3), but certainly that is not enough. In addition the CGIAR's Technical Advisory Committee (TAC) came forward with a working proposal toward the goal of poverty reduction, food security and sustainable agriculture. As important as it is to define and map poverty, which appears to be the major emphasis of TAC, it is even more urgent to understand the root causes of poverty and tackle such factors head on through agricultural research. Another emphasis of TAC is to assess the impacts that unpredictable and extreme climatic events will have on the poor. Describing how long-term warming trends will affect small farm production, although important, is not as relevant as understanding the adaptability of agroecosystems on which the poor depend or how to enhance the resiliency of smallholders farming systems to climate change.

What is lacking in these new definitions is the explicit description of the scientific bases of NRM and of methods to increase our understanding of the structure and dynamics of agricultural and natural resource ecosystems and providing guidelines to their productive and sustainable management. A relevant NRM strategy requires the use of general agroecological principles and customizing agricultural technologies to local needs and circumstances. Where the conventional technology transfer model breaks down is where new management systems need to be tailored and adapted in a site-specific way to highly variable and diverse farm conditions. Agroecological principles have universal applicability but the technological forms through which those principals become operational depend on the prevailing environmental and socio-economic conditions at each site (Uphoff, 2002).

Agroecology as a Fundamental Scientific Basis for NRM

In trying to improve agricultural production, most scientists have disregarded a key point in the development of a more self-sufficient and sustaining agriculture: a deep understanding of the nature of agroecosystems and the principles by which they function. Given this limitation, agroecology has emerged as the discipline that provides the basic ecological principles for how to study, design and manage agroecosystems that are both productive and natural resource conserving, and that are also culturally sensitive, socially just and economically viable (Altieri, 1995).

Agroecology goes beyond a one-dimensional view of agroecosystems —their genetics, agronomy, edaphology, etc.— to embrace an understanding of ecological and social levels of co-evolution, structure and function. Instead of focusing on one particular component of the agroecosystem, agroecology emphasises the interrelatedness of all agroecosystem components and the complex dynamics of ecological processes (Vandermeer, 1995).

Agroecosystems are communities of plants and animals interacting with their physical and chemical environments that have been modified by people to produce food, fibre, fuel and other products for human consumption and processing. Agroecology is the holistic study of agroecosystems, including all environmental and human elements. It focuses on the form, dynamics and functions of their interrelationships and the processes in which they are involved. An area used for agricultural production, e.g. a field, is seen as a complex system in which ecological processes found under natural conditions also occur, e.g. nutrient cycling, predator/prey interactions, competition, symbiosis, successional changes, etc. (Gliessman, 1998). Implicit in agroecological research is the idea that, by understanding these ecological relationships and processes, agroecosystems can be manipulated to improve production and to produce more sustainably, with fewer negative environmental or social impacts and fewer external inputs (Gliessman, 1998).

Ecological concepts are utilized to favor natural processes and biological interactions that optimize synergies so that diversified farms are

Table 4.
Agroecosystem process optimized through the use of agroecological technologies

- Organic accumulation and nutrient cycling.
- Soil biological activity.
- Natural control mechanisms (disease suppression of insects, weed interference).
- Resource conservation and regeneration (soil, water, germplasm, etc.).
- General enhancement of agrobiodiversity and synergisms between components.

able to sponsor their own soil fertility, crop protection and productivity. By assembling crops, animals, trees, soils and other factors in spatial/temporal diversified schemes, several processes are optimized (Table 4). Such processes are crucial in determining the sustainability of agricultural systems (Vandermeer *et al.,* 1998).

Agroecology takes greater advantage of natural processes and beneficial on-farm interactions in order to reduce off-farm input use and to improve the efficiency of farming systems. Technologies emphasized tend to enhance the functional biodiversity of agroecosystems as well as the conservation of existing on-farm resources. Promoted technologies such as cover crops, green manures, intercropping, agroforestry and crop-livestock mixtures, are multi-functional as their adoption usually means favorable changes in various components of the farming systems at the same time (Gliessman, 1998).

Most of these technologies may function as an «ecological turntable» by activating and influencing components of the agroecosystem and processes such as:

1. Recycling of biomass and balancing nutrient flow and availability.
2. Securing favourable soil conditions for plant growth, through enhanced organic matter and soil biotic activity.
3. Minimizing losses of solar radiation, air, water and nutrients by way of microclimate management, water harvesting and soil cover.
4. Enhancing species and genetic diversification of the agroecosystem in time and space.
5. Enhancing beneficial biological interactions and synergisms among agrobiodiversity components resulting in the promotion of key ecological processes and services.

Challenging Topics for Agroecological Research

Mimicking Nature

At the heart of the agroecology strategy is the idea that an agroecosystem should mimic the functioning of local ecosystems thus exhibiting tight nutrient cycling, complex structure, and enhanced biodiversity. The expectation is that such agricultural mimics, like their natural models, can be productive, pest resistant and conservative of nutrients (Ewel, 1999).

This succession analog method requires a detailed description of a natural ecosystem in a specific environment and the botanical characterization of all potential crop components. When this information is available, the first step is to find crop plants that are structurally and functionally similar to the plants of the natural ecosystem. The spatial and chronological arrangement of the plants in the natural ecosystem are then used to design an analogous crop system (Hart, 1980). In Costa Rica, researchers conducted spatial and temporal replacements of wild species by botanically/structurally/ecologically similar cultivars. Thus, successional members of the natural system such as *Heliconia* spp, cucurbitaceous vines, *Ipomoea* spp., legume vines, shrubs, grasses, and small trees were replaced by plantain (*Musa* spp.), squash (*Curcurbita* spp.) varieties, and yams (*Dioscorea* spp.). By years two and three, fast-growing tree crops (Brazil nuts [*Bertholletia excelsa*], peach [*Prunus persica*], palm [*Chamaerops* spp.], rosewood [*Dalbergia* spp.]) may form an additional stratum, thus maintaining continuous crop cover, avoiding site degradation and nutrient leaching, and providing crop yields throughout the year (Ewel, 1986).

According to Ewel (1999), the only region where it would be advantageous to imitate natural ecosystems rather than struggle to impose simplicity through high inputs in ecosystems that are inherently complex, is the humid tropical lowlands. This area epitomizes environments of low abiotic stress but overwhelming biotic intricacy. The keys to agricultural success in this region are to (i) channel productivity into outputs of nutritional and economic importance, (ii) maintain adequate vegetational diversity to compensate for losses in a system simple enough to be horticulturally manageable, (iii) manage plants and herbivores to facilitate associational resistance, and (iv) use perennial plants to maintain soil fertility, guard against erosion, and make full use of resources. The idea however has also been proved in the temperate latitudes. Soule and Piper (1992) proposed utilizing the prairie of the US Great Plains as an appropriate model to develop an agroecosystem dominated by mixtures of perennial grasses, legumes and composites, all plants that differ in seasonal nutrient use and would thereby play complimentary and facilitating roles in the field. The use of perennial species would mimic the original prairie's soil-retaining, soil-building aspects. The legume component would help maintain an internal soil fertility supply and the diversity of crop species, including some native species, would allow development of natural checks and balances of herbivores, diseases and weeds. This natural systems agriculture (NSA) idea which was developed at The Land Institute in 1977 features an ecologically sound perennial food-grain-producing system where soil erosion goes to near zero, chemical contamination from agrochemicals plummets, along with agriculture's dependence on fossil fuels. A primary goal of NSA is to sufficiently *mimic the natural structure* to be *granted the function* of its components. Domesticating wild perennials and increasing seed yield and at the same time perennializing the major crops to be planted as domestic prairies is a major NSA strategy (Jackson, 2002).

To many, the ecosystem-analog approach is the basis for the promotion of agroforestry systems, especially the construction of forest-like agroecosystems that imitate successional vegetation, which exhibit low requirements for fertilizer, high use of available nutrients, and high protection from pests (Sanchez, 1995).

Understanding Multi-Species Agroecosystems

In temperate or semiarid areas where complex natural ecosystems are not present as a model, the main strategy lies in the use of agroecological principles as part of the design criterion, thus replacing what has become a strictly economic decision making process with one that also includes ecological ideas (Altieri *et al.,* 1983).

Recent ecological research indicates that diverse natural communities are indeed more productive than simple systems (Tilman *et al.,* 1996), just as many agricultural studies have shown that complex, multi-species agricultural systems are more dependable in production and more sustainable in terms of resource conservation than simplified agroecosystems (Vandermeer *et al.,* 1998). Significant yield increases have been reported in diverse cropping systems compared to monocultures (Francis, 1986; Vandermeer, 1989). Enhanced yields in diverse cropping systems may result from a variety of mechanisms, such as more efficient use of resources (light, water, nutrients) or reduced pest damage. Intercropping, which breaks down the monoculture structure, can provide pest control benefits, weed control advantages reduced wind erosion, and improved water infiltration (Francis, 1986).

The mechanisms that result in higher productivity in diverse agroecosystems are embedded in the process of facilitation. Facilitation occurs when one crop modifies the environment in a way that benefits a second crop, for example, by lowering the population of a critical herbivore, or by releasing nutrients that can be taken up by the second crop (Vandermeer, 1989). Facilitation may result in overyielding even where direct competition between crops is substantial. Ecological studies suggest that more diverse plant communities are more resistant to disturbance and more resilient to environmental perturbations like drought (Tilman *et al.,* 1996). In agricultural situations this means that polycultures exhibit greater yield stability and less productivity declines during a drought than in the case of monocultures. Natarajan and Willey (1986) examined the effect of drought on enhanced yields with polycultures by manipulating water stress on intercrops of sorghum (*Sorghum bicolor*) and peanut (*Arachis* spp.), millet (*Panicum* spp.) and peanut, and sorghum and millet. Although total biomass production in both polycultures and monocultures decreased as water stress increased, all of these intercrops overyielded consistently at five levels of moisture availability, ranging from 297 to 584 mm of water applied over the cropping season. Quite interestingly, the rate of overyielding actually increased with water stress, such that the relative differences in productivity between monocultures and polyculture became more accentuated as stress increased.

Surveys conducted in hillsides after Hurricane Mitch in Central America showed that farmers using sustainable practices such as cover crops, intercropping and agroforestry suffered less damage than their conventional neighbors. The survey, spearheaded by the Campesino a Campesino movement, mobilized 100 farmer-technician teams and 1,743 farmers to carry out paired observations of specific agroecological indicators on 1,804 neighboring, sustainable and conventional farms. The study spanned 360 communities and 24 departments in Nicaragua, Honduras and Guatemala. Sustainable plots had 20% to 40% more topsoil, greater soil moisture, less erosion and experienced lower economic losses than their conventional neighbors (Holt-Gimenez, 2001). These data are of great significance to resource-poor farmers living in marginal environments and should provide the basis for an NRM strategy that privileges the temporal and spatial diversification of cropping systems as this leads to higher productivity and likely to greater stability and ecological resiliency.

Integrating Effects of Soil Management: Healthy Soils – Healthy Plants

As emphasized earlier, crop diversification strategies must be complemented by regular applications of organic amendments (crop residues, animal manures, and composts) to maintain or improve soil quality and productivity. Much is known about the benefits of multi-species rotations, cover crops, agroforestry, and intercrops (Francis, 1986). Less well known are the multifunctional effects of organic amendments beyond the documented effects on improved soil structure and nutrient content. Well-aged manures and composts can serve as sources of growth-stimulating substances, such as indole –3-acetic acid and humic and fulvic acids (Magdoff and van Es, 2000). Beneficial effects of humic acid substances on plant growth are mediated by a series of mechanisms, many similar to those resulting form the direct application of plant growth regulators.

The ability of a crop plant to resist or tolerate pests is tied to optimal physical, chemical and biological properties of soils. Adequate moisture, good soil tilth, moderate pH, right amounts of organic matter and nutrients, and a diverse and active community of soil organisms all contribute to plant health. Organic rich soils generally exhibit good soil fertility as well as complex food webs and beneficial organisms that prevent infection by disease causing organisms such as *Pythium* and *Rhizoctonia* (Hendrix *et al.,* 1990). Composts may alter resistance of plants to disease. Trankner (1992) observed that powdery mildew of wheat (*Triticum* spp.) and barley (*Hordeum* spp.) was less severe in compost-amended than in unamended soils. He also reported lower incidence of early blight and bacterial spot of tomato (*Lycopersicon esculentum*) field-grown plants in compost-amended soil than in the control. A number of pathogenic nematodes can also be suppressed with the application of organic amendments (Rodriguez-Kabana, 1986). On the other hand, farming practices such as high applications of N fertilizer can create nutrition imbalances, and render crops susceptible to diseases such as *Phytophtora* and *Fusariu*m and stimulate outbreaks of Homopteran insects such as aphids and leafhoppers (Slansky and Rodriguez, 1987). In fact there is increasing evidence that crops grown in organic rich and biologically active soils are less susceptible to pest attack (Luna, 1988). Many studies (Scriber, 1984) suggest that the physiological susceptibility of crops to insect pests and pathogens may be affected by the form of fertilizer used (organic vs. chemical fertilizer).

The literature is abundant on the benefits of organic amendment additions that encourage resident antagonists thus enhancing biological control of plant diseases (Campbell, 1984). Several bacteria species of the genus *Bacillus* and *Pseudomonas*, as well as the fungus *Trichoderma* are key antagonists that suppress pathogens through competition, lysis, antibiosis or hyperparasitism (Palti, 1981).

Studies documenting lower abundance of several insect herbivores in low-input systems, have partly attributed such reduction to a low N content in organically farmed crops. In Japan, density of immigrants of the planthopper *Sogatella furcifera* was significantly lower while settling rate of female adults and survival rate of immature stages of ensuing generations were lower in organic rice fields. Consequently, the density of planthopper nymphs and adults in the ensuing generations decreased in organically farmed fields (Kajimura, 1995). In England, conventional winter wheat fields developed a larger infestation of the aphid

Metopolophium dirhodum than its organic counterpart. This crop also had higher levels of free protein amino acids in its leaves during June, which were believed to have resulted from a N top dressing of the crop early in April. However, the difference in the aphid infestations between crops was attributed to the aphid's response to relative proportions of certain non-protein to protein amino acids in the leaves at the time of aphid settling on crops (Kowalski and Visser, 1979). In greenhouse experiments, when given a choice of maize grown on organic versus chemically fertilized soils, European corn borer (*Ostrinia nubilalis*) females preferred to lay significantly more eggs in chemically fertilized plants (Phelan *et al.,* 1995).

In the case of weeds, Liebman and Gallandt (1997) assessed the impacts of organic soil amendments on weed regeneration, resource use and allelopatic interaction. Their results from temperate region sweet corn (*Zea mays*) and potato (*Solanum tuberosum*) producing systems showed that weed species appear to be more susceptible to phytotoxic effects of crop residues and other organic soil amendments that crop species, possibly because of differences in seed mass. They suggest that delayed patterns of N availability in low-external-input systems may favor large-seeded crops over small-seeded weeds. They also found that additions of organic materials can change the incidence and severity of soil-borne diseases affecting weeds but not crops. Such results suggest that these mechanisms ubiquitous to organically managed soils can reduce weed density and growth while maintaining acceptable crop yields.

Such findings are of key importance to resource-poor farmers such as Cakchiquel farmers in Patzúm, Guatemala who have experienced increased pest populations (aphids and corn earworms (*Heliothis zea*)) in maize since they abandoned organic fertilization and adopted synthetic fertilizers (Morales *et al.,* 2001). Many farmers undergoing modernization may be facing similar impacts due to higher fertilizer use, which in turn may create subtle imbalances in the agroecology of specific farming systems.

Vegetational Diversity and Pest Outbreaks

Throughout the years many ecologists have conducted experiments testing the theory that decreased plant diversity in agroecosystems leads to enhanced herbivorous insect abundance (Altieri and Letorneau, 1982; Andow, 1991). Many of these experiments have shown that mixing certain plant species with the primary host of a specialized herbivore gives a fairly consistent result: specialized insect pest species usually exhibit higher abundance in monoculture than in diversified crop systems (Altieri, 1994).

Several reviews have been published documenting the effects of within-habitat diversity on insects (Altieri and Nicholls, 1999; Landis *et al.,* 2000). Two main ecological hypotheses (natural enemy hypothesis and the resource concentration hypothesis) have been offered to explain why insect communities in agroecosystems can be stabilized by constructing vegetational architectures that support natural enemies and/ or directly inhibit pest attack (Smith and McSorely, 2000). The literature is full of examples of experiments documenting that diversification of cropping systems often leads to reduced pest populations. In the review by Risch *et al.* (1983) 150 published studies documenting the effects of agroecosystem diversification on insect pest abundance were summarized; 198 total herbivore species were examined in these studies. Fifty-three percent of these species were found to be less abundant in the more diversified system, 18% were more abundant in the diversified system, 9% showed no difference, and 20% showed a variable response.

Many of these studies have transcended the research phase and have found applicability to control specific pests such as Lepidopteran stemborers in Africa. Scientists at the International Center of Insect Physiology and Ecology (ICIPE) developed a habitat management system which uses two kinds of crops that are planted together with maize: a plant that repels these borers (the push) and another that attracts (the pull) them (Khan *et al.,* 1998). The push-pull system has been tested on over 450 farms in two districts of Kenya and has now been released for uptake by the national extension systems in East Africa. Participating farmers in the breadbasket of Trans Nzoia are reporting a 15-20 percent increase in maize yield. In the semi-arid Suba district —plagued by both stemborers and striga— a substantial increase in milk yield has occurred in the last four years, with farmers now being able to support grade cows on the fodder produced. When farmers plant maize together with the push-pull plants, a return of US $2.30 for every dollar invested is made, as compared to only $1.40 obtained by planting maize as a monocrop. Two of the most useful trap crops that pull in the borers' natural enemies such as the parasitic wasp (*Cotesia sesamiae*), are napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum vulgare sudanese*), both important fodder plants; these are planted in a border around the maize. Two excellent borer-repelling crops which are planted between the rows of maize are molasses grass (*Melinis minutifolia*), which also repels ticks, and the leguminous silverleaf (*Desmodium*), which in addition can suppress the parasitic weed *Striga* by a factor of 40 compared to maize monocrop. *Desmodium's* N-fixing ability increases soil fertility; and it is an excellent forage. As an added bonus, sale of *Desmodium* seed is proving to be a new income-generating opportunity for women in the project areas (Khan *et al.,* 1997).

It is clear that both empirical data and theoretical arguments suggest that differences in pest abundance between diverse and simple annual cropping systems can be explained by both differences in the movement, colonization and reproductive behaviour of herbivores and by the activities of natural enemies. The studies further suggest that the more diverse the agroecosystems and the longer this diversity remains undisturbed, the more internal links develop to promote greater insect stability (Altieri and Nicholls, 1999). Research along these lines is crucial to a vast majority of small farmers who rely on the rich complex of predators and parasites associated with their mixed cropping systems for insect pest control. Any changes on the levels of plant diversity in such systems can lead to disruptions of natural pest control mechanisms, potentially making farmers more dependent on pesticides.

Regardless, more studies are needed to determine the underlying elements of plant mixtures that disrupt pest invasion and that favour natural enemies. Research must also expand to assess the effects of genetic diversity, achieved through variety mixtures, on the suppression of plant pathogens. In the area of plant disease control, evidence suggests that genetic heterogeneity reduces the vulnerability of monocultured crops to disease. Recent research in China, where four different mixtures of rice varieties grown by farmers from fifteen different townships over 3,000 hectares, suffered 44% less blast incidence and exhibited 89% greater yield than homogeneous fields without the need to use fungicides (Zhu *et al.,* 2000). More studies along these lines will allow more precise planning of cropping designs for optimal pest and disease regulation.

Conversion

In some areas the challenge is to revert systems that have already undergone modernization and where farmers experience high become commodified, therefore farmers continue to be dependent on input suppliers, many of a corporate nature (Altieri and Rosset, 1996). Clearly, as it stands today, «input substitution» has lost its «pro-poor» potential. A notable exception are advances in Cuba, where small-scale artisanal production of biopesticides and biofertilizers is conducted in cooperatives using local materials and made available to farmers at low costs.

System redesign on the contrary arises from the transformation of agroecosystem function and structure by promoting management guided to ensure the following processes:

1. increasing above and below ground biodiversity;
2. increasing biomass production and soil organic matter content;
3. optimal planning of plant-animal sequences and combinations and efficient use of locally available resources; and
4. enhancement of functional complementarities between the various farm components.

Promotion of biodiversity within agricultural systems is the cornerstone strategy of system redesign, as research has demonstrated that (Power, 1999):

- Higher diversity (genetic, taxonomic, structural, resource) within the cropping system leads to higher diversity in associated biota.
- Increased biodiversity leads to more effective pest control and pollination.
- Increased biodiversity leads to tighter nutrient cycling.

As more information about specific relationships between biodiversity, ecosystem processes, and productivity in a variety of agricultural systems is accumulated, design guidelines can be developed further and used to improve agroecosystem sustainability and resource conservation.

Syndromes of Production

One of the frustrations of research in sustainable agriculture has been the inability of low-input practices to outperform conventional practices in side-by-side experimental comparisons, despite the success of many organic and low-input production systems in practice (Vandermeer, 1997). A potential explanation for this paradox was offered by Andow and Hidaka (1989) in their description of «syndromes of production». These researchers compared the traditional shizeñ system of rice (*Oryza sativa*) production with the contemporary Japanese high input system. Although rice yields were comparable in the two systems, management practices differed in almost every respect: irrigation practice, transplanting technique, plant density, fertility source and quantity, and management of insects, diseases, and weeds. Andow and Hidaka (1989) argue that systems like shizeñ function in a qualitatively different way than conventional systems. This array of cultural technologies and pest management practices result in functional differences that cannot be accounted for by any single practice.

Thus a production syndrome is a set of management practices that are mutually adaptive and lead to high performance. However, subsets of this collection of practices may be substantially less adaptive; that is, the interaction among practices leads to improved system performance that cannot be explained by the additive effects of individual practices. In other words, each production system represents a distinct group of management techniques and by implication, ecological relations. This re-emphasizes the fact that agroecological designs are site-specific and what may be applicable elsewhere are not the techniques but rather the ecological principles that underlie sustainability. It is of no use to transfer technologies from one site to another, if the set of ecological interactions associated with such techniques cannot be replicated.

Assessing the Sustainability of Agroecosystems

How can the sustainability of an agroecosystem be evaluated? How does a given strategy impact on the overall sustainability of the natural resource management system? What is the appropriate approach to explore its economic, environmental and social dimensions? These are unavoidable questions faced by scientists and development practitioners dealing with complex agroecosystems. A number of people working on alternative agroecological strategies have attempted to arrive at a framework that offers a response to the above and other questions (Conway, 1994). There is much argument on whether to use location specific or universal indicators. Some argue that the important indicators of sustainability are location specific and change with the situation prevailing on a farm (Harrington, 1992). For example, in the steeplands, soil erosion has a major impact on sustainability, but in the flat lowland rice paddies, soil loss due to erosion is insignificant and may not be a useful indicator. Based on this principle, therefore, the protocol for measuring sustainability starts with a list of potential indicators from which practitioners select a subset of indicators that is felt to be appropriate for the particular farm being evaluated.

A strong current of opinion thinks that the definition and consequently the procedure for measuring sustainable agriculture is the same regardless of the diversity of situations that prevails on different farms. Under this principle, sustainability is defined by a set of requirements that must be met by any farm regardless of the wide differences in the prevailing situation (Harrington, 1992). The procedure of using a common set of indicators offers a protocol for measuring sustainability at the farm level by: (i) defining the requirements for sustainability, (ii) selecting the common set of indicators, (iii) specifying the threshold levels, (iv) transforming the indicators into a sustainability index, and (v) testing the procedure using a set of data from selected farms (Gomez *et al.,* 1996). According to this method, a farming system is considered sustainable if it conserves the natural resource base and continues to satisfy the needs of the farmer, the manager of the system. Any system that fails to satisfy these two requirements is bound to change significantly over the short term and is therefore considered not sustainable. Using threshold levels (minimum value of an indicator above which starts a trend towards

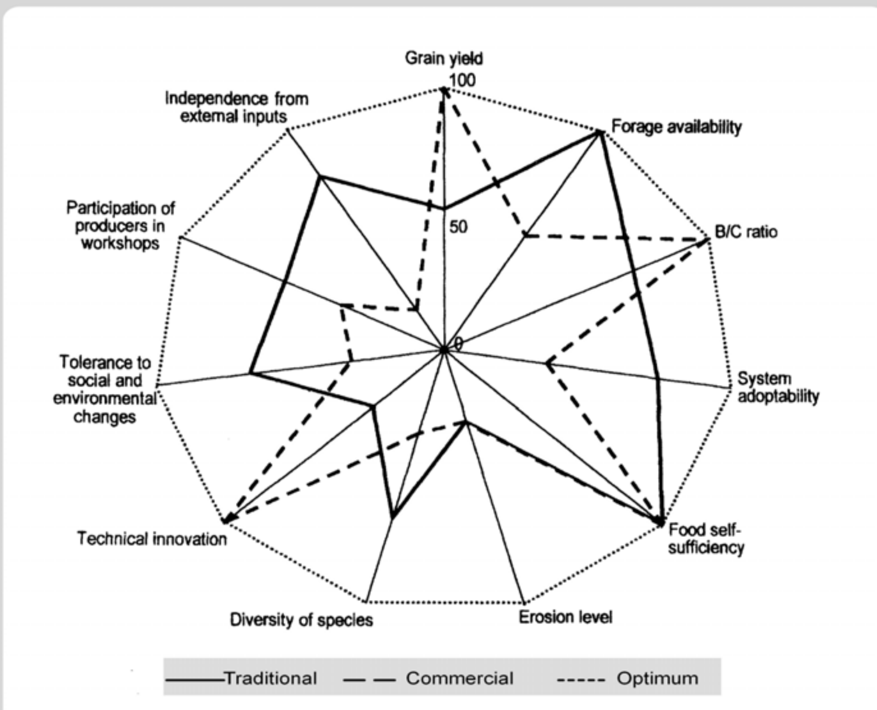

Fig. 3 An AMOEBA-type diagram featuring 11 Indicators for the evaluation of the sustainability of two contrasting agrosilvopastoral system in Casa Blanca, Michoacan, Mexico (Lopez-Ridaura et al., 2000)

sustainability) Gomez *et al.* (1996) used yields, profit and stability (frequency of disaster) as farmers satisfaction indicators, while soil depth, water holding capacity, nutrient balance, organic matter content, ground cover, and biological diversity were used as indicators of resource conservation.

In contrast, by working with optimal values (rather than with tresholds) of sustainability Lopez-Ridaura *et al.* (2000) used indicators such as independence from external inputs, grain yield, system adoptability, food self-sufficiency, diversity of species, etc. As shown in Figure 3, an AMOEBA-type diagram is used to show, in qualitative terms, how far the objective has been reached for each indicator by giving the percentage of the actual value with respect to the ideal value (reference value). This enables a simple, yet comprehensive comparison of the advantages and limitations of two systems being evaluated and compared.

Applying Agroecology to Improve the Productivity of Small Farming Systems

Since the early 1980s, hundreds of agroecologically-based projects have been promoted by NGOs throughout the developing world, which incorporate elements of both traditional knowledge and modern agricultural science. A variety of projects exist featuring resource-conserving yet highly productive systems, such as polycultures, agroforestry, and the integration of crops and livestock, etc. (Altieri *et al.,* 1998). Such alternative approaches can be described as low-input technologies, but this designation refers to the external inputs required. The amount of labour, skills, and management that are required as inputs to make land and other factors of production most productive is quite substantial. So rather than focus on what is not being utilised, it is better to focus on what is most important to increase food output, labour, knowledge and management (Uphoff and Altieri, 1999).

Agroecological alternative approaches are based on using locally available resources as much as possible, though they do not totally reject the use of external inputs. However, farmers cannot benefit from technologies that are not available, affordable, or appropriate to their conditions. Purchased inputs present special problems and risks for less-secure farmers, particularly where supplies and the credit to facilitate purchases are inadequate.

The analysis of dozens of NGO-led agroecological projects show convincingly that agroecological systems are not limited to producing low outputs, as some critics have asserted. Increases in production of 50 to 100 percent are fairly common with most alternative production methods. In some of these systems, yields for crops that the poor rely on most- rice (*Oryza sativa*), beans (*Phaseolus vulgaris*), maize, cassava (*Manihot esculenta*), potatoes (*Manihot esculenta*), barley– have been increased by several-fold, relying on labour and know-how more than on expensive purchased inputs, and capitalizing on processes of intensification and synergy (Uphoff, 2002).

In a recent study of 208 agroecologically based projects and/or initiatives throughout the developing world, Pretty and Hine (2000) documented clear increases in food production over some 29 million hectares, with nearly 9 million households benefiting from increased food diversity and security. Promoted sustainable agriculture practices led to 50-100% increases in per hectare food production (about 1.71 Mg per year per household) in rain-fed areas typical of small farmers living in marginal environments; that is an area of about 3.58 million hectares, cultivated by about 4.42 million farmers. Such yield enhancements are a true breakthrough for achieving food security among farmers isolated from mainstream agricultural institutions.

More important than just yields, agroecological interventions raise total production significantly through diversification of farming systems, such as raising fish in rice paddies or growing crops with trees, or adding goats or poultry to household operations (Uphoff and Altieri, 1999). Agroecological approaches increased the stability of production as seen in lower coefficients of variance in crop yield with better soil and water management (Francis, 1988).

It is difficult, however, to quantify all the potentials of such diversified and intensified systems because there is too little research and experience to establish their limits. Nevertheless, data from agroecological field projects show that traditional crop and animal combinations can often be adapted to increase productivity when the biological structuring of the farm is improved and labour and local resources are efficiently used (Altieri, 1999). In general, data shows that over time agroecological systems exhibit more stable levels of total production per unit area than high-input systems; produce economically favourable rates of return; provide a return to labour and other inputs sufficient for a livelihood acceptable to small farmers and their families; and ensure soil protection and conservation as well as enhanced biodiversity (Pretty, 1997).

Current Limitations to the Widespread Use of Agroecology

With increasing evidence and awareness of the advantages of agroecology, why hasn't it spread more rapidly and how can it be multiplied and adopted more widely? A key obstacle to the use of agroecology is the demand for specificity in its application. Contrary to conventional systems featuring homogeneous technological packages designed for ease of adoption and that lead to agroecosystem simplification, agroecological systems require that principles are applied creatively within each particular agroecosystem. Field practitioners must have more diversified information on ecology and on agricultural and social sciences in general. Today's agronomy curricula, focused on applying the «Green Revolution» technological kit, is simply unfit to deal with the complex realities facing small farmers (Pearse, 1980). This situation is changing, although slowly, as many agricultural universities have started to incorporate agroecology and sustainability issues into the conventional agronomic curriculum (Altieri and Francis, 1992).

The high variability of ecological processes and their interactions with heterogeneous social, cultural, political, and economic factors generate local systems that are exceptionally unique. When the heterogeneity of the rural poor is considered, the inappropriateness of technological recipes or blueprints becomes obvious. The only way that the specificity of local systems —from regions to watersheds and all the way down to a farmer's field— can be taken into account is through site-specific NRM (Beets, 1990). This does not mean however, that agroecological schemes adapted to specific conditions may not be applicable at ecologically and socially homologous larger scales. What implies is the need to understand

Table 5. Key constrains to implementing sustainable agriculture partnerships (modified form, Thrupp, 1996)

Macroeconomics policies and institutions
Pesticides incentives and subsidies
Export orientation and monocultural focus of conventional policies
Lack of incentives for institutional partnerships
Pressures forma agrochemical companies
Political and economic power wielded against IPM
Advertising and sales practices
Funding/door issues and sustainability questions
Lack of funding, especially long term support
Lack of recognition of IPN/sustainable agriculture benefits
Need for reducing dependency on donors and the developing local support
Lack of information and outreach on innovative alternative methods
Weak internal capacities of institutions involved
Institutional rigidities among some collaborators
Lack of experience with agroecology and participatory methods
Social and health, concerns sometimes neglected
Lack of communication and cooperation skills (among some groups)

the principles that explain why such schemes work at the local level, and later applying such principles at broader scales.

NRM site-specificity requires an exceptionally large body of knowledge that no single research institution can generate and manage on its own. This is one reason why the inclusion of local communities at all stages of projects (design, experimentation, technology development, evaluation, dissemination, etc.) is a key element in successful rural development. The inventive self-reliance of rural populations is a resource that must be urgently and effectively mobilised (Richards, 1985).

On the other hand, technological or ecological intentions are not enough to disseminate agroecology. As pointed out in Table 5, there are many factors that constraint the implementation of sustainable agriculture initiatives. Major changes must be made in policies, institutions, and research and development agendas to make sure that agroecological alternatives are adopted, made equitably and broadly accessible, and multiplied so that their full benefit for sustainable food security can be realized. It must be recognized that a major constraint to the spread of agroecology has been that powerful economic and institutional interests have backed research and development for the conventional agroindustrial approach, while research and development for agroecology and sustainable approaches has been largely ignored or even ostracised. Only in recent years has there been growing realisation of the advantages of alternative agricultural technologies (Pretty, 1995).

The evidence shows that sustainable agricultural systems can be both economically, environmentally and socially viable, and contribute positively to local livelihoods (Uphoff and Altieri, 1999). But without appropriate policy support, they are likely to remain localised in extent. Therefore, a major challenge for the future entails promoting institutional and policy changes to realize the potential of the alternative approaches. Necessary changes include:

- Increasing public investments in agroecological – participatory methods.
- Changes in policies to stop subsidies of conventional technologies and to provide support for agroecological approaches.
- Improvement of infrastructure for poor and marginal areas.
- Appropriate equitable market opportunities including fair market access and market information to small farmers.
- Security of tenure and progressive decentralization processes.
- Change in attitudes and philosophy among decision-makers, scientists, and others to acknowledge and promote alternatives.

- Strategies of institutions encouraging equitable partnerships with local NGOs and farmers; replace top-down transfer of technology model with participatory technology development and farmer centered research and extension.

Scaling Up of Agroecological Innovations

Throughout Africa, Asia and Latin America there are many NGOs involved in promoting agroecological initiatives that have demonstrated a positive impact on the livelihoods of small farming communities in various countries (Pretty, 1995). Success is dependent on the use of a variety of agroecological improvements that in addition to farm diversification favouring a better use of local resources, also emphasise human capital enhancement and community empowerment through training and participatory methods as well as higher access to markets, credit and income generating activities (Figure 4). Pretty and Hine's (2001) analysis point at the following factors as underlying the success of agroecological improvements:

- Appropriate technology adapted by farmers' experimentation;
- Social learning and participatory approaches;
- Good linkages between farmers and external agencies, together with the existence of working partnerships between agencies;
- Presence of social capital at local level.

In most cases, farmers adopting agroecological models achieved significant levels of food security and natural resource conservation. Given the benefits and advantages of such initiatives, two basic questions emerge: (l) why these benefits have not disseminated more widely and (2) how to scale-up these initiatives to enable wider impact? For the purposes of this paper, scaling up is defined as the dissemination and adoption of agroecological principles over substantial areas by large numbers of farmers and technical staff. In other words, scaling up means achieving a significant increase in the knowledge and management of agroecological principles and technologies between farmers of varied socio-economic and biophysical conditions, and between institutional actors involved in peasant agricultural development.

One important factor limiting the spread of agroecological innovations is that for the most part NGOs promoting such initiatives have not analysed or systematized the principles that determined the level of

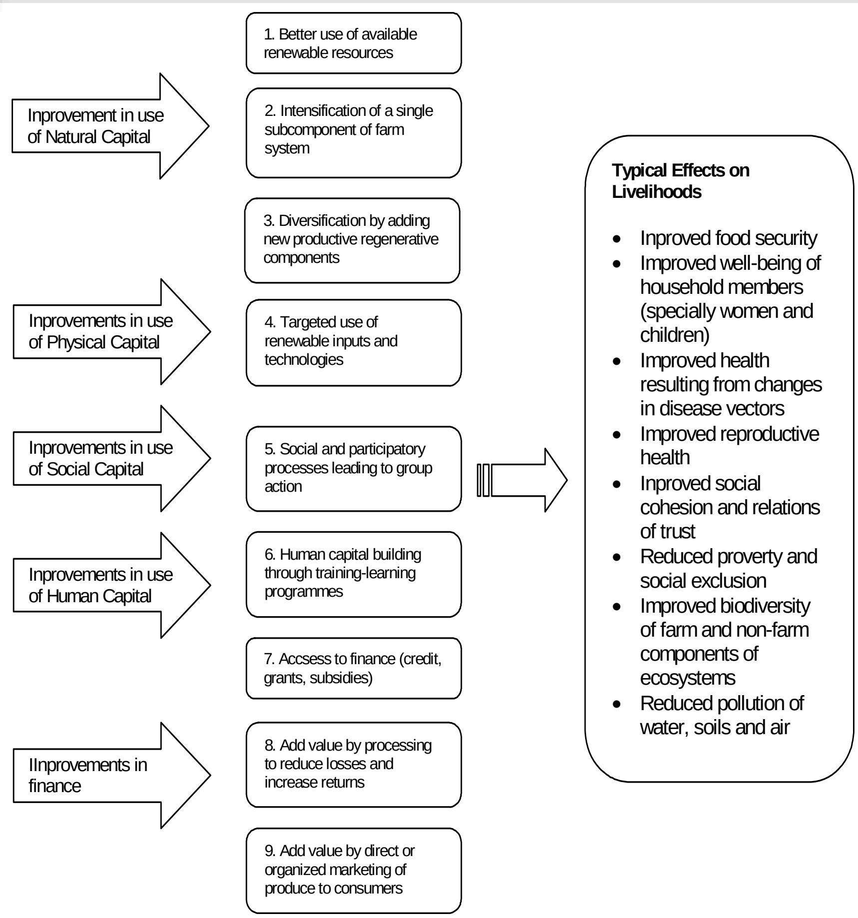

Fig. 4. Entry points for sustainable agriculture omprovements leadings to more sustainable livelihoods (Pretty and Hine, 2000)

success of the local initiatives, nor have been able to validate specific strategies for the scaling-up of such initiatives. A starting point therefore should be the understanding of the agroecological and socio-economic conditions under which alternatives were adopted and implemented at the local level. Such information can shed light on the constraints and opportunities farmers to whom benefits should be expanded at a more regional level are likely to face.

An unexplored approach is to provide additional methodological or technical ingredients to existing cases that have reached a certain level of success. Clearly, in each country there are restraining factors such as lack of markets, and lack of appropriate agricultural policies and technologies which limit scaling up. On the other hand, opportunities for scaling up exist, including the systematisation and application of approaches that have met with success at local levels, and the removal of constraining factors (IIRR, 2000). Thus scaling up strategies must capitalise on mechanisms conducive to the spread of knowledge and techniques, such as:

- Strengthening of producers' organizations through alternative marketing channels. The main idea is to evaluate whether the promotion of alternative farmer-led markets constitute a mechanism to enhance the economic viability of the agroecological approach and thus provide the basis for the scaling-up process.

- Develop methods for rescuing/collecting/evaluating promising agreocological technologies generated by experimenting farmers and making them known to other farmers for wide adoption in various areas. Mechanisms to disseminate technologies with high potential may involve farmer exchange visits, regional-national farmer conferences, and publication of manuals that explain the technologies for the use by technicians involved in agroecological development programs.

- Training government research and extension agencies on agroecology in order for these organizations to include agroecological principles in their extension programs.

• Develop working linkages between NGOs and farmers organizations. Such alliance between technicians and farmers is critical for the dissemination of successful agroecological production systems emphasizing biodiversity management and rational use of natural resources.

Cooper and Denning (2001) provide ten fundamental conditions and processes that should be considered when scaling-up agroforestry

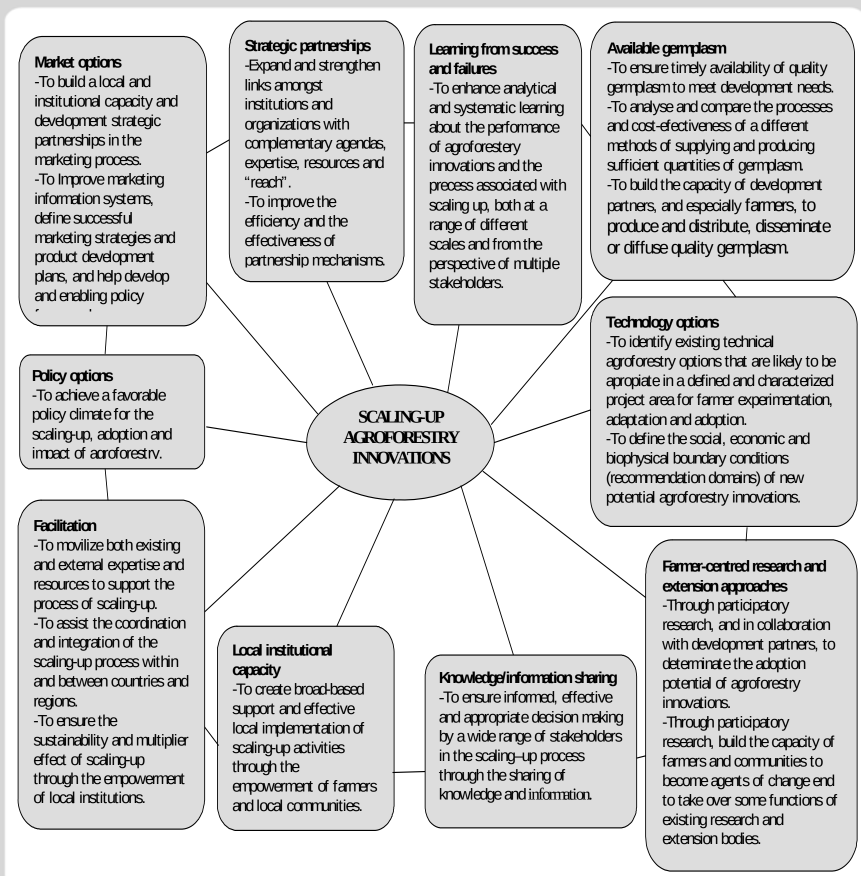

Fig. 5 Key requirements and components for the scaling-up of agroecological innovations (Cooper and Denning, 2001)

innovations. More effective farmers organizations, research-extension institutional partnerships; exchanges, training, technology transfer and validation in the context of farmer to farmer activities, enhanced participation of small farmers in niche markets, etc, are all important requirements (Figure 5). From their worldwide survey of sustainable agriculture initiatives, Pretty and Hine (2001) concluded that if sustainable agriculture is to spread to larger numbers of farmers and communities, then future attention needs to be focused on:

1. Ensuring the policy environment is enabling rather than disabling.
2. Investing in infrastructure for markets, transport and communications.
3. Ensuring the support of government agencies, in particular, for local sustainable agricultural initiatives.
4. Developing social capital within rural communities and between external agencies.

The main expectation of a scaling – up process is that it should expand the geographical coverage of participating institutions and their target agroecological projects while allowing an evaluation of the impact of the strategies employed. A key research goal should be that the methodology used will allow for a comparative analysis of the experiences learned, extracting principles that can be applied in the scaling-up of other existing local initiatives, thus illuminating other development processes.

Outlook and Prospects

There is no question that small farmers located in marginal environments in the developing world can produce much of their needed food (Uphoff and Altieri, 1999; Pretty and Hine, 2000). The evidence is conclusive: new approaches and technologies spearheaded by farmers, NGOs and some local governments around the world are already making a sufficient contribution to food security at the household, national, and regional levels. A variety of agroecological and participatory approaches in many countries show very positive outcomes even under adverse conditions. Potentials include: raising cereal yields from 50 to 200 percent, increasing stability of production through diversification, improving diets and income, contributing to national food security and even to exports and conservation of the natural resource base and agrobiodiversity (Pretty, 1995; Uphoff and Altieri, 1999).

Whether the potential and spread of these thousands of local agroecological innovations is realized depends on several factors and

Table 6.
Elements and contributions of an appropriate NRM strategy

Contribute to greater environmental preservation	Promotion of resource – conserving multifunctional technologies
Enhance production and household food security	Participatory approaches for community involvement and empowerment
Provide on —and off— farm employment	Institutional partnerships
Provision of local imputs and marketing opportunities	Effective and supportive policies

actions. First, proposed NRM strategies have to deliberately target the poor, and not only aim at increasing production and conserving natural resources, but also create employment, provide access to local inputs and output markets (Table 6). New strategies must focus on the facilitation of farmer learning to become experts on NRM and at capturing the opportunities in their diverse environments (Uphoff, 2002).

Second, researchers and rural development practitioners will need to translate general ecological principles and natural resource management concepts into practical advice directly relevant to the needs and circumstances of small-holders. The new pro-poor technological agenda must incorporate agroecological perspectives. A focus on resource conserving technologies, that uses labour efficiently, and on diversified farming systems based on natural ecosystem processes will be essential. This implies a clear understanding of the relationship between biodiversity and agroecosystem function and identifying management practices and designs that will enhance the right kind of biodiversity which in turn will contribute to the maintenance and productivity of agroecosystems.

Technological solutions will be location specific and information intensive rather than capital intensive. The many existing examples of traditional and NGO-led methods of natural resource management provide opportunities to explore the potential of combining local farmer knowledge and skills with those of external agents to develop and/or adapt appropriate farming techniques.

Any serious attempt at developing sustainable agricultural technologies must bring to bear local knowledge and skills on the research process (Richards, 1995; Toledo, 2000). Particular emphasis must be given to involving farmers directly in the formulation of the research agenda and on their active participation in the process of technological innovation and dissemination. The focus should be in strengthening local research and problem-solving capacities. Organizing local people around NRM projects that make effective use of traditional skills and knowledge provides a launching pad for additional learning and organizing, thus improving prospects for community empowerment and self-reliant development.

Third, major changes must be made in policies, institutions, and research and development to make sure that agroecological alternatives are adopted, made equitably and broadly accessible, and multiplied so that their full benefit for sustainable food security can be realized. Existing subsidies and policy incentives for conventional chemical approaches must be dismantled. Corporate control over the food system must also be challenged. The strengthening of local institutional capacity and widening access of farmers to support services that facilitate use of technologies will be critical Governments and international public organizations must encourage and support effective partnerships between NGOs, local universities, and farmer organizations in order to assist and empower poor farmers to achieve food security, income generation, and natural resource conservation.

There is also need to increase rural incomes through interventions other than enhancing yields, such as complementary marketing and processing activities. Therefore equitable market opportunities should also be developed, emphasizing fair trade and other mechanisms that link farmers and consumers more directly. The ultimate challenge is to increase investment and research in agroecology and scale up projects that have already proven successful to thousands of other farmers. This will generate a meaningful impact on the income, food security, and environmental well being of the world's population, especially of the millions of poor farmers yet untouched by modern agricultural technology.

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Chapter 7

Enhancing the Productity of Latin American Traditional Peasant Farming Systems Through an Agroecological Approach

The great majority of farmers in Latin America are peasants who still farm small plots of land, usually in marginal environments utilizing traditional and subsistence methods. The contribution of the 16 million peasant units to regional food security is however substantial. Research has shown that peasant systems, which mostly rely on local resources and complex cropping patterns, are reasonably productive despite their land endowments and low use of external inputs. Moreover analysis of NGO-led agroecological initiatives show that traditional crop and animal systems can be adapted to increase productivity by biologically re-structuring peasant farms which in turn leads to optimization of key agroecosystem processes (nutrient cycling, organic matter accumulation, biological pest regulation, etc.) and efficient use of labor and local resources. Examples of such grassroots projects are herein described to show that agroecological approaches can offer opportunities to substantially increase food production while preserving the natural resource base and empowering rural communities.

Although most traditional agricultural systems and practices encompass mechanisms to stabilize production in risk-prone environments without external subsidies, most agroecologists recognize that traditional systems and indigenous knowledge will not yield panaceas for agricultural problems (Altieri, I995; Gliessman, I998). Nevertheless, traditional ways of farming refined over many generations by intelligent land users, provide insights into sustainably managing soils, water, crops, animals and pests (Thrupp, l998). Perhaps the most rewarding aspect of agroecological research has been that by understanding the features of traditional agriculture, such as the ability to bear risk, biological folk taxonomies, the production efficiency of symbiotic crop mixtures, etc., important information on how to develop agricultural technologies best suited to the needs and circumstances of specific peasant groups has been obtained. This information has been a critical input for the application of agroecology in rural development programs.

Since the early 1980s, more than 200 projects promoted by NGOs in Latin America have concentrated on promoting agroecological technologies which are sensitive to the complexity of peasant farming systems (Altieri and Masera, 1993). This agroecological approach offers an alternate path to agricultural intensification by relying on local farming knowledge and techniques adjusted to different local conditions, management of diverse on-farm resources and inputs, and incorporation of contemporary scientific understanding of biological principles and resources in farming systems. Second, it offers the only practical way to actually restore agricultural lands that have been degraded by conventional agronomic practices. Third, it offers an environmentally sound and affordable way for smallholders to sustainable intensify production in marginal areas. Finally, it has the potential to reverse the anti-peasant biases inherent in strategies that emphasize purchased inputs and machinery, valuing instead the assets that small farmers already possess, including local knowledge and the low opportunity costs for labor that prevail in the regions where they live (Altieri *et. al.,* 1998).

This paper contends that there is enough evidence available —despite the fact that researchers have paid little attention to these systems— to suggest that agroecological technologies promise to contribute to food security on many levels. Critics of such alternative production systems point to lower crop yields than in high-input conventional systems. Yet all too often, it is precisely the emphasis on yield a measure of the performance of a single crop that blinds analysts to broader measures of sustainability and to the greater per unit area productivity and environmental services obtained in complex, integrated agroecological systems that feature many crop varieties together with animals and trees. Moreover, there are many cases where even yields of single crops are higher in agroecological systems that have undergone the full conversion process (Lampkin, l992).

Assessments of various initiatives in Latin America show that agroecological technologies can bring significant environmental and economic benefits to farmers and communities (Altieri, 1995; Pretty, 1995; Thrupp, 1996). If such experiences were to be scaled up, multiplied, extrapolated, and supported in alternative policy scenarios, the gains in food security and environmental conservation would be substantial. This article summarizes some cases from Latin America that explore the potential of the agroecological approach to sustainably increase productivity of smallholder farming systems, while preserving the resource base and at the same time empowering local communities.

The Productivity of Traditional Farming Systems

Despite the increasing industrialization of agriculture, the great majority of the farmers in Latin America are peasants, or small producers, who still farm the valleys and slopes of rural landscapes with traditional and subsistence methods. Peasant production units reached about 16 million in the late 1980s occupying close to 160 million hectares, involving 75 million people representing almost two thirds of the Latin America's total rural population (Ortega, l986).

The contribution of peasant agriculture to the general food supply in the region is significant. In the l980s it reached approximately 41 percent of the agricultural output for domestic consumption, and is responsible for producing at the regional level 51 percent of the maize, 77 percent of the beans, and 61 percent of the potatoes (Table 1).

Table 1. Estimated arable land and population on steep slopes of selected Latin American countries and their contribution to total agricultural output[1]

Country	Arable Land (%)	Agricultural population (%)	Percent contribution to agricultural Output (including coffee)	Contribution to country's total Agricultural Production Corn (%)	Potato (%)
Ecuador	25	40	33	50	70
Colombia	25	50	26	50	70
Peru	25	50	21	20	50
Guatemala	75	65	25	50	75
El Salvador	75	50	18	50	-
Honduras	80	20	19	40	100
Haiti	80	65	30	70	70
Dominican Republic	80	30	31	40	50

[1] Modified alter Posner and McPherson (1982)

In Brazil, small peasant producers control about 33 percent of the area sown to maize, 61 percent of that under beans, and 64 percent of that planted to cassava. In Ecuador the peasant sector occupies more than 50 percent of the area devoted to food crops such as maize, beans, barley and okra. In Mexico, peasants occupy at least 70 percent of the area assigned to maize and 60 percent of the area under beans (Ortega, 1986).

Most peasant systems are productive despite their low use of chemical inputs. Generally, agricultural labor has a high return per unit of input. The energy return to labor expended in a typical highland Mayan maize farm is high enough to ensure continuation of the present system. To work a hectare of land, which normally yields 4,230,692 calories requires some 395 hours; thus, an hour's labor produces about 10,700 calories. A family of three adults and seven children eat about 4,830,000 calories of maize per year, thus current systems provide food security for a typical family of 5 or 7 people (Gladwin and Truman, 1989).

Also in these systems, favorable rates of return between inputs and outputs in energy terms are realized. On Mexican hillsides, maize yields in hand-labor dependent swidden systems are about 1,940 kg/ha, exhibiting an output/input ratio of 11:1. In Guatemala, similar systems yield about 1,066 kg/ha of maize, with an energy efficiency ratio of 4.84. Yield per seed planted vary from 130-200. When animal traction is utilized, yields do not necessarily increase but the energy efficiency drops to values ranging from 3.11-4.34. When fertilizers and other agrochemicals are utilized yields can increase to levels of 5-7 t/ha, but energy ratios are highly inefficient (less than 2.5). In addition, most peasants are poor and generally cannot afford such inputs unless agrochemicals are subsidized (Pimentel and Pimentel, 1979).

In many areas of the region, traditional farmers have developed and/or inherited complex farming systems, adapted to the local conditions, that have helped them to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science (Denevan, 1995).

The persistence of more than three million hectares under traditional agriculture in the form of raised fields, terraces, polycultures, agroforestry systems, etc., document a successful indigenous agricultural strategy and comprises a tribute to the «creativity» of peasants throughout Latin America. These microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain year-round yields. An example are the chinampas in Mexico which according to Sanders (l957) in the mid 1950s exhibited maize yields of 3.5 to 6.3 tones per hectare (Table 2). At the same time, these were the highest long-term yields achieved anywhere in Mexico. In comparison, average maize yields in the United States in 1955 were 2.6 tones per hectare, and did not pass the 4 tones per hectare mark until 1965 (USDA, 1972). Sanders (1957) estimated that that each hectare of chinampa could produce enough food for 15 to 20persons per year at modern subsistence levels. Recent research has indicated that each chinampero can work about three quarters of a hectare of chinampa

Table 2. Maize yields from chinanpa plots during the1950s

Location	Plot size (ha)	Yield kg/ha)
Tlahuac	0.32	5500
	0.10	3750-4500
	0.16	4650-5500
	0.10	3750-4500
	0.16	4650
	0.16	6300
San Gregorio	0.20	3750-4500
	0.21	3600-4350
	0.10	3750-4500
	0.11	4950

Source: Sanders, 1957

per year (Jimenez-Osornio and del Amo, 1986), meaning that each farmer can support 12 to 15 people.

A salient feature of traditional farming systems is their degree of plant diversity in the form of polycultures and/or agroforestry patterns (Chang, 1977; Clawson, 1985; Thrupp, 1998). This peasant strategy of minimizing risk by planting several species and varieties of crops, stabilizes yields over the long term, promotes diet diversity, and maximizes returns under low levels of technology and limited resources (Harwood, 1979). Much of the production of staple crops in the Latin American tropics occurs in polycultures. More than 40 percent of the cassava, 60 percent of the maize, and 80 percent of the beans in that region are grown in mixtures with each other or other crops (Francis, 1986, Table 3). In most multiple cropping systems developed by smallholders, productivity in terms of harvestable products per unit area is higher than under sole cropping with the same level of management. Yield advantages can range from 20 percent to 60 percent. These differences can be explained by a combination of factors which include the reduction of losses due to weeds, insects and diseases and a more efficient use of the available resources of water, light and nutrients (Beets, 1982).

Table 3. Yields and total biomass of maize, beans and squash (kg/ha) in policulture and compared with several densities (plants/(ha) of each crop in monoculture

Crop		Monoculture				Polyculture
Maize						
	Density	33,000	40,000	66,000	100,000	50,000
	Yield	990	1,150	1,230	1,770	1,720
	Biomass	2,823	3,119	4,847	4,871	5,927
Beans						
	Density	56,800	64,000	100,00	133,200	40,000
	Yield	425	740	610	695	110
	Biomass	853	895	843	1,390	253
Squash						
	Density	1,200	1,875	7,500	30,000	3,300
	Yield	15	215	430	225	80
	Biomass	241	841	1,254	802	478
Total poyculture yield						1,910
Total polyculture mass						6,659

Source: Gliessman, 1998

In Mexico, 1.73 hectares of land has to be planted with maize to produce as much food as one hectare planted with a mixture of maize, squash, and beans. In addition, a maize-squash-bean polyculture can produce up to four tons per hectare of dry matter for plowing into the soil, compared with two tons in a maize monoculture (Table 3). In Brazil, polycultures containing 12,500 maize plants/ha and 150,000 bean plants/ha exhibited a yield advantage of 28 percent. In drier environments, maize is replaced by sorghum in the intercropping without affecting the productive capacity of cowpeas or beans and yielding LER values of 1.25-1.58. This system exhibits a greater stability of production as sorghum is more tolerant to drought.

Tropical agroecosystems composed of agricultural and fallow fields, complex home gardens, and agroforestry plots, commonly contain well over 100 plant species per field, which are used for construction materials, firewood, tools, medicines, livestock feed, and human food. Examples include multiple-use agroforestry systems managed by the Huastecs and Lacondones in Mexico, the Bora and Kayapo Indians in the Amazon basin and many other ethnic groups who incorporate trees into their production systems (Wilken, 1977). Such home gardens are a highly efficient form of land use incorporating a variety of crops with different growth habits. The result is a structure similar to tropical forests, with diverse species and a layered configuration (Denevan *et al.,* 1984). Because of the nearly year-round growing conditions, indigenous farmers are able to stagger crop and tree plantings and harvesting to increase overall yields. For example the Bora plant a wide variety of crops, including some 22 varieties of sweet and bitter manioc interspersed among pineapples, fruit trees and minor annual crops.

In the Amazon, the Kayapo yields are roughly 200% higher than colonist systems and 175 times that of livestock (Hecht, 1989). In Mexico, Huastec Indians manage a number of agricultural and fallow fields, complex home gardens and forest plots totaling about 300 species. Small areas around the houses commonly average 80-125 useful plant species, mostly native medicinal plants (Alcorn, l984).

Ecological Mechanisms Underlying the Productivity of Traditional

Farming Systems

The high levels of productivity that characterize the chinampas result from several factors. First, cropping is nearly continuous; only rarely is the chinampa left without a crop. As a result, 3 to 4 crops are produced each year. One of the primary mechanisms by which this intensity is maintained are the seedbeds, in which young plants are germinated before the older crops are harvested. Second, the chinampa maintain a high level of soil fertility despite the continual harvest of crops because they are supplied with high quantities of organic fertilizers. The lakes themselves serve as giant catch basins for nutrients. The aquatic plants function as nutrient concentrators, absorbing nutrients that occur in low concentration in the water and storing them inside their tissue. The use of these plants along with canal mud and muddy water (for irrigation)insures that an adequate supply of nutrients is always available to the growing crops. Third, there is plenty of water for the growing crop. The narrowness of the chinampas is a design feature that ensures that water from the canal infiltrates the chinampa, giving rise to a zone of moisture within reach of the crop's roots. Even if during the dry season the lake levels fall below the rooting zone, the narrowness of the chinampa allows the chinampero to irrigate from a canoe. Fourth, there is a large amount of individual care given to each plant in the chinampa. Such careful husbandry facilitates high yields (Gliesman *et. al.,* 1981).

By interplanting, farmers achieve several production and conservation objectives simultaneously. With crop mixtures, farmers can take advantage of the ability of cropping systems to reuse their own stored nutrients and the tendency of certain crops to enrich the soil with organic matter (Francis, 1986). In «forest-like» agricultural systems cycles are tight and closed. In many tropical agroforestry systems such as the traditional coffee under shade trees (*Inga* sp., *Erythrina* sp., etc.) total nitrogen inputs from shade tree leaves, litter, and symbiotic fixation can be well over ten times higher than the net nitrogen output by harvest which usually averages 20 kg/ha/year. In other words, the system amply compensates the nitrogen loss by harvest with a subsidy from the shade trees. In highly co-evolved systems, researchers have found evidence of synchrony between the peaks of nitrogen transfer to the soil by decomposing litter and the periods of high nitrogen demand by flowering and fruiting coffee plants (Nair, 1984).

Crops grown simultaneously enhance the abundance of predators and parasites, which in turn prevent the build-up of pests, thus minimizing the need to use expensive and dangerous chemical insecticides. For example, in the tropical lowlands, corn-bean-squash polycultures suffer less attack by caterpillars, leafhoppers, thrips, etc., than corresponding monocultures, because such systems harbor greater numbers of parasitic wasps. The plant diversity also provides alternative habitat and food sources such as pollen, nectar, and alternative hosts to predators and parasites. In Tabasco, Mexico, it was found that eggs and larvae of the lepidopteran pest *Diaphania hyalinata* exhibited a 69 percent parasitization rate in the polycultures as opposed to only 29 percent rate in monocultures. Similarly, in the Cauca valley of Colombia, larvae of *Spodoptera frugiperda* suffered greater parasitization and predation in the corn-bean mixtures by a series of *Hymenopteran* wasps and predacious beetles than in corn monocultures (Altieri, 1994).

This mixing of crop species can also delay the onset of diseases by reducing the spread of disease carrying spores, and by modifying environmental conditions so that they are less favorable to the spread of certain pathogens. In general, the peasant farmers of traditional agriculture are less vulnerable to catastrophic loss because they grow a wide variety of cultivars. Many of these plants are landraces grown from seed passed down from generation to generation and selected over the years to produce desired production characteristics. Landraces are genetically more heterogeneous than modern cultivars and can offer a variety of defenses against vulnerability (Thurston, 1991).

Integration of animals (cattle, swine, poultry) into farming systems in addition to providing milk, meat, and draft adds another tropic level to the system, making it even more complex. Animals are fed crop residues and weeds with little negative impact on crop productivity. This serves to turn otherwise unusable biomass into animal protein. Animals recycle the nutrient content of plants, transforming them into manure. The need for animal fed also broadens the crop base to include plant species useful for conserving soil and water. Legumes are often planted to provide quality forage but also serve to improve nitrogen content of soils (Beets, 1990).

Building on Traditional Farming: NGO-Led Agroecological Initiatives

In Latin America, economic change, fueled by capital and market penetration, is leading to an ecological breakdown that is starting to destroy the sustainability of traditional agriculture. After creating resource-conserving systems for centuries, traditional cultures in areas such as Mesoamerica, the Amazon, and the Andes are now being undermined by external political and economic forces. Biodivesity is decreasing on farms, soil degradation is accelerating, community and social organizations are breaking down, genetic resources are being eroded and traditions lost. Under this scenario, and given commercial pressures and urban demands, many developers argue that the performance of subsistence agriculture is unsatisfactory, and that intensification of production is essential for the transition from subsistence to commercial production (Blauert and Zadek, 1998). In reality the challenge is to guide such transition in a way that it yields and income are increased without threatening food security, raising the debt of peasants, and further exacerbating environmental degradation. Many agroecologists contend that this can be done by generating and promoting resource conserving technologies, a source of which are the very traditional systems that modernity is destroying (Altieri, 1991).

Taking traditional farming knowledge as a strategy point, a quest has begun in the developing world for affordable, productive, and ecologically sound small scale agricultural alternatives. In many ways, the emergence of agroecology stimulated a number of non-governmental organizations (NGOs) and other institutions to actively search for new kinds of agricultural development and resource management strategies that, based on local participation, skills and resources, have enhanced small farm productivity while conserving resources (Thrupp, 1996). Today there are hundreds of examples where rural producers in partnership with NGOs and other organizations, have promoted and implemented alternative, agroecological development projects which incorporate elements of both traditional knowledge and modern agricultural science, featuring resource-conserving yet highly productive systems, such as polycultures, agroforestry, and the integration of crops and livestock etc.

Stabilizing the Hillside of Central America

Perhaps the major agricultural challenge in Latin America is to design cropping systems for hillside areas, that are both productive and reduce erosion. Several organizations have taken on this challenge with initiatives that emphasize the stewardship of soil resources, utilization of local resources, and inputs produced on farm.

Since the mid 1980s, the private voluntary organization World Neighbors has sponsored an agricultural development and training program in Honduras to control erosion and restore the fertility of degraded soils. Soil conservation practices were introduced-such as drainage and contour ditches, grass barriers, and rock walls-and organic fertilization methods were emphasized, such as chicken manure and intercropping with legumes. Program yields tripled or quadrupled from 400 kilograms per hectare to 1,200-1,600 kilograms, depending on the farmer. This tripling in per-hectare grain production has ensured that the 1,200 families participating in the program have ample grain supplies for the ensuing year. Subsequently, COSECHA, a local NGO promoting farmer-to-farmer methodologies on soil conservation and agroecology, helped some 300 farmers experiment with terracing, cover crops, and other new techniques. Half of these farmers have already tripled their corn and bean yields; 35 have gone beyond staple production and are growing carrots, lettuce, and other vegetables to sell in the local markets. Sixty local villagers are now agricultural extensionists and 50 villages have requested training as a result of hearing of these impacts. The landless and near-landless have benefited with the increase in labor wages from US $2 to $3 per day in the project area. Outmigration has been replaced by inmigration, with many people moving back from the urban slums of Tegucigalpa to occupy farms and houses they had previously abandoned, so increasing the population of Guinope. The main difficulties have been in marketing of new cash crops, as structures do not exist for vegetable storage and transportation to urban areas (Bunch, 1987).

In Cantarranas, the adoption of velvetbean (*Mucuna pruriens),* which can fix up to 150 kg N/ha as well as produce 35 tones of organic matter per year, has tripled maize yields to 2,500 kg/ha. Labor requirements for weeding have been cut by 75 percent and, herbicides eliminated entirely. The focus on village extensionists was not only more efficient and less costly than using professional extensionists, it also helped to build local capacity and provide crucial leadership experience (Bunch, 1990).

Throughout Central America, CIDDICO and other NGOs have promoted the use of grain legumes to be used as green manure, an inexpensive source of organic fertilizer to build up organic matter. Hundreds of farmers in the northern coast of Honduras are using velvet bean *(Mucuna pruriens)* with excellent results, including corn yields of about 3,000 kg/ha, more than double than national average, erosion control, weed suppression and reduced land preparation costs. The velvet beans produce nearly 30 t/ha of biomass per year, or about 90-100 kg of N/ha per year (Flores, 1989). Taking advantage of well established farmer to farmer networks such as the *campesino a campesino* movement in Nicaragua and elsewhere, the spread of this simple technology has occurred rapidly. In just one year, more than 1,000 peasants recovered degraded land in the Nicaraguan San Juan watershed (Holtz-Gimenez, 1996). Economic analyses of these projects indicate that farmers adopting cover cropping have lowered their utilization of chemical fertilizers (from 1,900 kg/ha to 400 kg/ha) while increasing yields from 700kg to 2,000 kg/ha, with production costs about 22 percent lower than farmers using chemical fertilizers and monocultures (Buckles *et. al.,* 1998).

Scientists and NGOs promoting slash/mulch systems based on the traditional «tapado» system, used on the Central American hillsides, have also reported increased bean and maize yields (about 3,000kg/ha) and considerable reduction in labor inputs as cover crops smother aggressive weeds, thus minimizing the need for weeding. Another advantage is that the use of drought resistant mulch legumes such as *Dolichos lablab* provide good forage for livestock (Thurston *et. al.,* 1994). These kinds of agroecological approaches are currently being used on a relatively small percentage of land, but as their benefits are being recognized by farmers, they are spreading quickly. Such methods have strong potential and offer important advantages for other areas of Central America and beyond.

Soil Conservation in the Dominican Republic

Several years ago, Plan Sierra, an ecodevelopment project took on the challenge of breaking the link between rural poverty and environmental degradation. In the central cordillera of the Dominican Republic. The strategy consisted in developing alternative production systems for the highly erosive conucos used by local farmers. Controlling erosion in the Sierra is not only important for the betterment of the life of these farmers but also represents hydroelectric potential as well as an additional 50,000 hectares of irrigated land in the downstream Cibao valley (Altieri, 1990).

The main goal of Plan Sierra is agroecological strategy was the development and diffusion of production systems that provided sustainable yields without degrading the soil thus ensuring the farmers' productivity and food self-sufficiency. More specifically, the objectives were to allow farmers to more efficiently use local resources such as soil moisture and nutrients, crop and animal residue, natural vegetation, genetic diversity, and family labor. In this way it would be possible to satisfy basic family needs for food, firewood, construction materials, medicinals, income, and so on.

From a management point of view the strategy consisted of a series of farming methods integrated in several ways:

1. Soil conservation practices such as terracing, minimum tillage, alley cropping, living barriers, and mulching.

2. Use of leguminous trees and shrubs such as *Gliricidia, Calliandra, Canavalia, Cajanus*, and *Acacia* planted in alleys, for nitrogen fixation, biomass production, green manure, forage production, and sediment capture.

3. Use of organic fertilizers based on the optimal use of plant and animal residues.

4. Adequate combination and management of polycultures and/or rotations planted in contour and optimal crop densities and planting dates.

5. Conservation and storage of water through mulching and water harvesting techniques.

In various farms animals, crops, trees, and/or shrubs, are all integrated to result in multiple benefits such as soil protection, diversified food production, firewood, improved soil fertility, and so on. Since more than 2,000 farmers have adopted some of the improved practices an important task of Plan Sierra was to determine the erosion reduction potential of the proposed systems. This proved difficult because most of the available methods to estimate erosion are not applicable for measuring soil loss in farming systems managed by resource-poor farmers under marginal conditions. Given the lack of financial resources and research infrastructure at Plan Sierra it was necessary to develop a simple method using measuring sticks to estimate soil loss in a range of concuos including those traditionally managed by farmers and the «improved ones» developed and promoted by Plan Sierra.

Based on field data collected in 1988-1989 on the accumulated erosion rates of three traditional and one improved farming system, the alternative systems recommended by Plan Sierra exhibited substantially less soil loss than the traditional shifting cultivation, cassava and guandul monocultures. The positive performance of the agroecologically improved conuco seemed related to the continuous soil cover provision through intercropping, mulching, and rotations, as well as the shortening of the slope and sediment capture provided by alley cropping and living barriers (Altieri, l985).

Recreating Incan Agriculture

Researchers have uncovered remnants of more than 170,000 hectares of «ridged-fields» in Surinam, Venezuela, Colombia, Ecuador, Peru and Bolivia (Denevan,1995). Many of these systems apparently consisted of raised fields on seasonally-flooded lands in savannas and in highland basins. In Peru, NGO's have studied such pre-Columbian technologies in search of solutions to contemporary problems of high altitude farming. A fascinating example is the revival of an ingenious system of raised fields that evolved on the high plans of the Peruvian Andes about 3,000 years ago. According to archeological evidence these Waru-Warus platforms of soil surrounded by ditches filled with water, were able to produce bumper crops despite floods, droughts, and the killing frost common at altitudes of nearly 4,000 meters (Erickson and Chandler,1989).

In 1984 several NGO's and state agencies created the Proyecto Interinstitucional de Rehabilitacion de Waru-Warus (PIWA) to assist local farmers in reconstructing ancient systems. The combination of raised beds and canals has proven to have important temperature moderation effects extending the growing season and leading to higher productivity on the Waru-Warus compared to chemically fertilized normal pampa soils. In the Huatta district, reconstructed raised fields produced impressive harvest, exhibiting a sustained potato yield of 8-14 t/ha/yr. These figures contrast favorably with the average Puno potato yields of 1-4 t/ha/yr. In Camjata the potato fields reached 13 t/ha/yr and quinoa yields reached 2 t/ha/yr. in Waru-Warus. It is estimated that the initial construction, rebuilding every ten years, and annual planting, weeding, harvest and maintenance of raised fields planted in potatoes requires 270 person-days/ha/yr. Clearly, raised beds require strong social cohesion for the cooperative work needed on beds and canals. For the construction of the fields, NGOs organized labor at the individual, family, multi-family, and communal levels.

Elsewhere in Peru, several NGOs in partnership with local government agencies have engaged in programs to restore abandoned ancient terraces. For example, in Cajamarca, in 1983, EDAC-CIED together with peasant communities initiated an all-encompassing soil conservation project. Over ten years they planted more than 550,000 trees and reconstructed about 850 hectares of terraces and 173 hectares of drainage and infiltration canals. The end result is about 1,124 hectares of land under construction measures (roughly 32% of the total arable land), benefiting 1,247 families (about 52% of the total in the area). Crop yields have improved significantly. For example, potato yields went from 5t/ha to 8t/ha and oca yields jumped from 3 to 8t/ha. Enhanced crop production, fattening of cattle and raising of alpaca for wool, have increased the income of families from an average of $108 per year in 1983 to more than $500 today (Sanchez, 1994).

In the Colca valley of southern Peru, PRAVTIR (Programa de Acondicionamiento Territorial y Vivienda Rural) sponsors terrace reconstruction by offering peasant communities low-interest loans and seeds or other inputs to restore large areas (up to 30 hectares) of abandoned terraces. The advantages of the terraces is that they minimize risks in terms of frost and/or drought, reducing soil loss, broadening cropping options because of the microclimatic and hydraulic advantages of terraces, thus improving productivity. First year yields from new bench terraces showed a 43-65% increase of potatoes, maize, and barley, compared to the crops grown on sloping fields (Table4). The native legume *Lupinus mutabilis* is used as a rotational or associated crop on the terraces; it fixes nitrogen, which is available to companion crops, minimizing fertilizer needs and increasing production. One of the main constraints of this technology is that it is highly labor intensive. It is estimated that it would require 2,000 worker-days to complete the reconstruction of 1 hectare, although in other areas reconstruction has proven less labor intensive, requiring only 300-500 worker/day/ha (Treacey, 1989). 1989).

NGOs have also evaluated traditional farming systems above 4,000 meters, where maca (*Lepidium meyenii)* is the only crop capable of offering farmers secure yields. Research shows that maca grown in virgin soils or fallowed between 5-8 years, exhibited significantly higher yields (11.8 and 14.6 t/ha respectively) than maca grown after bitter potatoes (11.3 t/ha). NGOs now are advising farmers to grow maca in virgin or fallow soils in a rotative pattern, to use areas not suitable for other crops and taking advantage of the local labor and low costs of the maca-based system (UNDP, 1995; Altieri, l996).

Table 4. First year per hectare yields of crops on new bench terraces, compared to yields on sloping fields (kg/ha)

Crop[a]	Terraced[b]	Non-terraced[c]	Percent increase	N[d]
Potatoes	17,206	12,206	43	71
Maize	2,982	1,807	65	18
Barley	1,910	1,333	43	56
Barley (forage)	23,000	25,865	45	159

a All crops treated with chemical fertilizrs
b Water absorption terraces with earthen walls and inward platform slope
c Fields sloping between 20 and 50 percent located next to the terraced field for control
d N= number of terrace/field sites

Source: Treacey, 1984

Organic Farming in the Andes

In the Bolivian highlands, average potato production is falling despite a 15 percent annual increase in the use of chemical fertilizers. Due to increases in the cost of fertilizer, potato farmers must produce more than double the amount of potatoes compared with previous years to buy the same quality of imported fertilizer (Augstburger, 1983). Members of the former Proyecto de Agrobiologia de Cochabamba, now called AGRUCO, are attempting to reverse this trend by helping peasants recover their production autonomy. In experiments conducted in neutral soils, higher yields were obtained with manure than with chemical fertilizers. In Bolivia, organic manures are deficient in phosphorous. Therefore, AGRUCO recommends phosphate rock and bone meal, both of which can be obtained locally and inexpensively, to increase the phosphorous content of organic manures. To further replace the use of fertilizers and meet the nitrogen requirements of potatoes and cereals, intercropping and rotational systems have been designed that use the native

Table 5. Performance of traditional, modern and agroecological potato-based production systems in Bolivia

	Traditional low-imput	Modern high-imput	Agroecological system
Potato yields (metric tons/ha)	9.2	17.6	11.4
Chemical fertilizer (N + P_2O_5, kg/ha)	0.0	80 + 120	0.0
Lupine biomass (metric tons/ha)	0.0	0.0	1.5
Energy efficiency (out-put/input)	15.7	4.8	30.5
Net income per Invested Boliviano	6.2	9.4	9.9

Source: Rist, 1992

species *Lupinus mutabilis*. Experiments have revealed that *L. mutabilis* can fix 200 kg of nitrogen per hectare per year, which becomes partly available to the associated or subsequent potato crop, thus significantly minimizing the need for fertilizers (Augstburger, 1983). Intercropped potato/lupine overyielded corresponding potato monocultures, and also substantially reduced the incidence of virus diseases.

Other studies in Bolivia, where Lupine has been used as a rotational crop, show that, although yields are greater in chemically fertilized and machinery-prepared potato fields, energy costs are higher and net economic benefits lower than with the agroecological system (Table 5). Surveys indicate that farmers prefer this alternative system because it optimizes the use of scarce resources, labor and available capital, and is available to even poor producers.

In the Interandean valleys of Cajamarca, near San Marcos traditional farming systems have been drastically modified through elements of conventional farming and urban influences, creating a market-oriented monoculture agriculture which favors cash crops rather than Andean crops. Centro IDEAS, an agricultural NGO, has implemented an organic agriculture proposal in order to revert the above process, supporting a more appropriate rural development strategy that rescues elements of the local traditional agriculture and ensuring food self-sufficiency as well as the preservation of natural resources (Chavez, 1989).

The basic aspects of the proposal are:

- Rational use of local resources, conservation of natural resources, and intensive use of human and animal labor.
- High diversity of native (Andean) and exotic crops, herbs, shrubs, trees, and animals grown in polycultural and rotational patterns.
- Creation of favorable microclimates through the use of shelterbelts, and living fences and reforestation with native and exotic fruit and trees.
- Recycling of organic residues and optimal management of small animals.

This proposal was implemented in a 1.9 ha model farm inserted in an area with similar conditions facing the average campesino of the region. The farm was divided into 9 plots, each following a particular rotational design (Table 6). After 3 years of operation, field results showed the following trends:

Table 6. Model farm rotational design

Plot	Year 1	Year 2	Year 3
1	Maize, beans, quinoa Kiwicha, squash and chiclayo	Wheat	Barley
2	Barley	*Lupinus* and lentils	Linaza
3	Wheat	Favas and oats quinoa, kiwicha	Maize, beans,
4	Rye	Wheat,	Lentils
5	Lupinus	Maize, beans, quinoa, kiwicha, squash and Chiclayo	Wheat
6	Fallow	Linaza	Barley and lentils

Source: Chavez, 1989

- Organic matter content increased from low to medium and high levels, and N levels increased slightly. Addition of natural fertilizers were necessary to maintain optimum levels of organic matter and nitrogen.
- Phosphorous and potassium increased in all plots.
- Crop yields varied among plots, however in plots with good soils, (plot 1) high yields of corn and wheat were obtained.
- Polycultures overyielded monocultures in all instances.
- To farm 1 ha of the model farm it was necessary to use 100 man-hours, 15 oxen-hours, and about 100 kg seeds. These preliminary results indicate that the proposed farm design enhances the diversity of food crops available to the family, increases income through higher productivity, and maintains the ecological integrity of the natural resource base.

Since then, this model experience extended to 12 farmers who have undergone conversion to agroecological management in the Peruvian Sierra and Coast. A recent evaluation of the experiences showed that after a 2-5 year conversion process, income increased progressively due to a 20 percent increase in productivity (Alvarado de la Fuente and Wiener Fresco, 1998). Of the thirty three different organic technologies offered by the IDEAS, the 12 case study farmers favored: organic fertilization (11 cases), intercropping (10 cases), animal integration (10 cases), and agroforestry systems (8 cases).

Agroecological Approaches in Brazil

The state government extension and research service, EPAGRI (Empresa de Pesquisa Agropecuaria e Difusao de Technologia de Santa Catarina), works with farmers in the southern Brazilian state of Santa Catarina. The technological focus is on soil and water conservation at the micro-watershed level using contour grass barriers, contour ploughing and green manures. Some 60 cover crop species have been tested with farmers, including both leguminous plants such as velvetbean, jackbean, lablab, cowpeas, many vetches and crotalarias, and non-legumes such as oats and turnips. For farmers these involved no cash costs, except for the purchase of seed. These are intercropped or planted during fallow periods, and are used in cropping systems with maize, onions, cassava, wheat, grapes, tomatoes, soybeans, tobacco, and orchards (Monegat, 199l).

The major on-farm impacts of the project have been on crop yields, soil quality and moisture retention, and labor demand. Maize yields have risen since 1987 from 3 to 5t/ha and soybeans from 2.8 to 4.7t/ha. Soils are darker in color, moist and biologically active. The reduced need for most weeding and ploughing has meant significant labor savings for small farmers. From this work, it has become clear that maintaining soil cover is more important in preventing erosion than terraces or conservation barriers. It is also considerably cheaper for farmers to sustain. EPAGRI has reached some 38,000 farmers in 60 micro-watersheds since 1991

(Guijt, 1998). They have helped more than 11,000 farmers develop farm plans and supplied 4300 tons of green manure seed.

In the savannahs of the Brazilian Cerrados where soybean monoculture dominates many problems associated with inappropriate land development have become evident. A key to production stability in the Cerrados is soil conservation and soil fertility replenishment as maintenance and increase of soil organic content is of paramount importance. For this reason NGOs and government researchers have concentrated efforts on the design of appropriate crop rotation and minimum tillage systems. The adoption of maize-soybean rotations have increased yields , slowed soil erosion and decreased pest and disease problems that affected soybean monocrops. Better weed control as well as soil organic maintenance has also been observed in such rotational systems (Spehar and Souza, 1996).

Another promoted alternative technique has been the use of green manures such as *Crotalaria juncea* and *Stizolobium atterrimum.* Researchers have shown grain crops following green manure yielded up to 46% more than monocultures during normal rainy seasons. Although the most common way of using green manures is to plant a legume after the main crop has been harvested, green manures can be intercropped with long cycle crops. In the case of maize –green manure intercrop, best performance is observed when *S. atterrimum* is sown 30 days after the maize. Maize can also be intercropped with perennial pasture legumes such as *Zornia* sp and *Stylosanthes* spp, a system of double purpose: produces food and fodder (Spehar and Souza, 1996).

In the hot and dry climate of Ceara, farmers combine production of sheep, goats, maize and beans, but productivity is low and environmental degradation is increasing. In the period between 1986 and 1991, ESPLAR, a local NGO engaged in a broad development program, involving the whole state of Ceara, through a massive training program in agroecology for village leaders. The training spearheaded a series of village-level activities reaching about 600 farmers which resulted in (VonderWeid, 1994):

1. The return of arboreal cotton cultivation in mixed cropping with leucaena, algarrobo *(Prosopis juliflora)* and sabia *(Mimosa caesalpiniaefdia).* A shorter cycle variety was introduced, which together with integrated control of the boll weevil, made it possible to restore cotton fields.

2. The use of small dams for irrigated vegetable production.

3. Enriching the capoeiras (areas with secondary vegetation regrowth) with selected plant species made it possible to support 50 percent more goats per land unit.

4. Introduction of herbaceous legumes for fodder (especially cunha [*Bradburya sagittata*]), in crop mixtures or rotated with maize and beans.

5. Planting along contour lines to reduce runoff.

In a similar semi-arid environment, as part of its research for alternatives to slash and burn, the Center for Alternative Technologies of Ouricouri developed a three year experiment to demonstrate the viability of land clearing without burning. The strategy had four components: the rationalized use of labor; the use of crops that compete with natural vegetation regrowth; efficient soil protection; and the harvesting and retention of rainwater. The work reaches at least 500 farmers in 30 communities (Guijt, 1998). The no-burning alternative involved cutting and clearing bush and tree vegetation, sowing crops more densely, and using cattle and horse manure. The first-year results indicated that reasonable production was possible and that tree and bush regrowth can be controlled. One negative aspect, however was the need to use over one-sixth of the available area for the storage of trunks and branches. In the second year bean output increased by over 100 percent relative to the historical average, though the low productivity of maize raised doubts as to its suitability under semi-arid agroecological conditions. Sorghum exhibited a better performance.

The accumulation of plant material by the third year was enough to use as mulch. Unfortunately, the initial rains were followed by prolonged drought, and bean output fell sharply because of fungal disease. Nevertheless, the maize yield (552 kg/ha) was above the regional average of 500 kg/ha. (Vonder Weid, 1994)

Integrated Production Systems

A number of NGOs promote the integrated use of a variety of management technologies and practices. The emphasis is on diversified farms in which each component of the farming system biologically reinforces the other components; for instance, where wastes from one component become inputs to another. Since 1980, CET, a Chilean NGO has engaged in a rural development program aimed at helping peasants reach year-round food self sufficiency while rebuilding the productive capacity of their small land holdings (Altieri, 1995). The approach has been to set up several 0.5 ha model farms, which consist of a spatial and temporal rotational sequence of forage and row crops, vegetables, forest and fruit trees, and animals. Components are chosen according to crop or animal nutritional contributions to subsequent rotational steps, their adaptation to local agroclimatic conditions, local peasant consumption patterns and finally, market opportunities. Most vegetables are grown in heavily composted raised beds located in the garden section, each of which can yield up to 83 kg of fresh vegetables per month, a considerable improvement to the 20-30 kg produced in spontaneous gardens tended around households. The rest of the 200-square meter area surrounding the house is used as an orchard, and for animals, (cows, hens, rabbits, and langstroth behives).

Vegetables, cereals, legumes and forage plants are produced in a six year rotational system within a small area adjacent to the garden. Relatively constant production is achieved (about six tons per year of useful biomass from 13 different crop species) by dividing the land into as many small fields of fairly equal productive capacity as there are years in the rotation. The rotation is designed to produce the maximum variety of basic crops in six plots, taking advantage of the soil-restoring properties and biological control features of the rotation.

Over the years, soil fertility in the original demonstration farm has improved, and no serious pest or disease problems have appeared. Fruit trees in the orchard and fencerows, as well as forage crops are highly productive. Milk and egg production far exceeds that on conventional farms. A nutritional analysis of the system based on its key components shows that for a typical family it produces a 250% surplus of protein, 80 and 550% surplus of vitamin A and C, respectively, and a 330% surplus of calcium. A household economic analysis indicates that, the balance between selling surpluses and buying preferred items provides a net income beyond consumption of US $790. If all of the farm output were sold at whole sale prices, the family could generate a monthly net income

Table 7. Performance of designed polycultures in two Cuban cooperatives

	Yield (t/ha)				
Polyculture	**1**	**2**	**3**	**LER**	**Ligthhouse**
Cassava-beans-maize	15.6	1.34	2.5	2.82	«28 de septiembre»
Cassava-tomato-maize	11.9	21.2	3.7	2.17	«Gilberto Leon»
Cassava-maize	13.3	3.39	—	1.79	«Gilberto Leon»
Beans-maize-cabbage	0.77	3.6	2.0	1.77	«28 de septiembre»
Sweet potato-maize	12.6	2.0	—	1.45	«Gilberto Leon»
Sorghum-squash	0.7	5.3	—	1.01	«28 de septiembre»

Source: SANE, 1998

1.5 times greater than the monthly legal minimum wage in Chile, while dedicating only a relatively few hours per week to the farm. The time freed up is used by farmers for other on-farm or off-farm income generating activities.

In Cuba, the Asociacion Cubana de Agricultura Organica (ACAO), a non-governmental organization formed by scientists, farmers, and extension personnel, has played a pioneering role in promoting alternative production modules (Rosset, 1997). In 1995, ACAO helped establish three integrated farming systems called «agroecological light houses» in cooperatives (CPAs) in the province of Havana. After the first six months, all three CPAs had incorporated agroecological innovations (i.e., tree integration, planned crop rotation, polycultures, green manures, etc.) to varying degrees, which, with time, have led to enhancement of production and biodiversity, and improvement in soil quality, especially organic matter content. Several polycultures such as cassava-beans-maize, cassava-tomato-maize, and sweet potato-maize were tested in the CPAs. Productivity evaluation of these polycultures indicates 2.82, 2.17 and 1.45 times greater productivity than monocultures, respectively.

Table 8. Productive and efficiency performance of the 75% animal/25% crop integrated module in Cuba

Productive parameters	1st year	3rd year
Area (ha)	1	1
Total production (t/ha)	4.4	5.1
Energy produced (Mcal/ha)	3,797	4,885
Protein produced (kg/ha)	168	171
Number of people fed by one ha	4	4.8
Imputs (energy expeditures, Mcal)		
-Human labor	596	359
-Animal work	16.8	18.8
-Tractor energy	277.3	1,38.6

Source: SANE, 1998

The use of *Crotalaria juncea* and *Vigna unguiculata* as green manure have ensured a production of squash equivalent to that obtainable applying 175 kg/ha of urea. In addition, such legumes improved the physical and chemical characteristics of the soil and effectively broke the life cycles of insect pests such as the sweet potato weevil (SANE, 1998).

At the Cuban Instituto de Investigacion de Pastos, several agroecological modules with various proportions of the farm area devoted to agriculture and animal production were established. Monitoring of production and efficiencies of a 75% pasture /25% crop module, reveals that total production increases over time, and that energy and labor inputs decrease as the biological structuring of the system begins to sponsor the productivity of the agroecosystem. Total biomass production increased from 4.4 to 5.1 t/ha after 3 years of integrated management. Energy inputs decreased, which resulted in enhanced energy efficiency from (4.4 to 9.5) (Table 8). Human labor demands for management also decreased over time from 13 hours of human labor/day to 4-5 hours. Such models have been promoted, extensively in other areas through field days and farmers cross visits (SANE, 1998).

Conclusions

Most research conducted on traditional and peasant agriculture in Latin America suggests that small holder systems are sustainably productive, biologically regenerative, and energy-efficient, and also tend to be equity enhancing, participative, and socially just. In general, traditional agriculturalists have met the environmental requirements of their food-producing systems by relying on local resources plus human and animal energy, thereby using low levels of input technology.

While it may be argued that peasant agriculture generally lacks the potential of producing meaningful marketable surplus, it does ensure food security. Many scientists wrongly believe that traditional systems do not produce more because hand tools and draft animals put a ceiling on productivity. Productivity may be low but the causes appear to be more social, not technical. When the subsistence farmer succeeds in providing food, there is no pressure to innovate or to enhance yields. Nevertheless, agroecological field projects show that traditional crop and animal combinations can often be adapted to increase productivity when the biological structuring of the farm is improved and labor and local resources are efficiently used (Table 9, Altieri, 1995). In fact, most agroecological technologies promoted by NGOs can improve traditional agricultural yields increasing output per area of marginal land from some 400-600 kg/ha to 2000-2500 kg/ha. enhancing also the general agrodiversity and its associated positive effects on food security and environmental integrity. Some projects emphasizing green manures and other organic management techniques can increase maize yields from 1-1.5 t/ha (a typical highland peasant yield) to 3-4 t/ha. Polycultures produce more combined yield in a given area than could be obtained from monocultures of the component species. Most traditional or NGO promoted polycultures

TABLE 9: Extent and impacts of agroecological technologies and practices implemented by NGOs in peasant farming systems throughout Latin America

Country	Organization Involved	Agroecological Intervention	No. of Farmers or Farming Units Affected	No. of Hectares Affected	Dominant Crops	Yield Increases (%)
Brazil	EPAGRI AS-PTA	Green Manures Cover Crops	38,000 Families	1,330,000	Maize Wheat	198 – 246 %
Guatemala	Altertec and others	Soil Conservation, Green Manures Organic Farming	17,000 Units	17,000	Maize	250 %
Honduras	CIDDICO COSECHA	Soil Conservation , Green Manures	27,000 Units	42,000	Maize	250 %
EL Salvador	COAGRES	Rotations ,Green Manures, Compost, Botanical pesticides	>200 Farmers	nd	Cereals	40 – 60 %
Mexico	Oaxacan Cooperatives	Compost ,Terracing, Contour Planting	3,000 Families	23,500	Coffee	140 %
Peru	***PRATVIR***	Rehabilitation of Ancient Terraces	>1250 Families	> 1000	Andean Crops	141 – 165 %
	CIED PIWA-CIED	Raised Fields	nd	250	Andean Crops	333 %
	CIED	Watershed Agricultural Rehabilitation	>100 Families	N/A	Andean Crops	30 – 50 %
	IDEAS	Intercropping, Agroforestry, Composting	12 Families	25	Several Crops	20 %
Dominican Republic	***Plan Sierra Swedforest-Fudeco***	Soil Conservation , Dry Forest Management. Silvopastoral Systems	>2,500 Families	>1,000	Several Crops	50 – 70 %
Chile	***CET***	Integrated Farms, Organic Farming	>1,000 Families	>2,250	Several Crops	>50 %
Cuba	***ACAO***	Integrated Farms	4 Cooperatives	250	Several Crops	50 – 70 %

Nd= no data
Source: Browder 1989, Altieri 1995, Pretty 1997

exhibit LER values greater than 1.5. Moreover, yield variability of cereal/ legume polycultures are much lower than for monocultures of the components (Table 10).

Table 10. Coefficient of variability of yields registred in different cropping systems during 3 years in Costa Rica

Croping system	Monoculture (mean of sole crops)	Polyculture
Cassava/bean	33.04	27.54
Cassava/maize	28.76	18.09
Cassava/maize/sweet potato	31.05	21.44
Cassava/maize/bean	25.04	14.95

Source: Francis, 1986

In general, data shows that over time agroecological systems exhibit more stable levels of total production per unit area than high-input systems; produce economically favorable rates of return; provide a return to labor and other inputs sufficient for a livelihood acceptable to small farmers and their families; and ensure soil protection and conservation as well as enhance biodiversity.

For a region like Latin America which is considered to be 52.2 percent self-reliant on major food crops as it produces enough food to satisfy the needs of its population, agroecological approaches that can double yields of the existing 16 million peasant units can safely increase the output of peasant agriculture for domestic consumption to acceptable levels well into the future. To address hunger and malnutrition, however, it is not only necessary to produce more food, but this must be available for those who need it most. Land redistribution is also a key prerequisite in order for peasants to have access to acceptable land and thus perform their role in regional self-reliance.

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Chapter 8

Biological Control in Agroecosystems Through Management of Entomophagous Insects

Introduction

By the close of the 20th century, agriculturalists should have learned an important ecological lesson: plant communities that are modified to meet the special food and fiber needs of humans become subject to heavy pest damage and generally the more intensely such communities are modified, the more abundant and serious the pests (Altieri, 1994).

Large monocultures composed of genetically similar or identical plants, and that have been selected for increased palatability are highly vulnerable to adapted herbivores (Price, 1981). Moreover, agricultural practices commonly used in the management of monocultures (pesticides, chemical fertilizers, etc.) tend to disrupt the natural enemies of herbivores and often exacerbate pest problems (Papavizas, 1981).

The inherent ecological stability and self-regulating characteristics of natural ecosystems are lost when humans simplify natural communities through the shattering of the fragile thread of community interactions. This breakdown however can be repaired by restoring the shattered elements of community homeostasis through the addition or enhancement of functional biodiversity in agroecosystems. One of the most important reasons for restoring and/or maintaining biodiversity in agriculture is that it performs a variety of ecological services. One of such services is the regulation of abundance of undesirable organisms through predation, parasitization, and competition (Altieri, 1994). Probably every insect population in nature is attacked to some degree by one or more natural enemies, thus predators, parasites, and pathogens act as natural control agents resulting in the regulation of herbivore numbers in a particular ecosystem. This regulation has been termed biological control and has been defined by DeBach (1964) as «the action of parasites, predators, or pathogens in maintaining another organism's population density at a lower average than would occur in their absence». As practiced, biological control can be self-sustaining and distinguishes itself from all other forms of pest control by acting in a density-dependent manner, that is: natural enemies increase in intensity and destroy a larger population of the population as the density of that population increases, and vice-versa (DeBach and Rosen, 1991).

Applied biological control can be considered a strategy to restore functional biodiversity in agroecosystems by adding, through classical and augmentative bio-control techniques, «missing» entomophagous insects or by enhancing naturally occurring predators and parasitoids through conservation and habitat management. In this paper, we discuss the ecological roles of predators and parasites in agroecosystems, and the various strategies used in biological control to employ entomophagous insects in order to regulate insect populations in agriculture.

The Role and Impact of Predators

Insects that prey upon other insects and spider mites occur in most orders but primarily in the orders Coleoptera, Odonata, Neuroptera, Hymenoptera, Diptera, and Hemiptera. Predatory insects feed on all host stages: egg, larval (or nymphal), pupal, and adult. From the standpoint of feeding habit, there are two kinds of predators, those with chewing mouth parts (e.g. lady beetles [*Coccinellidae*] and ground beetles [*Carabidae*]), which simply chew up and bolt down their prey and those with piercing mouth parts, which suck the juices from their prey (e.g. assassin bugs

[*Reduviidae*], lacewing larvae [*Chrysopidae*], hover fly larvae [*Syrphidae*]). The sucking type of feeder often injects a powerful toxin which quickly immobilizes the prey. Many predators are agile, ferocious hunters, actively seeking their prey on the ground or on vegetation, as do beetles, lacewing larvae and mites, or catching it in flight, as do dragonflies and robber flies (Huffaker and Messenger, 1976).

Many species are predaceous in both the larval and adult stages, although not necessarily on the same kinds of prey. Others are predaceous only as larvae, whereas the adults may feed on nectar, honeydew etc., and provide prey for her larvae by depositing eggs among the prey, because their larvae are sometimes incapable of finding it on their own (DeBach and Rossen, 1991).

The importance of predators in naturally occurring biological control is crucial. This role has been highlighted by the world-wide eruption of spider mites in many cropping systems in the wake of widespread use of chemical insecticide which mainly resulted from the elimination of predators of spider mites by the pesticides (Van den Bosch and Messenger, 1973). Tetranychid mite pest species were in greater abundance in commercial apple orchards due to the elimination of predator populations by pesticide sprays and due to better nutritional vigor of commercial apple trees, a factor known to stimulate phytophagous mite buildup (Croft, 1990).

The predator species richness in particular agroecosystems can be impressive. For example, Whitcomb and Bell (1964) reported 602 species of predaceous arthropods in Arkansas cotton fields and about 1,000 species of predatory species in Florida soybean fields. Such diversity can exert major regulatory pressures on herbivores and DeBach (1964) considered indigenous predators to act as a sort of balance wheel in the «pest-natural enemy complex», tending to feed upon whatever pest is present in abundance. Even in situations where predators may be incapable of achieving natural control below economic levels, they slow down the rate of increase of potential pests or reduce pest infestations when more host-specific natural enemies are ineffective. In California's San Joaquin Valley cotton fields, predators are much more widely important in restraining lepidopterous pests (i.e. bollworm, cabbage looper, beet armyworm) than are parasites (Van den Bosch and Messenger, 1976). In Canada, researchers found that in insecticide-free apple orchards, five species of predaceous mirids accounted for 43.5-68.3% mortality of codling moth eggs and in Maine, researchers found a correlation between predation and aphid declines in potatoes (Croft,1990).

Among the most neglected and less understood predators, spiders can have a strong stabilizing influence on prey. Spiders rely on a complex assemblage of prey. The result is a spider community that is diverse and that maintains a fairly constant numerical representation —one that should exert considerable control on associated prey populations without extinction of these prey. Spiders thus serve as buffers that limit the initial exponential growth of given prey populations (Riechert and Lockley 1984). In Israel, larval populations of the pest *Spodoptera littoralis* did not develop in apple orchards to damaging proportions on trees occupied by spiders, whereas significant damage was observed on trees from which spiders had been removed. Further experimentation revealed that spider activity was responsible for a 98% reduction in larval densities. The reduction resulted both from spider consumption of prey (64% of the larvae present) and from larval abandonment of branches occupied by spiders (34%). In the absence of spiders, larvae abandoned branches with a frequency of only 1.4%. In another study the presence of micryphantids (sheet line weavers of the family Linyphiidae) in experimental plots resulted in significantly less leaf damage by the tobacco cutworm *Spodoptera litura* than was observed in plots from which the spiders had been removed. Here the primary predatory effect was one of causing the larvae to abandon plants occupied by spiders (Riechert and Lockley, 1984).

In agricultural systems, predators can be added by releasing them directly into the fields such as in the case of *Chrysoperla carnea*, various coccinellids, *Geocoris*, *Nabis* and phytoseiid mites, or by providing supplementary food (i.e. sucrose solutions, yeast products, pollen, etc.) to retain, arrest or attract specific predator species to the fields (Huffaker and Messenger, 1976).

Parasitoids: Biologcal Characteristics, Role and Impact

Most insects parasitic upon other insects are *protelean* parasites, i.e. they are parasitic only in their immature (larval) stages and lead free lives as adults. They usually consume all or most of the host's body and then pupate, either within or external to the host. The adult parasite emerges from the pupa and starts the next generation anew by actively searching for hosts in which to oviposit. Most adult parasites require food such as honeydew, nectar or pollen and many feed on their host's body fluids, as mentioned earlier. Others require free water as adults (DeBach and Rossen, 1991).

Parasites may be categorized as ectoparasites, feeding externally upon the host, and as endoparasites, developing internally within the host. Parasites may have one generation (univoltine) to one generation of the host or two or more generations (multivoltine) to one of the host. Life cycles are commonly short, ranging from 10 days to 4 weeks or so in midsummer but correspondingly longer in cold weather. The main groups of parasites utilized in biological control of insect pests are the Hymenoptera (mostly wasps of the superfamilies *Chalcidoidea*, *Ichneumonoidea* and *Proctotrupoidea*) and Diptera (flies, especially of the family *Tachinidae*).

Research on the diversity of parasitic Hymenoptera in agroecosystems has concentrated mostly on the study of parasitoid complexes attacking particular native as well as exotic pest species. Some pest species support a large number of parasitoid species, such as the hessian fly *Mayetiola destructor*, the wheat-stem sawfly *Cephus pygmeus,* the coconut beetle *Promecotheca caeruleipennis*, the bean gall sawfly *Pontania proxima*, and the coffee leaf miner *Perileucoptera coffeella*. Different crops support particular herbivore species, which, in turn, are attacked by one or several parasitoid species (Table 1 next page), although such associations may change according to geographical location, management intensity and crop arrangements (Waage and Greathead, 1986).

Table 1. Species richness of parasitoid complexes associated with different insect pests in a range of annual cropping systems (Altieri *et al.,* 1993)

Crop system	Pest species	No. of parasitoid species	Location
Cotton	*Spodoptera exigua*	11	California
	Trichoplusia ni	11	California
	Heliothis zea	14	California
	Bucculatrixthurberiella	3	California
	Estigmene acrea	3	California
	Spodoptera praefica	13	California
Sorghum	*Schizafis*	3	USA
Cassava	*Erinnys ello*	4	Brazil, Colombia
	Jatrophobia brasiliensis	4	West Indies, Peru
	Saissetia sp.	2	Cuba
Soyabeans	*Plathypena scabra*	14	Missouri, USA
	Pseudoplusia includens	12	Louisiana, USA
Potato	*Myzus persicae*	7	Maine, USA
	Acyrthosiphon solami	5	Maine, USA
	Aphis nasturtii	5	Maine, USA
Rice	*Nephotettix spp.*	3	Philippines
	Chilo supressalis	5	Philippines
Alfalfa	*Colias eurytheme*	2	California
	Spodoptera exigua	11	California
	Spodoptera (= Prodenia) praefica	13	California
	Heliothis zea	13	California
Tobacco	*Heliothis virescens*	2	Noth Carolina, USA

The relative complexity of Hymenoptera parasitoid communities associated with different cropping systems is determined by biological, environmental, and management factors. In large-scale monocultures, diversity is suppressed by pesticides, vegetational simplification and other environmental disturbances. In less disturbed agroecosystems, in addition to the absence of pesticides, parasitoid diversity seems related to crop diversity, ground cover, weeds and native vegetation adjacent to crops. In fact, the few studies conducted on this topic indicate that the vegetational settings associated with particular crops influence the kind, abundance, and time of arrival of parasitoids (Waage and Greathead, 1986).

In many cases, only one or two species of such complexes prove vital in the natural biological control of key insect pests. For example, in California's alfalfa fields, the braconid wasp *Apanteles medicaginis* plays a key role in regulating the numbers of the alfalfa caterpillar *Colias eurytheme*. Apparently, this pristine butterfly - wasp system moved from native clovers into the new and artificial irrigated alfalfa fields. Similarly in North Carolina's tobacco fields, *Campoletis perdistinctus* exerts a high parasitization rate on the budworm *Heliothis virescens*, in early summer prior to flowering when plants are most susceptible to budworm injury. After flowering and on post-harvest sucker tobacco, parasitization by *Campoletis perdistinctus* declines and the action of *Cardiochiles nigriceps* becomes an important budworm mortality factor (Huffaker and Messenger, 1976). In other cases, it is a combination of several parasitoid species that exerts regulation on a specific insect pest (Ehler and Miller, 1978).

Strategies of Biological Control: Classical Biological Control

Classical biological control is the regulation of a pest population by exotic natural enemies (parasites, predators, pathogens) that are imported for this purpose. Usually, the target species (pest) is an exotic that has reached higher population density in the new environment because of more favorable conditions than in its area of indigeneity (Rosen *et al.,* 1994). It involves the introduction of preferable host-specific, self-reproducing, density-dependent, host-seeking exotic natural enemies adapted to an exotic introduced pest, usually resulting in permanent control (Caltagirone, 1981).

Biological control agents, because they are often carefully selected to be those best adapted to their hosts, usually spontaneously spread

Table 2. Successful examples of classical biological control (after Caltagirone, 1981)

Exotic pest	Introduced natural enemy	Cropping system
Tretanychus urticae (two Spotted spider mites)	*Phytoseiulus persimilis* (predator)	Greenhouse
Trialeurodes vaporariorum (Greenhouse whitefly)	*Encarsia formosa* (parasite)	Greenhouse
Nezara viridula (Green stink bug)	*Trissolcus* (parasite)	vegetable-field crops
Aleurocanthus woghami (citrus blackfly)	*Eretmocerus serius* (parasite)	citrus
Terioaphis trifolii (spoted alafalfa aphid)	*Praon exxoletum, Trioxys complanatus, and Aphelinus asychis* (parasites)	alfalfa
Chromaphis juglandicola (walnut aphid)	*Trioxys pallidus* (parasite)	walnut
Aonidiella aurantii (California red scale)	*Aphytis spp*. (parasites)	citrus
Parlatoria oleae (olive scale)	*Aphytis maculicornis* and *Coccophagoides utilis* (parasites)	olive
Quadraspidiotus Perniciosus (San Jose scale)	*Prospaltella perniciosi*	stone and pome fruits
Antonina graminis (Rhodegrass mealybug)	*Anagyrus antoninae* (parasite)	grasses
Operophtera brumata (winter moth)	*Cyzenis albicans* and *Agrypon flaveolatum* (parasites)	oaks, apples
Oryctes rhinoceros (Rhinoceros beetle)	*Rabdionvirus oryctes* (baculovirus)	coconut palm, oil, palm

throughout much of the host's range, effecting widespread control at relatively little cost. Caltagirone (1981) describes 12 cases of successful classical biological control projects in which target pest species were reduced to a non-pest status by introduced natural enemies (Table 2).

All classical biological control projects, by definition, involve procurement of exotic natural enemies. In the majority of the cases, exploration is conducted in the presumed area of origin of the target species. After foreign exploration is completed, entomophagous insects must be introduced into the host country, where they are subjected to quarantine. Following quarantine, most natural enemies are mass cultured to allow release of sufficient numbers of the species at particular colonization sites, providing material for colonization in a variety of environments in a region, and allows for repeated colonizations over time if required (Van den Bosch and Messenger, 1973).

Augmentative Biological Control

This strategy involves the mass propagation and periodic release of exotic or native natural enemies tha may multiply during the growing season but are not expected to become a permanent part of the ecosystem (Batra, 1982). Augmentative releases may be made with either short —or long— term expectations depending upon the target pest, the species of natural enemy and the crop involved. The mass culture and dissemination of natural enemies was a popular method in the former Soviet Union and in China where the socio-economic structure, including collectivization of agriculture, integration of research and production, and a large, well organized labor force permitted the successful mass culture and widespread release of augmentative control agents. Recent political and socio-economic changes which embrace capitalist modes of production in those regions changed such scenarios. Cuba is the only country experiencing a massive revival in augmentative biological control since the collapse of the soviet bloc in 1989. The island has suffered an 80% decrease of fertilizer and pesticide imports and in order to ensure food security Cuban researchers and farmers have launched a massive biological control project. By the end of 1994, some 222 centers for

Table 3. Biological organisms for the control of insects pests in Cuba (Rosset and Benjamín, 1959)

Organism	Crop	Target pest
Bacillus thufingiensis	collards	*Pieyls sp*.
Tomatoes	*Heliothis arid Spodoptera*	
Watercress		
Pepper		
Bacillus thuringiensis	cassava	Erynnis sp.
Yucca	*Spodoptera*	
Sweet potato	*Spodoptera*	
Potato	*Heliothis*	
Corn		
Tobacco		
Beauveria bassiana	banana	*Cosmopolites sordidus*
Sweet potato	Curculionidae (weevils)	
Rice		
Citrus		
Metarhizium anisophae	grasses	Cercopidae (spittlebug)
Rice	Curculionidae	
Citrus		
Paecilomyces lilacinus	guava	Nematodes of the genus
Coffee	*Meliodogyne*	
Banana	*Meliodogyne*	
	Nematodes, mainly	*Radopholus*
	Similis	
Verticilllium lecanii	tomatoes	whiteflies
Pepper	whiteflyes	
Cucumber	whiteflies	
Squash		
Potato		
Beans		
Trichogramma sp.	grasses	Mocis Sp.
Cassava	*Erynnis sp.*	
Trichogramma sp.	Sugarcane	sugarcane borer
Pheidole megacephala (ant)	sweet potato	weevil

production of entomopathogens and entomophagous insects (CREEs) have been created (Rosset and Benjamin, 1993). In such centers they produce massive amounts of *Trichogramma* spp., *Beauvaria basiana*

Table 4. Some potential natural enemy candidates for argumentation through rearing in the United States (after ables and Ridgeway, 1991)

Argumentation natural enemy candidate	Target pest(s)	Cropping system(s)
ACARI		
Typhlodromus spp.	*Tretanychus mcdanielli*	Apples
	Steneotarsonemus pallidus	Strawberries
Phytoseiulus spp.	*Tetranychus urticae*	Strawberries
	Tetranychus spp.	Glasshouse crops
HEMIPTERA		
Jalysus spinosas	*Heliothis virescens*	Tobacco
	Manduca spp.	
NEUROPTERA		
Chrysopa carnea	*Heliothis* spp.	Numerous food and fiber crops
	Psudococcus spp.	Pears
		Other fruits
	Trichoplusia ni	Cabbage
	Aphids	Potatoes
COLEOPTERA		
Stethorus picipes	*Oligonychus punicae*	Avocado, other fruits and vegetables
Cocinella spp.	Aphids	Vegetables, fruits and nuts
Cryptolaemus montrouzieri	Mealybugs	Citrus
HYMENOPTERA		
Bracon kirkpatricki	*Pectinophora gossypiella*	Cotton
Bracon mellitor	*Anthonomus grandis*	Cotton
Macrocentrus ancylivorus	*Grapholitha molesta*	Peaches
Chelonus blackburni	*P. Gossypiella*	Cotton
Apanteles melanoscelus	*Lymantria dispar*	Forest and shade trees
Apanteles rebecula	*Pieris rapae*	Cabbage
Microplitis croceipes	*Heliothis* spp.	Numerous crops
Campoletis sonorensis	*Heliothis* spp.	Numerous crops
Praon spp.	Aphids	Numerous crops
Lysiphlebus spp.	Aphids	Numerous crops
Aphidius smithi	*Acyrthosiphon pisum*	Pears, other vegetables
Diaeretiella spp.	Aphids	Cole
Aphytis melinus	California red scale	Citrus
Encarsia formosa	Whiteflies	Greenhouse crops
Pediobius foveolatus	*Epilachna* spp.	Soybean, legume vegetables, squash
Trichogramma spp.	*Heliothis*	Numerous food and fiber crops
	Plusiine noctuids	Numerous food and fiber crops
	Pieris spp.	Cole crops
	Manduca spp.	Tobacco and tomatoes
	Ostrinia nubilalis	Corn
	Laspeyresia pomonella	Apples, other fruits
DIPTERA		
Lixophaga diatraeae	*Diatraea* spp.	Sugarcane
Eucelatoria spp.	*Heliothis* spp.	Numerous crops
Voria ruralis	*Trichoplusia ni*	Cole cops, many other crops

(78 metric tons) *Bacillus thuringinsis* (1,312 tons), *Verticillium lecanii* (196 tons) and *Metarhizium anisopliae* (142 tons) for the control of various pests in several major crops of the island (Table 3).

In the USA, success of augmentative pest control depends on the total number of individuals released (Ables and Ridgeway, 1981). Among the common agents commercially available for releases are *Trichogramma* wasps, the lacewing *Chrysopa carnea*, and several insect pathogens (*Bacillus* spp., *Beauvaria bassiana* and various nuclear polyhedrosis viruses). There are several potential natural enemy candidates for augmentation against *Heliothis* spp. in numerous crops. Examples include *C. carnea*, *Trichogramma* spp., *Microplitis croceips* and *Campoletis sonorensis*. Also aphids in numerous crops have a range of parasites (i.e. *Praon* spp., *Lysiphlebus* spp., *Aphidius* spp., *Diaeretiella* spp. and others) subject to mass rearing and release (Huffaker and Messenger, 1976). Selected examples of entomophages with potential for augmentation in the USA are given in Table 4 at next page (Ables and Ridgeway, 1981).

In cotton, data show that 50,000 to 100,000 *Trichogramma* spp. must be released per acre at a 2-5 day interval during peak *Heliothis* spp. egg-laying period to significantly increase parasitization and obtain control. Releases of up to 28,000 *L. testaceipes* per acre did not reduce greenbugs below economic threshold levels under normal monoculture conditions in the Texas high plains. However, recent developments in the use of semiochemicals (i.e. kairomones) point to great possibilities for increasing field behavior and efficiency of several parasitoids under monoculture situations (Nordlund *et al.,* 1981). The greatest utility of kairomones so far appears to be for aggregating and/or retaining released parasites in target locations (Hoy and Herzog, 1985).

Augmentative control can be cost-effective. Several corporations are commercially rearing and marketing a number of genera of parasitic wasps, the aphid predator, *Chrysopa carnea*, and the insect pathogens *Bacillus thuringiensis, B. popillae, Beauveria bassiana,* and several nuclear polyhedrosis viruses. In the early 80s treatments in which insects were used cost from $24.70 to $29.60 per hectare in orchards and $133 to $2,398 per hectare in greenhouses (Batra, 1982). Today, costs remain competitive.

Conservation and Habitat Management

This approach emphasizes management of agroecosystems in order to provide a general environment conducive to the conservation and enhancement of a complex natural enemy biota. By improving the availability of food, shelter and other environmental resources within and outside the crop field, the possibilities of increasing the populations and effective predatory and parasite behavior of beneficial arthropods through habitat management are great (Huffaker and Messenger, 1976). Small changes in agricultural practices can cause substantial increases in natural enemy populations during critical periods of the growing season. Some practices may simply involve the withdrawal of chemical pesticides or avoiding disturbing practices such as plowing and cultivating. Total removal of pesticides can restore parasitoid diversity and lead to renewed biological control of specific pests. Within two years, virtually all banana insect pests in Golfito, Costa Rica dropped to below economic threshold levels, due to enhanced parasitization and predation, after stopping insecticide (dieldrin and carbaryl) sprays. Similarly, in California's walnut orchards, natural biological control of the frosted scale and the calico scale was soon achieved by encyrtid parasitoids after removal of DDT sprays (Croft, 1990).

At times, it is necessary to provide supplementary resources. For example, erection of artificial nesting structures for *Polistes annularis* has increased predation against *Alabama argillacea* in cotton and *Manduca sexta* in tobacco. The addition of subsidiary food (e.g. mixtures of hydrolyzate, sugar and water) multiplied six-fold the oviposition of *Chrysopa carnea* and increased the abundance of *Syrhidae, Coccinellidae* and *Malachiidae* in alfalfa and cotton plots. To improve survival and reproduction of beneficial insects within an agroecosystem, it is often desirable to have subeconomic, fluctuating populations of alternate prey permanently present in the crop (Van den Bosch and Messenger, 1976). For example, the relative abundance of aphids on cabbage in South Africa can be a determining factor upon the effectiveness of general predators against larvae of the diamond-back moth, *Plutella maculipennis*. Addition of host populations proved effective in controlling *Pieris rapae* in cabbage. The continuous release of fertile *Pieris* butterflies increased the pest population nearly tenfold above normal spring populations, enabling the parasites *Trichogramma evanescens* and *Cotesia rubecula* to increase early and maintain themselves at an effective level throughout the season (Van den Bosch and Messenger, 1973).

It is widely believed that agroecosystem diversity is associated with long-term stability of included populations, presumably because a variety of parasites, predators, and competitors is always available to suppress population growth of potential pest species. Dispersal of food plants among other nonhost plants may make migration, host, and mate location, and consequently exponential growth of phytophages or pathogens, more difficult. Plant diversification of agroecosystems can result in increased environmental opportunities for natural enemies and, consequently, improved biological pest control. The various vegetational designs available in the form of polycultures, weed diversified crop systems, cover crops and living mulches and their effects on pest populations and associated natural enemies have been extensively reviewed (Altieri, 1994). Factors involved in pest regulation in diversified agroecosystems include: increased parasitoid/predator populations, available alternative prey/hosts for natural enemies, decreased colonization and reproduction of pests, feeding inhibition or chemical repelency from non-host plants, prevention of movement and emigration and optimum synchrony between pests and natural enemies.

Research has shown that by adding plant diversity to existing annual monocultures, it is possible to exert changes in habitat diversity which in turn favor natural enemy abundance and effectiveness. This information can be used to design mixed cropping systems that enhance predator and parasitoid diversity and abundance, thus resulting in lower pest loads than in monocultures. In general, it is accepted that in polycultural agroecosystems there is an increased abundance of arthropod predators and parasitoids due to enhanced availability of alternate prey, nectar sources and suitable microhabitats (Altieri, 1994). Table 5 provides various examples of observed pest reduction in polycultures.

Table 5. Selective examples of multiple cropping systems than effectively prevent insect pest outbreaks through enhancement of natural enemies (after Altieri, 1994)

Multiple cropping system involved	Pest(s) regulated	Factor(s)
Brassica crops and beans	*Brevicoryne brassicae* and Delia *brassicae*	Higher predation and disruption of oviposition behavior
Brussels sprouts intercropped with fava beans and/or mustard	Flea beetle, *Phyllotreta cruciferae* and cabbage aphid *Brevicoryne brassicae*	Reduced plant apparency trap cropping, enhanced biological control
Cabbage intercropped with white and red clover	*Erioischia brassicare*, cabbage aphids, and imported cabbage Butterfly (*Pieris rapae*)	Interference with colonization and increase of ground beetles
Cassava intercropped withcowpeas	Whiteflies, *Aleurotrachelus socialis* and *Trialeurodes viariabilis*	Changes in plant vigor and increased abundance of natural enemies
Corn intercropped with fava beans	Aphids, *Tetranychus urticae*, and *Macrodactylus* sp.	Enhenced abundance of predators
Corn intercropped with sweet potatoes	Leaf beetles (*Diabrotica* spp.) and leafhoppers (*Agallia lingula*)	Increase in parasitic wasps
Cotton intercropped with forage cowpea	Boll weevil (*Anthomonus grandis*)	Population increase of parasitic wasps (Eurytoma sp.)
Intercropping cotton with sorghum or maize	Corn earworm (*Heliothis zea*)	Increased abundance of predators
Strip cropping of cotton and alfalfa	Plant bugs (*Lygus Hesperus* and *L. elisus*)	Prevention of emigration and synchrony in the relationship between pests and natural enemies
Peaches intercropped with Strawberries	Strawberries leafroller (*Ancylis comptana*) and Oriental fruit moth (*Grapholita molesta*)	Population increase of parasites (*Macrocentrus ancylivora*, *Microbracon gelechise*, and *Lixophaga variabilis*)
Peanut intercropped with maize	Corn borer (*Ostrinia furnacalis*)	Abundance of spider (*Lycosa* sp.)
Sesame intercropped with cotton	*Heliothis* spp.	Increase of beneficial insects and Trap cropping

Increasing within-field plant diversity can enhance biological control. Considerable work in the former USSR was devoted to the use of nectar-bearing plants within orchards as a source of adult food for entomophagous insects to increase their effectiveness. Field experiments by Russians in the North Caucasus showed that the growing of *Phacelia* spp. in orchards greatly increased the parasitization of *Quadraspidiotus* *perniciosus* by its parasite *Aphytis proclia*. Three successive plantings of *Phacelia* flowers in orchards increased parasitization in about 70%. These same plants have been shown to increase the abundance of the wasp *Aphelinus mali* for the control of apple aphids and improve the activity of *Trichogramma spp.*

Manipulation of wild vegetation adjacent to crop fields can also be used to promote biological control, since the survival and activity of natural enemies often depends upon the resources provided by the vegetation around crop fields. Studies of tachinid and ichneumonid parasites attacking *Barathra brassicae* and *Plutella xylostella* were conducted near Moscow and the data show that parasite efficiency was substantially higher in cabbage fields when they were grown near flowering umbelliferous plants (Huffaker and Messenger, 1976).

In California, the egg parasite *Anagrus epos* was effective in controlling the grape leafhopper *Erythroneura elegantula* in vineyards adjacent to wild blackberries which harbour a non-economic leafhopper *Dikrella cruentata*, whose eggs serve as the only overwintering resource for *Anagrus*. Recent studies have shown that prune trees planted next to vineyards also allow early season buildup *of Anagrus epos*. Researchers now recommend that as many prune trees as possible should always be planted upwind from the vineyard. Also in California, parasitization of the alfalfa caterpillar, *Colias eurytheme*, by *Apanteles medicaginis* was far greater in California's San Joaquin Valley where weeds were in bloom along irrrigation canals in contrast to areas where the weeds were destroyed (DeBach, 1964).

In Norway's apple orchards, the numbers of the key pest *Argyresthia conjugella* is largely dependent on the amount of available food, i.e. the number of berries of the wild shrub *Sorbus aucuparia* that develop each year. Since only one larva develops in a single berry, the number of *Argyresthia* can never be higher than the total number of berries. Thus, in years when *Sorbus* has no berries in a certain area, no *Argyresthia* larvae are produced, and consequently there will be no parasites (the braconid *Microgaster politus*) in this area. Entomologists have suggested plantings of *Sorbus* which produce an abundanct and regular crop every year. *Argyresthia* always finds enough food to maintain its population at a reasonably high level. Under such conditions *Microgaster* and other natural enemies will also operate and reproduce sufficiently every year to regulate their host below the level where *Argyresthia* is forced to emigrate. Hence, apple avoids infestation (Edland, 1995).

Conclusions

Biological control through importation, augmentation and/or conservation of natural enemies can provide long-term regulation of pest species provided that in target agroecosystems proper cultural management (i.e. avoidance of disruptive agricultural practices and diversification of cropping systems) is adapted to foster an environment conducive to further the abundance and efficiency of predators and parasites. Under such conditions biological control can potentially become a self-perpetuating strategy, providing control at low cost and with none or minimal environmental impacts.

Large scale commercial agriculture involving crops that have a major complex of pests are initially likely to require the integration of chemical and cultural pest control methods along with the use of natural enemies. In such cases the conversion to a production system totally dependent on biological control will require a stepwise process of agroecological conversion including the efficient use of pesticides (IPM), input substitution (the replacement of insecticides for botanical or microbial insecticides) ending with the re-design of a diversified farming system which provides the environmental conditions for natural enemies, thus allowing the agroecosystem to sponsor its own natural protection against pests (Altieri, 1994).

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Chapter 9

Chapter 9

An Agroecological Basis for Insect Pest Management

Introduction

The integrated pest management concept (IPM) arose in the 1960s in response to concerns about impacts of pesticides on the environment. By providing an alternative to the strategy of unilateral intervention with chemicals, it was hoped that IPM would change the practise of crop protection to one that entailed a deeper understanding of insect and crop ecology thus resulting in a strategy which relied on the use of several complementary tactics. It was envisioned that ecological theory should provide a basis for predicting how specific changes in production practices and inputs might affect pest problems. It was also thought that ecology could aid in the design of agricultural systems less vulnerable to pest outbreaks. In such systems pesticides would be used as occasional supplements to natural regulatory mechanisms. In fact many authors wrote papers and reviews depicting the ecological basis of pest management (Southwood and Way, 1970; Price and Waldbauer, 1975; Pimentel and Goodman, 1978, Levins and Wilson 1979). But despite all this early work that provided much of the needed ecological foundations, most IPM programs deviated to become schemes of «intelligent pesticide management» and failed in putting ecologically based theory into practice.

Lewis *et al.,* (1997) argue that the main reason why IPM science has been slow to provide an understanding that will assist farmers to move beyond the current production methods is that IPM strategies have long been dominated by quests for «silver bullet» products to control pest outbreaks. The emphasis has been on tactics to suppress pests and reduce crop damage, and very little on why agroecosystems are vulnerable and how to make them more pest resilient. Agroecosystem redesign through ecosystem engineering involves a shift from linear, one-to-one relationships between target pests and a particular management tactic, to webs of relationships between insect pests, associated natural enemies and crop diversification schemes. Emphasis is on preventing pest problems by enhancing the «immunity» of the agroecosystem and on integrating pest management activities with other farming practices that maintain soil productivity and crop health, while ensuring food security and economic viability. Although understanding autoecological factors that explain why pests quickly adapt and succeed in agroecosystems is important, more crucial is to pinpoint what makes agroecosystems susceptible to pests. By designing agroecosystems that on the one side work against the pests' performance and on the other are less vulnerable to pest invasion, farmers can substantially reduce pest numbers.

It is herein argued that long term solutions to pest problems can be only achieved by restructuring and managing agricultural systems in ways that maximize the array of «built – in» preventive strengths, with therapeutic tactics serving strictly as backups of natural regulator processes. Among the three approaches suggested by Lewis *et al.,* (1997) to bring pest populations within acceptable bounds, ecosystem engineering is the most promising in harnessing the inherent strengths that emerge when agroecosystems are designed following agroecological principles.

Agroecology and Pest Management

One way of further advancing the ecosystem management approach in IPM is through the understanding that crop health and sustainable yields in the agroecosystem derives from the proper balance of crops, soils, nutrients, sunlight, moisture, and coexisting organisms. The agroecosystem is productive and healthy when this balance of rich growing conditions prevail, and when crop plants remain resilient to tolerate stress and adversity. Occasional disturbances can be overcome by vigorous agroecosystems, which are adaptable, and diverse enough to recover once the stress has passed (Altieri and Rosset, 1996). If the cause of disease, pest, soil degradation, etc, is understood as imbalance, then the goal of ecological engineering is to recover the balance. This is known in ecology as resilience, the maintenance of the system's functions to compensate for external stress factors, and requires a thorough understanding of the nature of the agroecosystems and the principles by which they function. Agroecology provides basic ecological principles on how to study, design and manage agroecosystems that are productive, enduring and natural resource conserving (Altieri, 1995). Agroecology goes beyond a one-dimensional view of agroecosystems —their genetics, agronomy, edaphology, etc.— to embrace an understanding of ecological and social levels of coevolution, structure, and function. Instead of focusing on one particular component of the agroecosystem, agroecology emphasizes the interrelatedness of all agroecosystem components and the complex dynamics of ecological processes such as nutrient cycling and pest regulation (Gliessman, 1999).

From a management perspective, the agroecological objective is to provide a balanced environment, sustainable yields, biologically mediated soil fertility, and natural pest regulation through the design of diversified agroecosystems and the use of low-input technologies (Altieri, 1994). The strategy is based on ecological principles that lead management to optimal recycling of nutrients and organic matter turnover, close energy flows, water and soil conservation, and balanced pest-natural enemy populations. The strategy exploits the complementation that results from the various combinations of crops, trees, and animals in spatial and temporal arrangements (Altieri and Nicholls, 1999). These combinations determine the establishment of a planned and associated functional biodiversity which, when correctly assembled, delivers key ecological services which subsidize agroecosystem processes that underlie agroecosystem health.

In other words, ecological concepts are utilized to favor natural processes and biological interactions that optimize synergies so that diversified farms are able to sponsor their own soil fertility, crop protection, and productivity through the activation of soil biology, the recycling of nutrients, the enhancement of beneficial arthropods and antagonists. Based on these principles, Agroecologists involved in pest management have developed a framework to achieve crop health through agroecosystem diversification and soil quality enhancement, key pillars of agroecosystem health. The main goal is to enhance the «*immunity*» of the agroecosystem (i.e. natural pest control mechanisms) and regulatory processes (i.e. nutrient cycling and population regulation) through management practices and agroecological designs that enhance plant species and genetic diversity in time and space, and the enhancement of organic matter accumulation and biological activity of the soil (Altieri, 1999).

Agroecosystems can be manipulated to improve production and produce more sustainably, with fewer negative environmental and social impacts and fewer external inputs (Altieri, 1995). The design of such systems is based on the application of the following ecological principles (Reinjtes *et al.,* 1992):

1. Enhance recycling of biomass and optimizing nutrient availability and balancing nutrient flow.
2. Securing favorable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biotic activity.
3. Minimizing losses due to flows of solar radiation, air and water by way of microclimate management, water harvesting and soil management through increased soil cover.
4. Species and genetic diversification of the agroecosystem in time and space.
5. Enhance beneficial biological interactions and synergisms among agrobiodiversity components thus resulting in the promotion of key ecological processes and services.

These principles can be applied by way of various techniques and strategies. Each of these will have different effects on productivity, stability and resiliency within the farm system, depending on the local opportunities, resource constraints and, in most cases, on the market. The ultimate goal of agroecological design is to integrate components so that overall biological efficiency is improved, biodiversity is preserved, and agroecosystem productivity and its self-sustaining capacity are maintained.

Understanding Pest Vulnerability in Agroecosystems

Over the past half-century, crop diversity has declined precipitously in conventional high-input farming systems in the USA and other industrialized countries, as well as in the agroexport regions of the developing world. Such reduction in crop diversity has resulted in the simplification of the landscape. The expansion of monocultures has decreased abundance and activity of natural enemies due to the removal of critical food resources and overwintering sites (Corbett and Rosenheim, 1996). Many scientists are concerned that, with accelerating rates of habitat removal, the contribution to pest suppression by biocontrol agents using these habitats is declining and consequently agroecosystems are becoming increasingly vulnerable to pest invasion and outbreaks.

A key task for agroecologists is to then understand why modern agroecosystems are so vulnerable to insect pests in order to reverse such vulnerability by increasing vegetational diversity in agricultural landscapes. Human manipulation and alteration of ecosystems for the purpose of establishing agricultural production makes agroecosystems structurally and functionally very different from natural ecosystems. Cultivation brings about many changes including horticultural simplicity, phenological uniformity, fertilization mediated nutritional changes in plant foliage, changes in plant characteristics through breeding and so on.

In general, monocultures do not constitute good environments for natural enemies (Andow, 1991). Such simple crop systems lack many of the resources such as refuge sites, pollen, nectar, and alternative prey and hosts, that natural enemies need to feed, reproduce, and thrive. Normal cultural activities such as tillage, weeding, spraying, and harvesting can have serious effects on the insects of the farm. To the pests, the monocrop is a dense and pure concentration of its basic food resource, so of course, many insect herbivores boom in such fertilized, weeded, and watered fields. For the natural enemies, such overly simplified cropping systems are less hospitable because natural enemies require more than prey, hosts to complete their life–cycles. Many parasitoid adults, for instance, require pollen and nectar to sustain themselves while they search for hosts.

Given the major differences between mechanized agroecosystems and natural ecosystems, especially the prevalence of monocultures and the high levels of disturbance, modern systems lack a suitable ecological infrastructure to resist pest invasions and outbreaks (Altieri, 1994; Landis *et al.,* 2000). As explained below, many factors underlie the vulnerability of monocultures to pest invasions:

a. Decreased Landscape Diversity. The spread of modern agriculture has resulted in tremendous changes in landscape diversity. There has been a consistent trend toward simplification that entails (1) the enlargement of fields, (2) the aggregation of fields, (3) an increase in the density of crop plants, (4) an increase in the uniformity of crop population age structure and physical quality, and (5) a decrease in inter- and intraspecific diversity within the planted field.

Although these trends appear to exist worldwide, they are more apparent, and certainly best documented, in industrialized countries. Increasingly, evidence suggests that these changes in landscape diversity have led to more insect outbreaks due to the expansion of monocultures at the expense of natural vegetation, through decreasing habitat diversity. One of the main characteristics of the modern agricultural landscape is the large size and homogeneity of crop monocultures, which fragment the natural landscape. This can directly affect the abundance and diversity of natural enemies, as the larger the area under monoculture the lower the viability of a given population of beneficial fauna. At hand is also the issue of colonization of crop «islands» by insects. In the case of annual crops, insects must colonize from the borders each season, and the larger the field, the greater is the distance that must be covered. Several studies suggest (not surprisingly) that natural enemies tend to colonize after their hosts/prey and that the lag tie between the arrival of pest and natural enemy increases with distance from border (source pool). For instance, Price (1976) found that the first occurrence of an herbivore and that of a predatory mite in a soybean field were separated by one week on the edge versus a three week lag in the center. To the extent that this is a general phenomenon, increased field size should lead to more frequent insect outbreaks.

b. Decreased On-Farm Plant Diversity. Throughout the years many ecologists have conducted experiments testing the theory that decreased plant diversity in agroecosystems allows greater chance for invasive species to colonize, subsequently leading to enhanced herbivorous insect abundance. Many of these experiments have shown that mixing certain plant species with the primary host of a specialized herbivore gives a fairly consistent result: specialized species usually exhibit higher abundance in monoculture than in diversified crop systems (Andow, 1983).

Several reviews have been published documenting the effects of within-habitat diversity on insects (Altieri and Letourneau, 1984; Risch *et al*. 1983). Two main ecological hypotheses (enemy hypothesis and the resource concentration hypothesis), have been offered to explain why insect populations tend to be gretaer in monocultures and how in agroecosystems insect populations can be stabilized by constructing vegetational architectures that support natural enemies and/or that directly exert inhibitory effects on pest attack (Root, 1973).

A recent study in Portugal illustrates the effects of decreased field plant diversity on increased pest incidence. As new policy and market forces prompt the conversion of traditional complex agroforest vineyard systems to monocultures, Altieri and Nicholls (2002) found higher prevalence of grape herbivores and *Botrytis* bunch rot. Although monocultures may be productive, such gains occurred at the expense of biodiversity and agricultural sustainability, reflected on higher pest vulnerability.

c. Pesticide Induced Insect Outbreaks. Many examples are reported in the literature of insect pest outbreaks and/or resurgence following insecticide applications (Pimentel and Perkins, 1980). Pesticides either fail to control the target pests or create new pest problems. Development of resistance in insect pest populations is the main way in which pesticide use can lead to pest control failure. More than 500 species of arthropods have become resistant to a series of insecticides and acaricides (Van Driesche and Bellows, 1996).

Another way in which pesticide use can foster outbreaks of pests is through the elimination of the target pest's natural enemies. Predators and parasites often experience higher mortality than herbivores following a given spray (Morse *et al*., 1987). This is due, in part, to the greater mobility of many natural enemies, which exposes them to more insecticide per unit time following a spray.

In addition, natural enemies appear to evolve resistance to insecticides much more slowly than do herbivores. This results from a smaller probability that some individuals in populations of natural enemies will have genes for insecticide resistance. This in turn is due to the much smaller size of the natural-enemy population relative to the pest population and the different evolutionary history of natural enemies and herbivores.

Pesticides also create new pest problems when natural enemies of ordinarily non-economic species are destroyed by chemicals. These «secondary pests» then reach higher density than normal and begin to cause economic damage (Pimentel and Lehman, 1993).

d. Fertilizer Induced Pest Outbreaks. Luna (1988) suggests that the physiological susceptibility of crops to insects may be affected by the form of fertilizer used (organic vs. chemical fertilizer). In most studies evaluating aphid and mite response to nitrogen fertilization, increases in nitrogen rates dramatically increased aphid and mite numbers. According to Van Emden (1966) increases in fecundity and developmental rates of the green peach aphid, *Myzus persicae*, were highly correlated to increased levels of soluble nitrogen in leaf tissue. In reviewing 50 years of research relating to crop nutrition and insect attack, Scriber (1984) found 135 studies showing increased damage and/or growth of leaf-chewing insects or mites in N-fertilized crops, versus fewer than 50 studies in which herbivore damage was reduced by normal fertilization regimes. In aggregate, these results suggest a hypothesis with implications for fertilizer use patterns in agriculture, namely that high nitrogen inputs can precipitate high levels of herbivore damage in crops. As a corollary, crop plants would be expected to be less prone to insect pests and diseases if organic soil amendments are used, these generally resulting in lower nitrogen concentrations in the plant tissue.

Studies (Altieri and Nicholls, 2003) documenting lower abundance of several insect herbivores in organic farming systems have partly attributed such reduction to low nitrogen content in the organically farmed crops. In comparative studies, conventional crops (treated with chemical fertilizer) tend to develop a larger infestation of insects (especially Homoptera) than organic counterparts.

Interestingly, it has been found that certain pesticides can also alter the nutritional biochemistry of crop plants by changing the concentrations of nitrogen, phosphorus, and potassium, by influencing the production of sugars, free amino acids, and proteins, and by influencing the aging process which affects surface hardness, drying, and wax deposition (Oka and Pimentel, 1976; Rodriguez *et al*., 1957).

e. Weather-Induced Insect Pest Outbreaks. It has been argued that weather can be the most important factor triggering insect outbreaks (Milne, 1957). For example, Miyashita (1963), in reviewing the dynamics of seven of the most serious insect pests in Japanese crops, concluded that weather was the principal cause of the outbreaks in each case. There are several ways in which weather can trigger insect outbreaks. Perhaps the most straightforward mechanism is direct stimulation of the insect and/or host plant physiology. The development and widespread use of degree-day models to predict outbreaks of particular pests and appropriate control strategies are an indication of the importance of the linkage between temperature and growth and the development of herbivorous insects and their host plants. Gutierrez *et al.* (1974) have shown that weather plays a key role in the development of cowpea-aphid populations in southeast Australia. In this case, a series of climatic events favors complex changes in aphid physiological development, migration, and dispersal in such a way as to cause localized outbreaks.

f. Changes Induced by Plant Breeding. Domestication and breeding can induce changes in plant quality and other crop characteristics that may render crops more susceptible to pests. Chen and Welter (2002) found populations of the moth *Homeosema electellum* (*Lepidoptera: Pyralidae*) to be consistently more abundant on sunflower cultivars grown in agriculture than on wild sunflower species in native habitats. Agricultural sunflowers were much larger than wild sunflowers and also exhibited uniformity in flowering which influenced both herbivory and also parasitism by Hymenopteran parasitoids. Wild sunflowers were less susceptible to the herbivore.

g. Transgenic Crops and Insect Pest Outbreaks. In the last six years transgenic crops have expanded in area reaching today about 58 million hectares worldwide. Such areas are dominated by monocultures of few crop varieties, mainly herbicide resistant soybeans and Bt corn, with a clear tendency towards decreased agricultural habitat diversity (Marvier, 2001). Several agroecologists argue that such massive and rapid deployment of transgenic crops will exacerbate the problems of conventional modern agriculture (Rissler and Mellon, 1996; Altieri, 2000). At issue is the genetic homogeneity of agroecosystems with bioengineered crops which in turn can make such systems increasingly vulnerable to pest and disease problems (NAS, 1972).

Transgenic crops may affect natural enemies in several ways: the enemy species may feed directly on corn tissues (e.g. pollen) or on hosts that have fed on Bt corn, or host populations may be reduced. By keeping Lepidoptera pest populations at extremely low levels, Bt crops could potentially starve natural enemies, as predators and parasitic wasps that feed on pests need a small amount of prey to survive in the agroecosystem. Among the natural enemies that live exclusively on insects which the transgenic crops are designed to kill (*Lepidoptera*), egg and larval parasitoids would be most affected because they are totally dependent on live hosts for development and survival, whereas some predators could theoretically thrive on dead or dying prey (Schuler *et al.,* 1999).

Natural enemies could also be affected directly through inter-trophic level effects of the toxin. The potential for Bt toxins moving through arthropod food chains poses serious implications for natural biocontrol in agricultural fields. Recent evidence shows that the Bt toxin can affect beneficial insect predators that feed on insect pests present in Bt crops (Hilbeck *et al*. 1998). Studies in Switzerland showed that mean total mortality of predaceous lacewing larvae (*Chysopidae*) raised on Bt fed prey was 62% compared to 37% when raised on Bt-free prey. These Bt prey fed *Chysopidae* also exhibited prolonged development time throughout their immature life stage (Hilbeck *et al*., 1998). Inter-trophic level effects of the Bt toxin raise serious concerns about the potential of the disruption of natural pest control.

In the case of herbicide tolerant crops, the biomass of weeds in agroecosystems is usually reduced with knock-on effects on higher trophic levels via reductions in resource availability (Hawes *et al.,* 2003). Elimination of weeds within or around fields that provide nectar or alternative prey/hosts for natural enemies, can significantly affect the abundance and diversity of predators and parasitoids in crop fields (Altieri, 1994).

Habitat Manipulation: Restoring Soil Health and Plant Diversity

The instability of agroecosystems, manifesting as the worsening of most insect pest problems (and therefore increase dependence on external inputs), is increasingly linked to the expansion of crop monocultures (Altieri, 1994). Plant communities that are modified to meet the special needs of humans become subject to heavy pest damage and generally the more intensely such communities are modified, the more abundant and serious the pests. The inherent self-regulation characteristics of natural communities are lost when humans modify such communities by promoting monocultures. Some agroecologists maintain that this breakdown can be repaired by the addition or enhancement of plant biodiversity at the field and landscape level (Gliessman, 1999; Altieri, 1999), forms of ecological engineering.

Emergent ecological properties develop in diversified agroecosystems allowing biodiversity to thrive and establish complex food webs and interactions. But biodiversification must be accompanied by improvement of soil quality, as the link between healthy soils and healthy plants is fundamental to ecologically based pest management. The lower pest levels widely reported in organic-farming systems may, in part, arise from plant-insect resistances mediated by biochemical or mineral-nutrient dynamics typical of crops under such management practices. Results from such studies provide evidence to support the view that the long-term joint management of plant diversity and soil organic matter can lead to better plant resistance against insect pests.

Harmonizing Soil and Plant Health in Agroecosystems

Although the integrity of the agroecosystem relies on synergies of plant diversity and the continuing function of the soil microbial community, and its relationship with organic matter (Altieri and Nicholls, 1999), the evolution of IPM and integrated soil fertility management (ISFM) have proceeded separately. This has prevented many scientists to realizing that many pest management methods used by farmers can also be considered soil fertility management strategies and vice-versa. There are positive interactions between soils and pests that once identified can provide guidelines for optimizing total agroecosystem function. Increasingly, new research suggests that the ability of a crop plant to resist or tolerate insect pests and diseases is tied to optimal physical, chemical and mainly biological properties of soils. Soils with high organic matter and active soil biological activity generally exhibit good soil fertility as well as complex food webs and beneficial organisms that prevent infection (Magdoff *et al.,* 2000).

Much of what we know today about the relationship between crop nutrition and pest incidence comes from studies comparing the effects of organic agricultural practices and modern conventional methods on specific pest populations. Soil fertility practices can impact the physiological susceptibility of crop plants to insect pests by affecting the resistance of individual plants to attack or by altering plant acceptability to certain herbivores. Some studies have also documented how the shift from organic soil management to chemical fertilizers has increased the potential of certain insects and diseases to cause economic losses.

The Effects of Nitrogen Fertilization on Insect Pests

The indirect effects of fertilization practices acting through changes in the nutrient composition of the crop have been reported to influence plant resistance to many insect pests. Among the nutritional factors that influence the level of arthropod damage in a crop, total nitrogen (N) has been considered critical for both plants and their consumers (Mattson, 1980; Scriber, 1984; Slansky *et al.,* 1987). Several other authors have also indicated increased aphid and mite populations from nitrogen fertilization especially herbivorous insect populations associated with *Brassica* crop plants known to increase in response to increased soil nitrogen levels (Luna, 1988; Altieri and Nicholls, 2003).

In a two-year study, Brodbeck *et al.,* (2001) found that populations of the thrips *Frankliniella occidentalis* were significantly higher on tomatoes that received higher rates of nitrogen fertilization. Seasonal trends in *F. occidentalis* on tomato were found to be correlated to the number of flowers per host plant and changed with the nitrogen status of flowers. Plants subjected to higher fertilization rates produced flowers that had higher nitrogen content as well as variations in several amino-acid profiles that coincided with peak thrip population density. Abundance of *F.*

occidentalis (particularly adult females) were most highly correlated to flower concentrations of phenylalanine during population peaks. Other insect populations found to increase following nitrogen fertilization included fall armyworm in maize, corn earworm on cotton, pear *psylla* on pear, Comstock mealybug (*Pseudococcus comstocki*) on apple, and European corn borer (*Ostrinia nubilalis*) on field corn (Luna, 1988).

In contrast, because plants are a source of nutrients to herbivorous insects, an increase in the nutrient content of the plant maybe argued to increase its acceptability as a food source to pest populations. Variations in herbivore response may be explained by differences in the feeding behavior of the herbivores themselves (Pimentel and Warneke, 1989). For example, with increasing nitrogen concentrations in creosotebush (*Larrea tridentata*) plants, populations of sucking insects were found to increase, but the number of chewing insects declined. With higher nitrogen fertilization, the amount of nutrients in the plant increases, as well as the amount of secondary compounds that may selectively affect herbivores feeding patterns. Thus protein digestion inhibitors that are found to accumulate in plant cell vacuoles are not consumed by sucking herbivores, but will harm chewing herbivores (Mattson, 1980).

Letourneau (1988) however questions if the «nitrogen-damage» hypothesis, based on Scriber's review, can be extrapolated to a general warning about fertilizer inputs associated to insect pest attack in agroecosystems. Of 100 studies of insects and mites on plants treated experimentally with high and low N fertilizer levels, Letourneau found two-thirds (67-100) of the insect and mite studies to show an increase in growth, survival, reproductive rate, population densities or plant damage levels in response to increased N fertilizer. The remaining third of the arthropods studied showed either a decrease in damage with fertilizer N or no significant change. The author also noted, that experimental design can affect the types of responses observed, suggesting that more reliable data emerged in experiments conducted in field plots, using damage level, population levels and reproductive rate in individual insect species as best predictors of insect response to increase N.

The Dynamics of Insect Herbivores in Organically Managed Systems

Studies documenting lower abundance of several insect herbivores in low-input systems have partly attributed such reductions to the lower nitrogen content in organically farmed crops (Lampkin, 1990). In Japan, density of immigrants' of the planthopper species *Sogatella furcifera* was significantly lower and the settling rate of female adults and survival rate of immature stages of ensuing generations were generally lower in organic compared to conventional rice fields. Consequently, the density of planthopper nymphs and adults in the ensuing generations was found to decrease in organically farmed fields (Kajimura, 1995). In India, the introduction of high yielding rice varieties by the Green Revolution was accompanied by increased and frequent inputs of fertilizers. In Tamil Nadu, the consumption of N, P, K fertilizers increased from 296.000 MT in 1970-71 to 791.000MT in 1996-97. Surprisingly, those changes unexpectedly influenced mosquito breeding and thereby affected the incidence of mosquito-borne disease. Researchers found that the application of urea in rice fields significantly increased the population densities of mosquito larvae and pupae (anophelines as well as culicines) in a dose-related manner. In contrast fields treated with organic fertilizers (farmyard manure or green manure from blue-green algae) exhibited significantly lower population densities of mosquito inmatures (Greenland, 1997).

In England, conventional winter wheat fields exhibited a larger infestation of the aphid *Metopolophium dirhodum* than their organic counterpart. The conventionally fertilized wheat crop also had higher levels of free protein amino acids in its leaves during June, which were attributed to a nitrogen top dressing applied early in April. However, the difference in the aphid infestations between crops was attributed to the aphid's response to the relative proportions of certain non-protein to protein amino acids present in the leaves at the time of aphid settling on crops (Kowalski *et al.,* 1979). The authors concluded that chemically fertilized winter wheat was more palatable than its organically grown counterpart; hence the higher level of infestation.

In greenhouse experiments, when given a choice of maize grown on organic versus chemically fertilized soils collected from nearby farms, European corn borer (*Ostrinia nubilalis*) females significantly laid more eggs in the chemically fertilized plants (Phelan *et al.,* 1995). Interestingly, there was significant variation in egg-laying among chemical fertilizer treatments within the conventionally managed soil, but in plants under the organic soil management, egg laying was uniformly low. Pooling results across all three farms showed that variance in egg laying was approximately 18 times higher among plants in conventionally managed soil than among plants grown under an organic regimen. The authors suggested that this difference is evidence for a form of biological buffering characteristically found more commonly in organically managed soils.

Altieri, *et al.* (1998) conducted a series of comparative experiments on various growing seasons between 1989-1996 in which broccoli was subjected to varying fertilization regimes (conventional versus organic). The goal was to test the effects of different nitrogen sources on the abundance of the key insect pests, cabbage aphid (*Brevicoryne brassicae*) and flea beetle (*Phyllotreta cruciferae*). Conventionally fertilized monoculture consistently developed a larger infestation of flea beetles and in some cases of the cabbage aphid, than the organically fertilized broccoli systems. The reduction in aphid and flea beetle infestations in the organically fertilized plots was attributed to lower levels of free nitrogen in the foliage of plants. This further supports the view that insect pest preference can be moderated by alterations to the type and amount of fertilizer used.

By contrast, a study comparing the population responses of *Brassica* pests to organic versus synthetic fertilizers, measured higher *Phyllotreta* flea beetles populations on sludge-amended collard (*Brassica oleracea*) plots early in the season compared to mineral-fertilizer-amended and unfertilized plots (Culliney *et al.,* 1986). However, later in the season, in these same plots, insect population levels were lowest in organic plots for beetles, aphids and lepidopteran pests. This suggests that the effects of fertilizer type vary with plant growth stage and that organic fertilizers do not necessarily diminish pest populations but, at times may increase them. For example, in a survey of California tomato producers, despite the pronounced differences in plant quality (N content of leaflets and shoots) both within and among tomato fields, Letourneau, *et al.* (1996) found no indication that greater concentrations of tissue N in tomato plants were associated with higher levels of insect damage.

Links Between Below and Above Ground Food Webs

Agroecology encourages practices that enhance the greatest abundance and diversity of above and below-ground organisms. While these epigeal and aerial components have usually been considered in isolation from one another, they are dependent upon each other. Producers provide the organic carbon sources that drive the decomposer activity, which is in turn responsible for mineralizing nutrients required for maintaining growth of the producers. On the other hand mutualists, herbivores, pathogens, predators and parasites affect producer-decomposer interactions both by directing changes in the flow of energy and resources or by imposing selective forces.

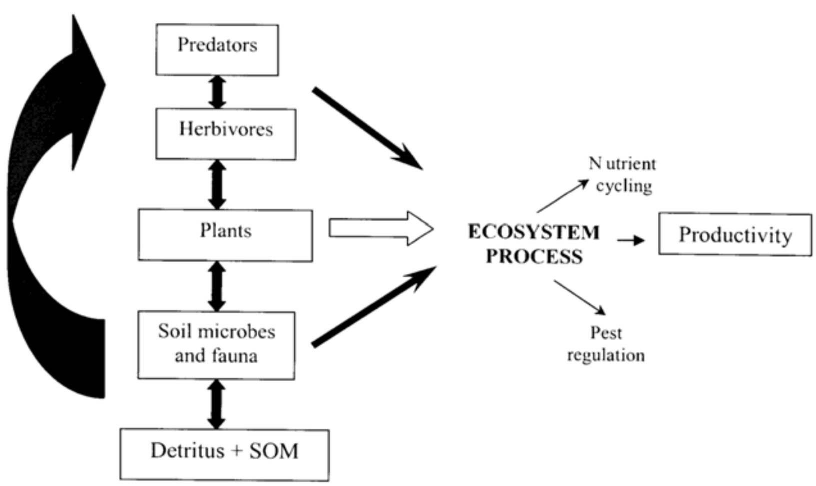
Research has demonstrated often complex and unexpected feedbacks between the elements of below and above ground trophic systems, with implications for the structure and functioning of the entire food web. For example, spiders by preying on important detrivorous and fungivorores can depress rates of litter decomposition potentially reducing plant growth. If decomposition and grazing food webs are linked by common top predators, it is possible that increase inputs of detritus could elevate the biomasss of primary producers via reduction of herbivory through predation. Such links could also have implications in pest regulation. Studies in tropical Asian irrigated rice agroecosystems by Settle *et al.* (1996) showed that by increasing organic matter in test plots, researchers could boost populations of detritivores and plankton-feeders, and in turn significantly boost the abundance of generalist predators. Surprisingly, organic matter management proved to be a key mechanism in the support of high levels of natural biological control. Such mechanisms have inherto been ignored by scientists as important elements in rice pest management.

Figure 1 suggets likely feedbacks between plants, ecosystem processes and biota at other trophic levels. In agroecosystems, plant species richness and functional diversity have been shown to affect both herbivore abundance and diversity. But increased diversity of plants may also influence organisms and processes in the soil and vice versa, though many aspects of this issue remain unexplored. More research is required to confirm feedbacks, as obviously the better researchers and farmers understand the intricate relationships among soils, microbes, crops, pests and natural enemies, the more skillfully they can incorporate the many elements of biodiversity in ecological engineering to optimize key processes essential to sustain agroecosystem productivity and health.

Conversion

In reality, the implementation of an ecologically based pest management strategy usually occurs while an agroecosystem is undergoing a process

Figure 1. Multi-level feedbacks between above and below-ground biodiversity



of conversion from a high-input conventional management system to a low-external-input system. This conversion can be conceptualized as a transitional process with three marked phases (MacRae *et al.,* 1990):

1. Increased efficiency of input use as emphasized by traditional integrated pest management.

2. Input substitution or substitution of environmentally benign inputs for agrochemical inputs as practiced by many organic farmers.

3. System redesign: diversification with an optimal crop/animal assemblage, which encourages synergism so that the agroecosystem may sponsor its own soil fertility, natural pest regulation, and crop productivity.

Many of the practices currently being promoted as components of IPM fall in categories 1 and 2. Both of these stages offer clear benefits in terms of lower environmental impacts as they decrease agrochemical input use and often can provide economic advantages compared to conventional systems. Incremental changes are likely to be more acceptable to farmers as drastic modifications that may be viewed as highly risky or that complicate management. But does the adoption of practices that increase the efficiency of input use or that substitute biologically based inputs for agrochemicals, but that leaves the monoculture structure intact, really have the potential to lead to the productive redesign of agricultural systems?

In general, the fine-tuning of input use through IPM does little to move farmers toward an alternative to high input systems. In most cases IPM translates to «intelligent pesticide management» as it results in selective use of pesticides according to a pre-determined economic threshold, which pests often «surpass» in monoculture situations. On the other hand, input substitution follows the same paradigm of conventional farming; overcoming the limiting factor but this time with biological or organic inputs. Many of these «alternative inputs» have become commodified, therefore farmers continue to be dependent on input suppliers, many of a corporate nature (Altieri and Rosset, 1996). Clearly, as it stands today, «input substitution» has lost much of its ecological potential. System redesign on the contrary arises from the transformation of agroecosystem function and structure by promoting management guided to ensure fundamental agroecosystem processes. Promotion of biodiversity within agricultural systems is the cornerstone strategy of system redesign, as research has demonstrated that higher diversity (genetic, taxonomic, structural, resource) within the cropping system leads to higher diversity in associated biota usually leading to more effective pest control and tighter nutrient cycling.

As more information about specific relationships between biodiversity, ecosystem processes, and productivity in a variety of agricultural systems is accumulated, design guidelines can be developed further and used to improve agroecosystem sustainability and resource conservation.

Syndromes of Production

One of the frustrations of research in sustainable agriculture has been the inability of low-input practices to outperform conventional practices in side-by-side experimental comparisons, despite the success of many organic and low-input production systems in practice (Vandermeer, 1997). A potential explanation for this paradox was offered by Andow and Hidaka (1989) in their description of «syndromes of production». These researchers compared the traditional shizeñ system of rice (*Oryza sativa*) production with the contemporary Japanese high input system. Although rice yields were comparable in the two systems, management practices differed in almost every respect: irrigation practice, transplanting technique, plant density, fertility source and quantity, and management of insects, diseases, and weeds. Andow and Hidaka (1989) argue that systems like shizeñ function in a qualitatively different way than conventional systems. This array of cultural technologies and pest management practices result in functional differences that cannot be accounted for by any single practice.

Thus a production syndrome is a set of management practices that are mutually adaptive and lead to high performance. However, subsets of this collection of practices may be substantially less adaptive; that is, the interaction among practices leads to improved system performance that cannot be explained by the additive effects of individual practices. In other words, each production system represents a distinct group of management techniques and by implication, ecological relations. This re-emphasizes the fact that agroecological designs (i.e. pest suppressive crop combinations) are site-specific and what may be applicable elsewhere are not the techniques, but rather the ecological principles that underlie sustainability. It is of no use to transfer technologies from one site to another, if the set of ecological interactions associated with such techniques cannot be replicated.

Diversified Agroecosystems and Pest Management

Diversified cropping systems, such as those based on intercropping and agroforestry or cover cropping of orchards, have been the target of much research recently. This interest is largely based on the emerging evidence that these systems are more stable and more resource conserving (Vandermeer, 1995). Many of these attributes are connected to the higher levels of functional biodiversity associated with complex farming systems. As diversity increases, so do opportunities for coexistence and beneficial interference between species that can enhance agroecosystem sustainability (Van Emden and Williams, 1974). Diverse systems encourage complex food webs which entail more potential connections and interactions among members, and many alternative paths of energy and material flow through it. For this and other reasons a more complex community exhibits more stable production and less fluctuations in the numbers of undesirable organisms. Studies further suggest that the more diverse the agroecosystems and the longer this diversity remains undisturbed, the more internal links develop to promote greater insect stability. It is clear, however, that the stability of the insect community depends not only on its trophic diversity, but also on the actual density-dependence nature of the trophic levels (Southwood and Way, 1970). In other words, stability will depend on the precision of the response of any particular trophic link to an increase in the population at a lower level.

Recent studies conducted in grassland systems suggest however, that there are no simple links between species diversity and ecosystem stability. What is apparent is that functional characteristics of component species are as important as the total number of species in determining processes and services in ecosystems (Tilman *et al.,* 1996). This finding has practical implications for agroecosystem management. If it is easier to mimic specific ecosystem processes than to duplicate all the complexity of nature, then the focus should be placed on a specific biodiversity component that plays a specific role, such as a plant that fixes nitrogen, provides cover for soil protection or harbors resources for natural enemies. In the case of farmers without major economic and resource limits and who can withstand that allow a certain risk of crop failure, a crop rotation or a simple polyculture may be all it takes to achieve a desired level of stability. But in the case of resource-poor farmers, who can not tolerate crop failure, highly diverse cropping systems would probably be the best choice. The obvious reason is that the benefit of complex agroecosystems is low risk; if a species falls to disease, pest attack or weather, another species is available to fill the void and maintain full use of resources. Thus there are potential ecological benefits to having several species in an agroecosystem: compensatory growth, full use of resources and nutrients, and pest protection (Ewel, 1999).

Plant Diversity and Insect Pest Incidence

An increasing body of literature documents the effects that plant diversity has on the regulation of insect herbivore populations by favoring the abundance and efficacy of associated natural enemies (Landis *et al.,* 2000). Research has shown that mixing certain plant species usually leads to density reductions of specialized herbivore. In a review of 150 published investigations Risch *et al.* (1983) found evidence to support the notion that specialized insect herbivores were less numerous in diverse systems (53% of 198 cases). In another comprehensive review 209 published studies that deal with the effects of vegetation diversity in agroecosystems on herbivores arthropod species, Andow (1991) found that fifty-two percent of the 287 total herbivore species examined in these studies were less abundant in polycultures than in monocultures, while only 15.3% (44 species) exhibited higher densities in polycultures. In a more recent review of 287 cases, Helenius (1998) found that the reduction of monophagous pests was greater in perennial systems, and that the reduction of polyphagous pest numbers was less in perennial than in annual systems. Helenius (1998) concluded that monophagous (specialists) insects are more susceptible to crop diversity than polyphagous insects. He cautioned about the increased risk of pest attack if the dominant herbivore fauna in a given agroecosystem is polyphagous. In examining numerous studies testing the responses of pest and beneficial arthropods to plant diversification in cruciferous crops, Hooks and Johnson (2003) concluded that biological parameters of herbivores impacted by crop diversification were mainly related to the behavior of the insect studied. Mechanisms accounting for herbivore responses to plant mixtures include reduced colonization, reduced adult tenure time in the crop, and oviposition interference. They suggest that lower herbivore populations in mixed *Brassica* plantings are due to lower plant size and quality of these crops in diverse systems than in monocultures. Hooks and Johnson (2003) urge changes on *Brassica* agronomy so that mixed cropping exhibits it crop protection benefits without yield reductions.

The ecological theory relating to the benefits of mixed versus simple cropping systems revolves around two possible explanations of how insect pest populations attain higher levels in monoculture systems compared with diverse ones. The two hypotheses proposed by Root (1973) are:

1. The enemies hypothesis which argues that pest numbers are reduced in more diverse systems because the activity of natural enemies is enhanced by environmental opportunities prevalent in complex systems.
2. The resource concentration hypothesis argues that the presence of more a diverse flora has direct negative effects on the ability of the

insect pests to find and utilize its host plant and also to remain in the crop habitat.

The resource concentration hypothesis predicts lower pest abundance in diverse communities because a specialist feeder is less likely to find its host plant due to the presence of confusing masking chemical stimuli, physical barriers to movement or other environmental effects such as shading; it will tend to remain in the intercrop for a shorter period of time simply because the probability of landing on a non-host plant is increased; it may have a lower survivorship and/or fecundity (Bach, 1980). The extent to which these factors operate will depend on the number of host plant species present and the relative preference of the pest for each, the absolute density and spatial arrangement of each host species and the interference effects from more host plants.

The enemies hypothesis attributes lower pest abundance in intercropped or more diverse systems to a higher density of predators and parasitoids (Bach, 1980). The greater density of natural enemies is caused by an improvement in conditions for their survival and reproduction, such as a greater temporal and spatial distribution of nectar and pollen sources, which can increase parasitoid reproductive potential and abundance of alternative host/prey when the pest species are scarce or at inappropriate stages (Risch, 1981; Jord *et al.,* this volume). These factors can in theory combine to provide more favorable conditions for natural enemies and thereby enhance their numbers and effectiveness as control agents.

The relative importance of these hypotheses has been investigated in two ways: (i) reviews of the literature relating to crop diversity and pest abundance; and (ii) by experimentation. Risch *et al.,* (1983) concluded that the resource concentration hypothesis was the most likely explanation for reductions in pest abundance in diverse systems. However, nineteen studies that tested the natural enemy hypothesis were reviewed by Russell (1989), who found that mortality rates from predators and parasitoids in diverse systems were higher in nine, lower in two, unchanged in three and variable in five. Russell (1989) concluded that the natural enemy hypothesis is an operational mechanism, but he considered the two hypotheses complementary. In studies of crop/weed systems, Baliddawa (1985) found that 56% of pest reductions in weed diversified cropping systems were caused by natural enemies.

One of the major problems has been predicting which cropping systems will reduce pest abundance, since not all combinations of crops will produce the desired effect and blind adherence to the principle that a more diversified system will reduce pest infestation is clearly inadequate and often totally wrong (Gurr *et al.,* 1998). To some researchers this indicates the need for caution and a greater understanding of the mechanisms involved to explain how, where and when such exceptions are likely to occur. It will only be through more detailed ecological studies that such an understanding can be gained and an appropriate predictive theory developed. This means that a greater emphasis has to be placed on ecological experiments rather than on purely descriptive comparative studies.

Recent Practical Case Studies

Despite some of the above mentioned knowledge gaps, many studies have transcended the research phase and have found applicability to regulate specific pests. Examples include:

1. Researchers working with farmers in ten townships in Yumman, China, covering an area of 5,350 hectares, encouraged farmers to switch from rice monocultures to planting variety mixtures of local rice with hybrids. Enhanced genetic diversity reduced blast incidence by 94% and increased total yields by 89%. By the end of two years, it was concluded that fungicides were no longer required (Zhu *et al.,* 2000; Wolfe, 2000).

2. In Africa, scientists at the International Center of Insect Physiology and Ecology (ICIPE) developed a habitat management system (push-pull system) which uses plants in the borders of maize fields which act as trap crops (Napier grass and Sudan grass) attracting

stemborer colonization away from maize (the push) and two plants intercropped with maize (molasses grass and silverleaf) that repel the stemborers (the pull) (Khan *et al.,* 1998, this volume). Border grasses also enhance the parasitization of stemborers by the wasp *Cotesia semamiae*, and are important fodder plants. The leguminous silverleaf (*Desmodium uncinatum*) suppresses the parasitic weed Striga by a factor of 40 when compared with maize monocrop. *Desmodium*'s N-fixing ability increases soil fertility; and it is excellent forage. As an added bonus, sale of *Desmodium* seed is proving to be a new income-generating opportunity for women in the project areas. The push-pull system has been tested on over 450 farms in two districts of Kenya and has now been released for uptake by the national extension systems in East Africa. Participating farmers in the breadbasket of Trans Nzoia are reporting a 15-20 percent increase in maize yield. In the semi-arid Suba district plagued by both stemborers and Striga a substantial increase in milk yield has occurred in the last four years, with farmers now being able to support increase numbers of dairy cows on the fodder produced. When farmers plant maize together with the push-pull plants, a return of US $2.30 for every dollar invested is made, as compared to only $1.40 obtained by planting maize as a monocrop.

3. Several researchers have introduced flowering plants as strips within crops as a way to enhance the availability of pollen and nectar, necessary for optimal reproduction, fecundity and longevity of many natural enemies of pests. *Phacelia tanacetifolia* strips have been used in wheat, sugar beets and cabbage leading to enhanced abundance of aphidophagous predators especially syrphid flies, and reduced aphid populations. In England in an attempt to provide suitable overwintering habitat within fields for aphid predators, researchers created «beetle banks» sown with perennial grasses such as *Dactylis glomerata* and *Holcus lanatus.* When these banks run parallel with the crop rows, great enhancement of predators (up to 1,500 beetles per square meter) can be achieved in only two years (Landis *et al.,* 2000).

4. In perennial cropping systems the presence of flowering undergrowth enhances the biological control of a series of insect pests. The beneficial

insectary role of *Phacelia* in apple orchards was well demonstrated by Russian and Canadian researchers more than 30 years ago (Altieri, 1994). Maintenance of floral diversity by organic farmers throughout the growing season in California vineyards, in the form of summer cover crops of buckwheat (*Fagopyrum esculentum*) and sunflower (*Helianthus annus*), had a substantial impact on the abundance of western grape leafhopper, *Erythroneura elegantula* (*Homoptera: Cicadellidae*), and western flower thrips, *Frankliniella occidentalis* (*Thysanoptera: Thripidae*), and associated natural enemies. During two consecutive years, vineyard systems with flowering cover crops were characterized by lower densities of leafhoppers and thrips, and larger populations and more species of general predators, including spiders. Although *Anagrus epos* (*Hymenoptera: Mymaridae*), the most important parasitoid, achieved high numbers and inflicted noticeable mortality of grape leafhopper eggs, no differences in egg parasitism rates were observed between cover cropped and monoculture systems. Mowing of cover crops forces movement of *Anagrus* and predators to adjacent vines resulting in the lowering of leafhopper densities in such vines. Results indicate that habitat diversification using summer cover crops that bloom most of the growing season, supports large numbers of predators and parasitoids thereby favoring enhanced biological control of leafhoppers and thrips in vineyards (Nicholls *et al.,* 2000).

5. In Washington State, USA, researchers reported that organic apple orchards that retained some level of plant diversity in the form of weeds mowed as needed, gave similar apple yields than conventional and integrated orchards. Their data showed that the low-external input organic system ranked first in environmental and economic sustainability as this system exhibited higher profitability, greater energy efficiency and lower negative environmental impact (Reganold *et al.,* 2001).

6. In Central America, Staver *et al.* (2001) designed pest-suppressive multistrata shade-grown coffee systems, selecting tree species and associations, density and spatial arrangement as well as shade management regimes with the main goal of creating optimum shade conditions for pest suppression. For example, in low-elevation coffee zones, 35-65% shade promotes leaf retention in the dry seasons and reduces *Cercospora coffeicola*, weeds and *Planococcus citri*; at the

same time, it enhances the effectiveness of microbial and parasitic organisms without contributing to increased *Hemileia vastatrix* levels or reducing yields.

7. Several entomologists have concluded that the abundance and diversity of predators and parasites within a field are closely related to the nature of the vegetation in the field margins. There is wide acceptance of the importance of field margins as reservoirs of the natural enemies of crop pests. Many studies have demonstrated increased abundance of natural enemies and more effective biological control where crops are bordered by wild vegetation from which natural enemies colonize. Parasitism of the armyworm, *Pseudaletia unipunctata*, was significantly higher in maize fields embedded in a complex landscape than in maize fields surrounded by simpler habitats. In a two year study researchers found higher parasitism of *Ostrinia nubilalis* larvae by the parasitoid *Eriborus terebrans* in edges of maize fields adjacent to wooded areas, than in field interiors (Landis *et al.,* 2000). Similarly in Germany, parasitism of rape pollen beetle was about 50% at the edge of the fields, while at the center of the fields parasitism dropped significantly to 20% (Thies and Tscharntke, 1999).

8. One way to introduce the beneficial biodiversity from surrounding landscapes into large-scale monocultures is by establishing vegetationally diverse corridors that allow the movement and distribution of useful arthropod biodiversity into the center of monocultures. Nicholls *et al.* (2001) established a vegetational corridor which connected to a riparian forest and cut across a vineyard monoculture. The corridor allowed natural enemies emerging from the riparian forest to disperse over large areas of otherwise monoculture vineyard systems. The corridor provided a constant supply of alternative food for predators effectively decoupling predators from a strict dependence on grape herbivores and avoiding a delayed colonization of the vineyard. This complex of predators continuously circulated into the vineyard interstices establishing a set of trophic interactions leading to a natural enemy enrichment, which led to lower numbers of leafhoppers and thrips on vines located up to 30-40 m from the corridor.

All of the above examples constitute forms of habitat diversification that provide resources and environmental conditions suitable for natural enemies. The challenge is to identify the type of biodiversity that is desirable to maintain and/or enhance in order to carry out ecological services of pest control, and then to determine the best practices that will encourage such desired biodiversity components.

Designing Pest-Stable Agroecosystems

The key challenge for the 21st century pest managers is to translate ecological principles into practical alternative systems to suit the specific needs of farming communities in different agroecological regions of the world. A major strategy emphasized in this chapter to design a more sustainable agriculture is to restore agricultural diversity in time and space by following key agroecological guidelines:

- Increase species diversity in time and space through multiple cropping and agroforestry designs.
- Increase genetic diversity through variety mixtures, multilines and use of local germplasm and varieties exhibiting horizontal resistance.
- Include and improved fallow through legume-based rotations, use of green manures, cover crops and/or livestock integration.
- Enhance landscape diversity with biological corridors, vegetationally diverse crop-field boundaries or by creating a mosaic of agroecosystems and maintaining areas of natural or secondary vegetation as part of the agroecosystem matrix.

As mentioned above, diversification schemes should be complemented by soil organic management as both strategies conform the pillars of agroecosystem health (Figure 2).

Different options to diversify cropping systems are available depending on whether the current monoculture systems to be modified are based on annual or perennial crops. Diversification can also take place outside the farm, for example, in crop-field boundaries with windbreaks, shelterbelts, and living fences, which can improve habitat for wildlife and beneficial insects, provide resources of wood, organic matter, resources for pollinating bees, and, in addition, modify wind speed and microclimate (Altieri and Letourneau, 1982). Plant diversification can be considered a form of conservation biological control with the goal of creating a suitable ecological infrastructure within the agricultural landscape to provide resources such as pollen and nectar for adult natural enemies, alternative prey or hosts, and shelter from adverse conditions. These resources must be integrated into the landscape in a way that is spatially and temporally favorable to natural enemies and practical for producers to implement.

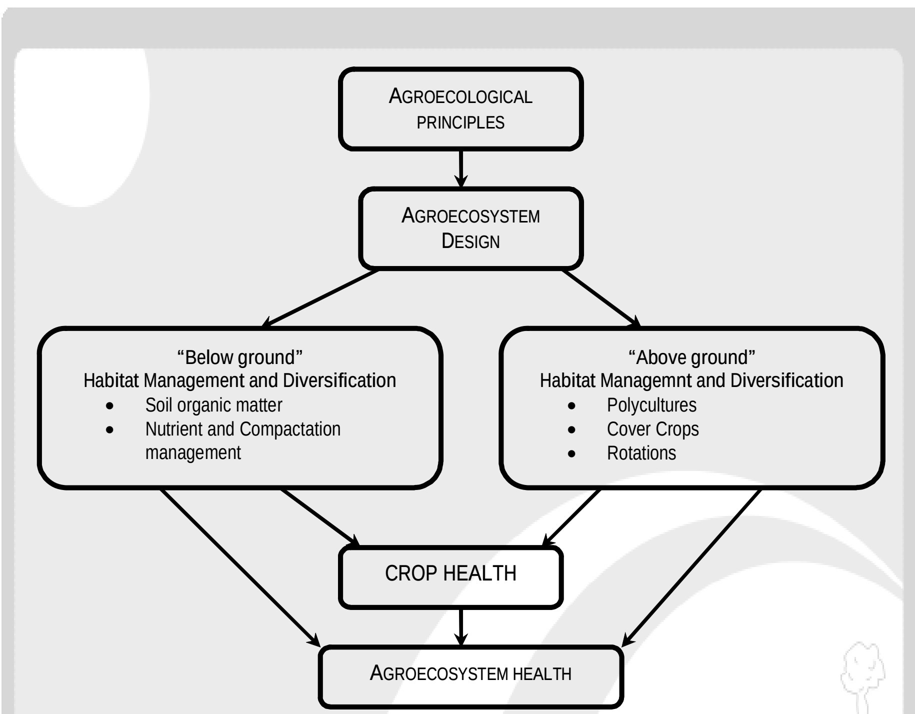


Figure 4. Pillars of agroecosystems health

Landis *et al.* (2000) recommended the following guidelines to be considered when implementing habitat management strategies:

a. Selection of the most appropriate plant species.

b. The spatial and temporal arrangement of such plants within and/or around the fields.

c. The spatial scale over which the habitat enhancement operates, with implications at the field or landscape level.

d. The predator/parasitoid behavioral mechanisms which are influenced by the habitat manipulation.

e. Potential conflicts that may emerge when adding new plants to the agroecosystem (i.e., in California, *Rubus* blackberries around vineyards increases populations of grape leafhopper parasitoids but can also enhance abundance of the sharpshooter which serves as a vector Pierce's disease).

f. Develop ways in which added plants do not upset other agronomic management practices, and select plants that preferentially have multiple effects such as improving pest regulation but at the same time improve soil fertility, weed suppression, etc.

In addition, Hooks and Johnson (2003) identified a need for more categorical research on the use of crop diversification, recommending that more attention should be devoted to:

1. defining ways to suppress pest through diversity without significant yield reductions;

2. determining how mixed cropping systems impact the population dynamics and searching behaviors of natural enemies;

3. discovering methods to make mixed plantings more economically feasible and compatible with conventional farm operations;

4. determining how mixed cropping systems can be effectively combined with other pest control tactics.

In some cases crop diversification may not suffice as a stand alone pest management tactic. However, if compatible with other pest management tactics (e.g. biological control, host plant resistance, etc.) some of the shortcomings associated with habitat management may be overcome. This of course will depend on the type of crop, the nature of surrounding habitats, the diversity of beneficial biota and the and prevalent pest. In diversified farms that have undergone agroecological conversion for three or more years, diversity usually provides all the needed protection. What is crucial is the identification of the type of biodiversity worthwhile maintaining and/or enhancing in order to carry out ecological services, and then determining those practices that will best encourage the desired biodiversity components. Figure 3 shows the many agricultural practices and designs with the potential for enhancing functional biodiversity and those having negative effect. The idea is to apply the best management practices for enhancing or regenerating the kind of biodiversity that not only enhances the sustainability of agroecosystems by providing ecological services such as biological control, but also nutrient cycling, water and soil conservation (Nicholls and Altieri, 2001).

If one or more alternative diversification schemes are used, the possibilities of complementary interactions between agroecosystem components are enhanced resulting in one or more of the following effects:

a. Continuous vegetation cover for soil protection.

b. Constant production of food, ensuring a varied diet and several marketing items.

c. Closing nutrient cycles and effective use of local resources.

d. Soil and water conservation through mulching and wind protection;

e. Enhanced biological pest control by providing through diversification resources to beneficial biota.

f. Increased multiple use capacity of the landscape.

g. Sustained crop production without relying on environmentally degrading chemical inputs.

In summary, key ecological principles for the design of diversified and sustainable agroecosystems include:

a. Increasing species diversity as this promotes fuller use of resources (nutrient, radiation, water, etc.), pest protection and compensatory growth. Many researchers have highlighted the importance of various spatial and temporal plant combinations to facilitate complementary resource use or to provide intercrop

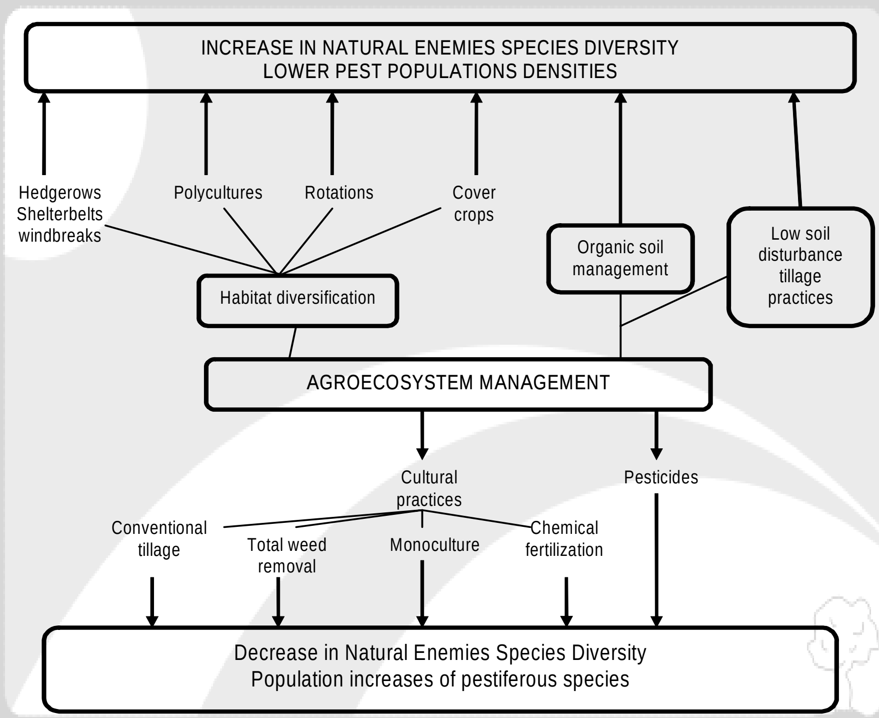


Figure 3. The effects of agroecosystem management and associated cultural practices on the diversity of natural enemies and the abundance of insect pests.

advantage such as in the case of legumes facilitating the growth of cereals by supplying extra nitrogen. Compensatory growth is another desirable trait because if one species succumbs to pests, weather or harvest; another species fills the void maintaining full use of available resources.

b. Enhance longevity through the addition of perennials that contain a thick canopy thus providing continual cover that can also protect the soil from erosion. Constant leaf fall builds organic matter and allows uninterrupted nutrition circulation. Dense, deep root systems of long-lived woody plants are an effective mechanism for nutrient capture offsetting the negative losses through leaching. Perennial vegetation also provides more habitat permanence contributing to more stable pest-enemy complexes.

c. Impose a fallow to restore soil fertility through biologically mediated mechanisms, and to reduce agricultural pest populations as life cycles are interrupted with forest regrowth or legume-based rotations.

d. Enhance additions of organic matter by including high biomass-producing plants as organic matter forms the foundation of complex food webs which may indirectly influence the abundance and diversity of natural enemies.

e. Increase landscape diversity by having in place a mosaic of agroecosystems representative of various stages of succession. Risk of complete failure is spread among, as well as within, the various cropping systems. Improved pest control is also linked to spatial heterogeneity at the landscape level.

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Chapter 10

Chapter 10

Designing and Implementing a Habitat Management Strategy to Enhance Biological Pest Control in Agroecosystems

Farmers can enhance the resistance and resilience of their crops and fields by reinforcing their built-in defenses against pests. This can be done by following two main strategies: increasing above —and below— ground biodiversity and improving soil health. This paper focuses on the role of beneficial insect biodiversity in farms, and on the ways of enhancing functional biodiversity in agroecosystems as a means of promoting biological control of insect pests (Wolfe, 2000).

Biodiversity is crucial to crop defenses: the more diverse the plants, animals and soil-borne organisms that inhabit a farming system, the more diverse the community of pest- fighting beneficial organisms the farm can support. One group of partners —beneficial predators— chew up plant-eating insects and mites or sucks out their juices. Another group —beneficial parasites— lay eggs inside pest eggs and/or larvae. A third group —beneficial disease-causing organisms that include fungi, bacteria, viruses, protozoa and nematodes— fatally sicken pests or keep them from feeding or reproducing. Plants also form complex associations with organisms around their roots, which offer protection against disease. Soil fungi and ground beetles can destroy the seeds of weeds that compete with plants. In addition the rich soil fauna play key roles in breaking up and decomposing organic matter thus making nutrients available to plants. Biodiversity in the form of polycultures may also make plants less «apparent» to pests; crops growing in monocultures may be so obvious to pests that the plants' defenses fall short of protecting them (Altieri and Letourneau, 1982).

Farmers can enhance biodiversity on their farms by:

- increasing plant diversity with crop rotations or with «polycultures» of cash and cover crops grown on the same land at the same time;
- managing vegetation surrounding fields to meet the needs of beneficial organisms;
- providing beneficial organisms with supplemental resources, such as artificial nesting structures, extra food and alternative prey;
- designing «corridors» of plants that usher beneficials from nearby forests or natural vegetation to field centers;
- selecting non-crop plants grown as strips in fields, whose flowers match beneficials' requirements.

Healthy soils are also essential to plant defenses. Unhealthy soils hinder crops' abilities to use their natural defenses and leave them vulnerable to potential pests. In contrast, healthy soils arm plants chemically with defenseboosting nutrients and are physically conducive to optimum root development and water use. Reduced susceptibility to pests is usually a reflection of differences in plant health as mediated by soil fertility management. Many studies document lower abundance of several insect pests in low-input systems and they attribute partly such reductions to the lower nitrogen content of organically farmed crops. In addition, the rich supplies of beneficial organisms that inhabit healthy soils can intensify nutrient uptake, release growthstimulating chemicals and antagonize disease-causing organisms. Healthy soils can also expose weed seeds to more predators and decomposers, and their slower release of nitrogen in spring can delay small-seeded weeds —which often need a flush of nitrogen to germinate and begin rapid growth— thereby giving larger-seeded crops a head start.

Farmers can improve soil health by:

- diversifying crop rotations including legumes and perennial forages;
- keeping soils covered year-round with living vegetation and/or crop residue;
- adding plenty of organic matter from animal manures, crop residues and other sources;
- reducing tillage intensity and protecting soils from erosion and compaction;
- using best-management techniques to supply balanced nutrients to plants without polluting water.

When farmers adopt agricultural practices that increase the abundance and diversity of above- and below-ground organisms, they strengthen their crops' abilities to withstand pests. In the process, farmers also improve soil fertility and crop productivity.

Biodiversity in Farms and its Function

Biodiversity in farms refers to all plant and animal organisms (crops, weeds, livestock, natural enemies, pollinators, soil fauna, etc.) present in and around farms. Biodiversity can be as varied as the various crops, weeds, arthropods, or microorganisms involved, according to geographical location, climatic, edaphic (soil-related), human, and socioeconomic factors. In general the degree of biodiversity in agroecosystems depends on four main characteristics of the agroecosystem:

- the diversity of vegetation within and around the agroecosystem;
- the permanence of the various crops within the agroecosystem;
- the intensity of management;
- the extent of the isolation of the agroecosystem from natural vegetation.

How diverse is the vegetation within and around the farm, how many crops comprise the rotation, how close is the farm to a forest, hedgerow, meadow or other natural vegetation, are all factors that contribute to a particular farm's level of biodiversity (Altieri and Nicholls, 2004).

The biodiversity components of farms can be classified in relation to the role they play in the functioning of cropping systems. According to this, agricultural biodiversity can be grouped as follows:

- productive biota: crops, trees, and animals chosen by farmers that play a determining role in the diversity and complexity of the agroecosystem;
- resource biota: organisms that contribute to productivity through pollination, biological control, decomposition, etc.;
- destructive biota: weeds, insect pests, microbial pathogens, etc., which farmers aim at reducing through cultural management.

Two distinct components of biodiversity can be recognized in agroecosystems. The first component, planned biodiversity, includes the crops and livestock purposely included in the agroecosystem by the farmer, and which will vary depending on the management inputs and crop spatial/ temporal arrangements. The second component, associated biodiversity, includes all soil flora and fauna, herbivores, carnivores, decomposers, etc., that colonize the agroecosystem from surrounding environments and that will thrive in the agroecosystem depending on its management and structure. The relationship of both types of biodiversity components is illustrated in Figure 1. Planned biodiversity has a direct function, as illustrated by the bold arrow connecting the planned biodiversity box with the ecosystem function box. Associated biodiversity also has a function, but it is mediated through planned biodiversity. Thus,

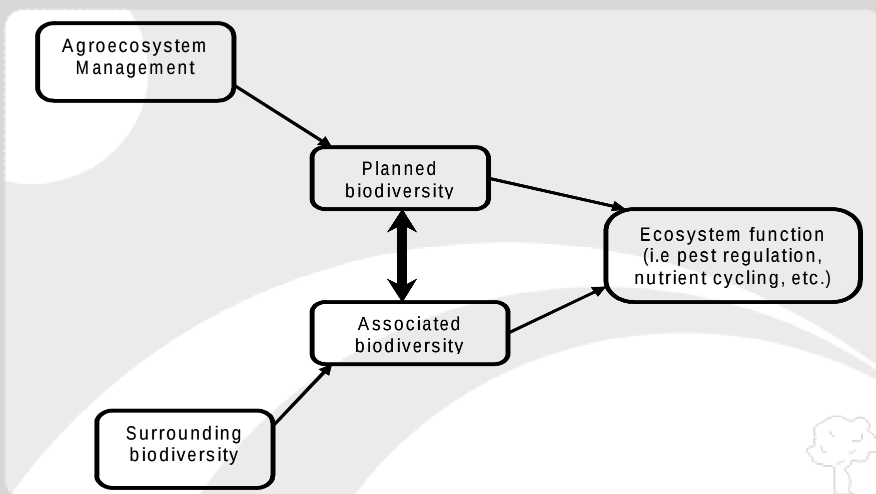

Figure 1. Relationships between several types of biodiversity and their role in agroecosystem function.

planned biodiversity also has an indirect function, illustrated by the dotted arrow in the figure, which is realized through its influence on the associated biodiversity.

For example, the trees in an agroforestry system create shade, which makes it possible to grow only sun-intolerant crops. So, the direct function of this second species (the trees) is to create shade. Yet along with the trees might come wasps that seek out the nectar in the tree's flowers. These wasps may in turn be the natural parasitoids of pests that normally attack crops. The wasps are part of the associated biodiversity. The trees then create shade (direct function) and attract wasps (indirect function).

Complementary interactions between the various biodiversity components can also be of a multiple nature. Some of these interactions can be used to induce positive and direct effects on the biological control of specific crop pests, soil fertility regeneration and/or enhancement and soil conservation. The exploitation of these interactions in real situations involves novel farm designs and management and requires an understanding of the numerous relationships between soils, microorganisms, plants, insect herbivores, and natural enemies. In fact the optimal behavior of agroecosystems depends on the level of interactions between the various biotic and abiotic components. By assembling a functional biodiversity (that is a collection of interacting organisms that play key functions in the farm) it is possible to initiate synergisms which subsidize farm processes by providing ecological services such as the activation of soil biology, the recycling of nutrients, the enhancement of beneficial arthropods and antagonists, and so on, all important in determining the sustainability of agroecosystems (Figure 2).

In modern agroecosystems, the experimental evidence suggests that biodiversity can be used for improved pest management. Several studies have shown that it is posible to stabilize the insect communities of agroecosystems by designing diverse cropping systems that support populations of natural enemies or have direct deterrent effects on pest herbivores.

The key is to identify the type of biodiversity that is desirable to maintain and/or enhance in order to carry out ecological services, and then to determine the best practices that will encourage the desired biodiversity components. There are many agricultural practices and designs that have the potential to enhance functional biodiversity, and others that negatively affect it. The idea is to apply the best management practices in order to enhance or regenerate the kind of biodiversity that can subsidize the sustainability of agroecosystems by providing ecological services such as biological pest control, nutrient cycling, water and soil conservation, etc. The role of farmers and researchers should be to encourage those agricultural practices that increase the abundance and diversity of above —and below— ground organisms, which in turn provide key ecological services to agroecosystems (see Figure 3 in page 234).

Thus, a key strategy in farming is to exploit the complementarity and synergy that result from the various combinations of crops, trees, and animals in agroecosystems that feature spatial and temporal arrangements such as polycultures, agroforestry systems and crop-livestock mixtures. In real situations, the exploitation of these interactions involves farming system design and management and requires an understanding of the numerous relationships among soils,

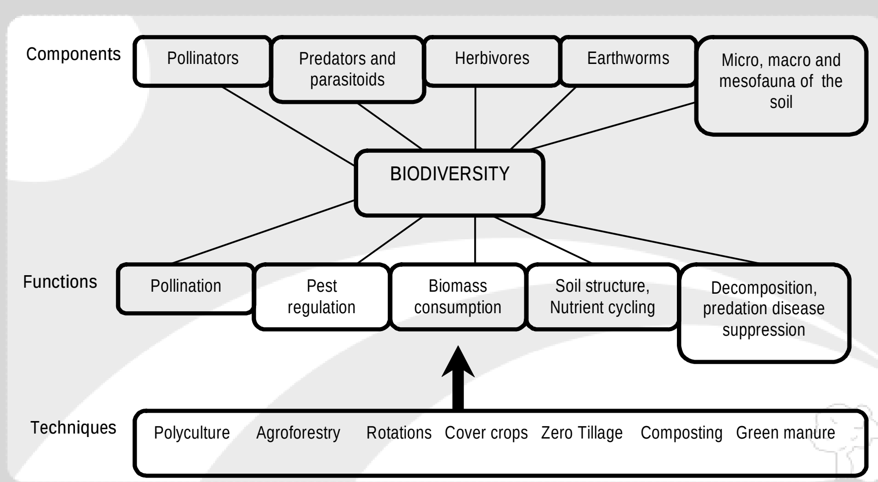

Figure 2. Components, functions and strategies to enhance functional biodiversity in agroecosystems.

microorganisms, plants, insect herbivores, and natural enemies (Baliddawa, 1985).

Biological Pest Control: A Strategy to Increase Biodiversity in Farms

Studies show that farmers can indeed bring pests and natural enemies into balance on biodiverse farms. One of the most powerful and long-lasting ways to keep pests from causing economic damage on your farm is to boost existing or naturally occurring beneficial organisms to effective levels by supplying them with appropriate habitat and alternative food sources.

Fewer beneficial organisms —predators, parasites and pest-sickening «pathogens»— live in monocultures or in fields routinely treated with pesticides than on more diverse farms where fewer pesticides are used. In general farms sharing many of these characteristics host bountiful beneficials (Lewis *et al.*, 1997):

- fields are small and surrounded by natural vegetation;
- cropping systems are diverse and plant populations in or around fields include perennials and flowering plants;
- crops are managed organically or with minimal synthetic agrichemicals;
- soils are high in organic matter and biological activity and —during the off-season— covered with mulch or vegetation.

Naturally occurring beneficials, at sufficient levels, can take a big bite out of pest populations. To exploit them effectively, farmers must:

- identify which beneficial organisms are present;
- understand their individual biological cycles and resource requirements.

With this information, farmers can devise management schemes that will increase the size and diversity of naturalenemy complexes and decrease pest problems.

Predators

Biodiverse farms are rich in predatory insects, spiders and mites. These beneficial arthropods prey on other insects and spider mites, and are critical to natural biological control. Most predators are «generalist» feeders, attacking a wide variety of insect species and life stages. Predators occur in most orders of insects but primarily in *Coleoptera, Odonata, Neuroptera, Hymenoptera, Diptera and Hemiptera*. Their impacts have been highlighted worldwide by eruptions of spider mite pests where chemical insecticides have eliminated the mites' predators. Tetranychid mites, for example, are usually very abundant in apple orchards where pesticides have destroyed natural predator populations.

The diversity of predator species in particular agroecosystems can be impressive. Researchers have reported more than six hundred species —from forty-five families— of predaceous arthropods in Arkansas cotton fields and about

1,000 species in Florida soybean fields. Such diversity can apply major regulatory pressures on pests. Indeed, many entomologists consider native, or indigenous, predators a sort of balance wheel in the «pest-natural enemy complex» because

Major characteristics of arthropod predators

- Adults and immatures are often generalists rather than specialists.
- They generally are larger than their prey.
- They kill or consume many prey.
- Males, females, immatures, and adults may be predatory.
- They attack immature and adult prey.
- They require pollen and nectar and additional food resources.

they tend to feed on whatever pest is overabundant. Even where predators can't force pest populations below economically damaging levels, they can and do slow down the rate at which potential pests increase. In sprayfree apple orchards in Canada, five species of predaceous true bugs were responsible for 44 to 68 percent of the mortality of codling moth eggs.

Parasitoids

Most parasitoids —parasitic insects that kill their hosts— live freely and independently as adults; they are lethal and dependent only in their immature stages. Parasitoids can be specialists, targeting either a single host species or several related species, or they can be generalists, developing in many types of hosts. Typically, they attack hosts larger than themselves, eating most or all of their hosts' bodies before pupating inside or outside them. With their uncanny ability to locate even sparsely populated hosts using chemical cues, parasitoid adults are much more efficient than predators at ferreting out their quarry.

Most parasitoids used in the biological control of insect pests are either Diptera flies, especially from the family *Tachinidae* —or *Hymenoptera* wasps from the superfamilies *Chalcidoidea, Ichneumonoidea,* and *Proctotrupoidea*. Parasitoid diversity is directly related to plant diversity: different crops, ground covers, weeds and adjacent vegetation support different pests, which in turn attract their

Major characteristics of insect parasitoids

- They are specialized in their choice of host.
- They are smaller than host.
- Only the female searches for host.
- Different parasitoid species can attack different life stages of host.
- Eggs or larvae are usually laid in, on, or near host.
- Immatures remain on or in host; adults are free-living, mobile, and may be predaceous.
- Immatures almost always kill host.
- Adults also require pollen and nectar.

own groups of parasitoids. In large-scale monocultures, parasitoid diversity is suppressed by vegetational simplification; in less-disturbed and pesticide-free agroecosystems, it is not unusual to find eleven to fifteen species of parasitoids hard at work. In many cases, just one or two species of parasitoids within these complexes prove vital to the natural biological control of primary insect pests. In California’s alfalfa fields, the braconid wasp Cotesia medicaginis plays a pivotal role in regulating the alfalfa caterpillar. This pristine butterfly-wasp system apparently moved into irrigated alfalfa from native clovers.

Enhancing Beneficial Insects by Designing Biodiverse Farms

Natural enemies do not fare well in monocultures. Normal cultural activities like tilling, weeding, spraying and harvesting take their toll, and overly simplified systems lack many of the resources essential to beneficials' survival and reproduction.

To complete their life cycles, natural enemies need more than prey and hosts: they need refuge sites and alternative food, hosts and prey which are usually absent in monocultures. For example, many adult parasites sustain themselves with pollen and nectar from nearby flowering weeds while searching for hosts. Predaceous ground beetles —like many other natural enemies— do not disperse far from their overwintering sites: access to permanent habitat near or within the field gives them a jump-start on early pest populations.

Farmers can minimize the disruptive impacts of modern crop production by understanding and supporting the biological needs of natural enemies. With this same knowledge, they can also design crop habitats that are friendlier to natural enemies.

Improving Crop Habitats for Natural Enemies

To conserve and develop rich complexes of natural enemies, farmers should avoid cropping practices that harm beneficials. Instead, they should substitute methods that enhance their survival. Start by reversing practices that disrupt natural biological control: these include insecticide applications, hedge removal and comprehensive herbicide use intended to eliminate weeds in and around fields.

Providing Supplementary Resources

Natural enemies benefit from many kinds of supplementary resources. In North Carolina, erecting artificial nesting structures for the red wasp *Polistes annularis* intensified its predation of cotton leafworms and tobacco hornworms. In California alfalfa and cotton plots, furnishing mixtures of hydrolyzate, sugar and water multiplied egg-laying by green lacewings six-fold and boosted populations of predatory syrphid flies, lady beetles and soft-winged flower beetles.

Farmers can increase the survival and reproduction of beneficial insects by allowing permanent populations of alternative prey to fluctuate below damaging levels. Use plants that host alternative prey to achieve this: plant them around your fields or even as strips within your fields. In cabbage, the relative abundance of aphids helps determine the effectiveness of the general predators that consume diamondback moth larvae. Similarly, in many regions, anthrocorid bugs benefit from alternative prey when their preferred prey, the western flower thrip, is scarce.

Another strategy —enhancing levels of a beneficial's preferred host— as controlled cabbage white butterflies in cole crops. Supplemented with continual releases of fertile females, populations of this pest escalated nearly ten-fold in spring. This enabled populations of two of its parasites —*Trichogramma evanescens* and *Apanteles rebecula*— to build up early and maintain themselves at effective levels all season long. Because of its obvious risks, this strategy should be restricted to situations where sources of pollen, nectar or alternative prey simply can't be obtained.

Increasing Within-Field Plant Diversity

By diversifying plants within agroecosystems, farmers can expand environmental opportunities for natural enemies and thereby improve biological pest control. One way to do this is to plant polycultures of annual crops —two or more crops simultaneously growing in close proximity. Farmers can also let some flowering weeds reach tolerable levels or use cover crops under orchards and vineyards.

Numerous researchers have shown that increasing plant —and thereby habitat— diversity favors the abundance and effectiveness of natural enemies. For example in cotton fields strip-cropped with alfalfa or sorghum, intensified populations of natural enemies have substantially decreased plant bugs and moth and butterfly pests. Beneficials reduced pest insects below economic threshold levels in Georgia cotton that was relay-cropped with crimson clover, eliminating the need for insecticides. In Canadian apple orchards, four to eighteen times as many pests were parasitized when wildflowers were numerous compared to when they were few. In this research, wild parsnip, wild carrot and buttercup proved essential to a number of parasitoids. In California organic vineyards, the general predators and Anagrus leafhopper egg parasites that control grape leafhoppers and thrips thrive in the presence of buckwheat and sunflowers. When these summer-blooming cover crops flower early, they allow populations of beneficials to surge ahead of those of pests. When they keep flowering throughout the growing season, they provide constant supplies of pollen, nectar and alternative prey. Mowing every other row of cover crops —an occasionally necessary practice— forces these beneficials out of the resource-rich cover crops and into vines (Andow, 1991).

In polycultures, apart from the evident increase in plant species diversity, there are changes in plant density and height, and therefore in vertical diversity. All these changes affect density of pests and other organisms. The combination of tall and short crops can also affect dispersal of insects within a cropping system. For example, in Cuba farmers grow strips of corn or sorghum every ten meters within vegetables or beans in order to provide physical barriers to reduce the dispersion of thrips *(Thrips palmi)*.

In China, researchers working with farmers in ten townships in Yumman, China, covering an area of 5350 hectares, encouraged farmers to switch from rice monocultures to planting variety mixtures of local tall rice with shorter hybrids. Tall plants provided a barrier for inoculum dispersal, but in addition enhanced genetic diversity reduced blast incidence by ninety-four percent and increased total yields by eighty-nine percent. By the end of two years, it was concluded that fungicides were no longer required.

Managing Vegetation Surrounding the Field

Hedgerows and other vegetation in field margins can serve as reservoirs for natural enemies. These habitats can be important overwintering sites for the predators of crop pests. They can also provide natural enemies with additional pollen, nectar and other resources.

Many studies have shown that beneficial arthropods do indeed move into crops from field margins, and biological control is usually more intensive in crop rows near wild vegetation than in field centers:

- In Germany, parasitism of the rape pollen beetle is about 50 percent greater at the edges of fields than in the middle.
- In Michigan, European corn borers at the outskirts of fields are more prone to parasitism by the ichneumonid wasp *Eriborus terebrans.*
- In Hawaiian sugar cane, nectar-bearing plants in field margins improve the numbers and efficiency of the sugar cane weevil parasite *Lixophaga sphenophori.*

Practical management strategies arise from understanding these relationships. A classical example comes from California, where the egg parasite Anagrus epos controls the grape leafhopper in vineyards adjacent to French prunes. The prunes harbor an economically insignificant leafhopper whose eggs provide Anagrus with its only winter food and shelter (Thies and Tscharntke, 1999).

Creating Corridors for Natural Enemies

Sowing diverse flowering plants into strips that cut across fields every 165 to 330 feet (50-100 meters) can provide natural enemies with highways of habitat. Beneficials can use these corridors to circulate and disperse into field centers.

European studies have confirmed that this practice increases the diversity and abundance of natural enemies. When sugar beet fields were drilled with corridors of tansy leaf (*Phacelia tanacetifolia*) every twenty to thirty rows, destruction of bean aphids by syrphids intensified. Similarly, strips of buckwheat and tansy leaf in Swiss cabbage fields increased populations of a small parasitic wasp that attacks the cabbage aphid. Because of its long summer flowering period, tansy leaf has also been used as a pollen source to boost syrphid populations in cereal fields. On large organic farms in California, strips of Alyssum are commonly planted every fifty to one hundred meters within lettuce and cruciferous crop fields to attract syrphid flies that control aphids.

Some grass species can be important for natural enemies. For example, they can provide temperature-moderating overwintering habitats for predaceous ground beetles. In England, researchers established «beetle banks» by sowing earth ridges with orchard grass at the centers of cereal fields. Recreating the qualities of field boundaries that favor high densities of overwintering predators, these banks particularly boosted populations of *Dometrias atricapillus* and *Tachyporus hypnorum,* two important cereal aphid predators. A 1994 study found that the natural enemies the beetle banks harbored were so cost-effective in preventing cereal aphid outbreaks that pesticide savings outweighed the labor and seed costs required to establish them. The ridges can be 1.3 feet high, 5 feet wide and 950 feet long (0.4 meters by 1.5 meters by 290 meters).

For more extended effects, it is recommended to plant corridors with longer-flowering shrubs. In northern California, researchers connected a riparian forest with the center of a large monoculture vineyard using a vegetational corridor of sixty plant species. This corridor, which included many woody and herbaceous perennials, bloomed throughout the growing season, furnishing natural enemies with a constant supply of alternative foods and breaking their strict dependence on grape-eating pests. A complex of predators entered the vineyard sooner, circulating continuously and thoroughly through the vines. The subsequent food-chain interactions enriched populations of natural enemies and curbed numbers of leafhoppers and thrips. These impacts were measured on vines as far as one hundred to one hundred fity feet (thirty to forty-five meters) from the corridor.

Selecting the Right Flowers

When choosing flowering plants to attract beneficial insects, note the size and shape of the blossoms. That's what dictates which insects will be able to access the flowers' pollen and nectar. For most beneficials, including parasitic wasps, the most helpful blossoms are small and relatively open. Plants from the aster, carrot and buckwheat families are especially useful (see Table 1 on pages 261-262).

It should also be noted when the flower produces pollen and nectar: timing is as important to natural enemies as blossom size and shape. Many beneficial insects are active only as adults and only for discrete periods during the growing season: they need pollen and nectar during these active times, particularly in the early season when prey are scarce. One of the easiest ways farmers can help is to provide them with mixtures of plants with relatively long, overlapping bloom times.

Current knowledge of which plants are the most useful sources of pollen, nectar, habitat and other critical needs is far from complete. Clearly, many plants encourage natural enemies, but scientists have much more to learn about which plants are associated with which beneficials, and how and when to make desirable plants available to target organisms. Because beneficial interactions are site-specific, geographic location and overall farm management are critical variables. In lieu of universal recommendations, which are impossible to make, farmers can discover many answers by investigating the usefulness of alternative flowering plants on their farms.

DESIGNING A HABITAT-MANAGEMENT STRATEGY

To design an effective plan for successful habitat management, first gather as much information as you can. Make a list of the most economically important pests on your farm. For each pest, try to find out:

- what are its food and habitat requirements;
- what factors influence its abundance;
- when does it enter the field and from where; what attracts it to the crop;
- how does it develop in the crop and when does it become economically damaging;

Enhancing biodiversity: A checklist for farmers

- Diversify enterprises by including more species of crops and livestock.
- Use legume-based crop rotations and mixed pastures.
- Intercrop or strip-crop annual crops where feasible.
- Mix varieties of the same crop.
- Use varieties that carry many genes—rather than just one or two—for tolerating the same disease.
- Emphasize open-pollinated crops over hybrids for their adaptability to local environments and greater genetic diversity.
- Grow cover crops in orchards, vineyards and crop fields.
- Leave strips of wild vegetation at field edges.
- Provide corridors for wildlife and beneficial insects.
- Practice agroforestry: where possible, combine trees or shrubs with crops or livestock to improve habitat continuity for natural enemies.
- Plant microclimate-modifying trees and native plants as windbreaks or hedgerows.
- Provide a source of water for birds and insects.
- Leave areas of the farm untouched as habitat for plant and animal diversity.

Key information needed in crafting a habitat management plan

1. Ecology of Pests and Beneficials

- What are the most important (economic) pests that require management?
- What are the most important predators and parasites of the pest?
- What are the primary food sources, habitat, and other ecological requirements of both pests and beneficials? (Where does the pest infest the field from, how is it attracted to the crop, and how does it develop in the crop? Where do the beneficials come from, how are they attracted to the crop, and how do they develop in the crop?)

2. Timing

- When do pest populations generally first appear and when do these populations become economically damaging?
- When do the most important predators and parasites of the pest appear?
- When do food sources (nectar, pollen, alternate hosts, and prey) for beneficials first appear? How long do they last?
- What native annuals and perennials can provide such habitat needs?

- what are its most important predators, parasites and pathogens;
- what are the primary needs of those beneficial organisms;
- where do these beneficials overwinter, when do they appear in the field, where do they come from, what attracts them to the crop, how do they develop in the crop and what keeps them in the field;
- when do the beneficials' critical resources —nectar, pollen, alternative hosts and prey— appear and how long are they available; are alternate food sources accessible nearby and at the right times; which native annuals and perennials can compensate for critical gaps in timing, especially when prey are scarce (Landis *et al.*, 2000).

Rolling Out the Strategy

This paper presents some ideas and principles for designing and implementing healthy, pest-resilient farming systems. It has been explained why reincorporating complexity and diversity is the first step towards sustainable pest management, and the paper describes the two pillars of agroecosystem health (see Figure 2 in page 230):

- fostering crop habitats that support beneficial fauna;
- developing soils rich in organic matter and microbial activity.

Well-considered and well-implemented strategies for soil and habitat management lead to diverse and abundant —although not always sufficient— populations of natural enemies. As farmers develop a healthier, more pest-resilient system for their farms they may ask themselves:

Guidelines for designing healthy and pest-resilient farming systems

- Increase species in time and space with crop rotations, polycultures, agroforestry and crop-livestock systems.
- Expand genetic diversity with variety mixtures, multilines and local germplasm.
- Conserve or introduce natural enemies and antagonists with habitat enhancement or augmentative releases.
- Boost soil biotic activity and improve soil structure with regular applications of organic matter.
- Enhance nutrient recycling with legumes and livestock.
- Maintain vegetative cover with reduced tillage, cover crops or mulches.
- Enhance landscape diversity with biological corridors, vegetationally diverse crop-field boundaries or mosaics of agroecosystems

- How can species diversity be increased to improve pest managment, compensate for pest damage and make fuller use of resources?
- How can the system's longevity be extended by including woody plants that capture and recirculate nutrients and provide more sustained support for beneficials?
- How can more organic matter be added to activate soil biology, build soil nutrition and improve soil structure?
- Finally, how can the landscape be diversified with mosaics of agroecosystems in different stages of succession and with windbreaks, living fences, etc.?

Once farmers have a thorough knowledge of the characteristics and needs of key pests and natural enemies, they are ready to begin designing a habitat-management strategy specific for their farm. Choose plants that offer multiple benefits —for example, ones that improve soil fertility, weedsuppression and pest regulation— and that don't disrupt desírvale farming practices. Avoid potential conflicts: in California, planting blackberries around vineyards boosts populations of grape leafhopper parasites but can also exacerbate populations of the blue-green sharpshooter that spreads the vinekilling Pierce's disease. In placing selected plants over space and time, use the scale-field —or landscape-level— that is most consistent with intended results. And, finally, keep it simple: the plan should be easy and inexpensive to implement and maintain, and should be easy to modify as needs change or results warrant change.

Table 1. Plants that attract beneficial insects

Beneficial	Pests	How to attract/conserve
Spider	Many insects	Carray, dill, fennel, cosmos, marigold, spearmint
Spider mite destroyer	Spider mite	Carrot family (goldenrod, yarrow) bishop's weed; maintain permanent plantings
Syrphid fly (hover flies) (Syrphidae family)	Aphid	Carrot family (Queen Anne's lace, dill, fennel, caraway, tansy, parsley, coriander, bishop' weed), the sunflower family (coreopsis, Gloriosa daisy, yarrow, cosmos, sunflower, marigolds, candytuft, sweet alyssum, ceanothus, holly-leaved cherry (*Prunnus ilicifolia*), buckwheat, scabiosa, spearmint, coyote brush (*Baccharis pilularis*, knotweed (*Polygonum aviculare*), California lilacs (*Ceanothus spp*.), soapbark tree, meadow foam (*Linnanthes douglasii*), baby-blue-eyes (*Nemophila)*.
Tachinid fly (Tachinidae family)	Cutworm, armyworm, ten caterpillar, cabbage lopper, gypsy moth, some acttack sawfly, Japanese beetle, May beetle, squash bug, green stink bug, sowbug	Carrot family (caraway, bishop's weed, coriander, dill, parsley, Queen Anne's lace, fennel) goldenrod, sweet clover, *Phacelia spp*., sweet alyssum, buckwheat, amaranth, buckthorn, *Heteromeles arbutifolia*
Tiger beetle (Cicindelidae family)	Many insects	Maintain permanent plantings and some exposed dirt or sand areas
Minute Pirate Bug (Anthocoridae family), (*Orius spp)*	Thrips, spider mite, leafhopper, corn earworm, small caterpillars, many other insects	Effective predators of corn earworm eggs. Carrot family (Queen Anne's lace, tansy, coriander, bishop's weed, chervil), sunflower family (cosmos, tidy tips (*Layia*), goldenrod, daisies, yarrow), baby-blue-eyes (*Nemophila*), hairy vetch, alfalfa, corn, crimson clover, buckwheat, blue elderberry (*Sambucus caerulea*), willows, shrubs. Maintain permanent plantings or hedgerows
Parasitic nematodes	Nematodes	Marigolds, chrysanthemum, gaillardia, helenium, *Eriophyllus lanatum*, horseweed (*Conyza canadensis*), hairy indigo, castor bean, *Crotalaria spp*., *Desmodium spp*., sesbania, mexicantea (*Chenopodium ambrosioides*), shattercane (*Sorghum bicolor*), lupines, *Phaseolus atropurpurens*
Praying mantis (*Mantis* spp)	Any insect	Cosmos, brambles. Protect native species by avoiding pesticides
Predatory mites (*Typhlodromus* spp)	Spider mite	There are many species of predatory mites with ecological requirements; especially with respect to humidity and temperature, particular to the species. Avoid use of insecticides. Provide beneficial refugia for non-crop habitat of non-crop mite prey.
Predatory thrips (Thripidae family)	Spider mites, aphid, other thrips, Oriental fruit moth, codling moth, bud moth, peach twig borer, alfalfa weevil, whitefly, leafminer, scale	There are several of predatory thrips. Predatory thrips populations may be conserved/maintained by having non-crop populations of plant-feeding mites (e.g. European red mite, two-spotted spider mite), scales, aphids, moth eggs, leafhoppers and other thrips
Rove beetle (Staphylinidae family)	Aphid, springtail, nematodes, flies; some are parasitic on cabbage-root maggot	Permanent plantings; interplant strips of rye, grains, and cover crops; much beds; make stone or plant walkways in garden to provide refuges.

Table 1. Plants that attract beneficial insects (continued)

Beneficial	Pests	How to attract/conserve
Aphid midge (*Aphidoletes aphidimyza*) (Larvae are aphid predators)	Aphid	Dill, ustard, thyme, sweet clover, shelter garden from strong winds; provide water in a pan filled with gravel
Aphid parasites (*Aphidius matricariae* and	Aphid	Nectar-rich plants with small flowers (anise, caraway, dill, parsley, mustard family, white clover, Queen Anne's lace, yarrow)
Assasing bug (Reduviidae family)	Many insects, including flies, tomato hormworm, large caterpillars	Permanet plantings for shelter (.g. hedgerows)
Bigeyed bugs (*Geocoris* spp) (Lyagaidae family)	Many insects, including other bugs, flea beetles, spider mites, insect eggs and small caterpillars will also eat seeds	Can build up in cool-season cover crops such a berseem clover (*Trifolium alexandrium*) and subterranean clovers (*Trifolium subterraneum*). Can be found on common knotweed (*Polygonum aviculare*)
Braconid wasp (Braconidae family)	Armyworm, cabbage worm, colding moth, gypsy moth, European corn borer, beetle larvae, flies, aphid, caterpillars, other insects	Nectar plants with small flowers (caraway, dill, parsley Queen Anne's lace, fennel, mustard, white clover, tansy, yarrow), sunflower, hairy vetch, buckwheat, cowpea, common knotweed, crocuses, spearmint)
Damsel bug (Nabidae family)	Aphid, thrips, leafhoppers, treehopper, small caterpillars	Anything in the sunflower family as well as goldenrod, yarrow alfalfa.
Ground beetle (Carabidae family)	Slug, snail, cutworm, cabbage-root-maggot; some prey on Colorado potato beetle, gypsy moth and ten caterpillar	Permanent plantings, amaranth; white clover in orchards, mulching.
Lacewing (Neuroptera family) (*Chrysoperla* and *Chrysopa*	Soft-bodied insects including aphid, thrips, mealybug, scale, caterpillars, mite	Carrot family (caraway, Queen Anne's lace, tansy, dill, angelica), sunflower family (coreopsis, cosmos, sunflowers, dandelion, goldenrod), buckwheat, corn, holly leaf cherry (*Prunus ilicifolia*), flowering bottle tree (*Brachychiton populneum*), soapbark tree (*Quillaja saponaria*). Provide water during dry spells
Lady beetle or ladybug (*Hippodamia* spp and others) (Coccinellidae family)	Aphid, mealybug, spider mite, soft scales	Once aphids leave a crop, lady beetles will also. To retain active lady beetles, maintain cover crops or other hosts of aphids or alternative prey. Carrot family (fennel, angelica, dill, tansy, bishop's weed (*Ammi*), Queen Anne's lace), sunflower family (goldenrod, coreopsis, cosmos, golden marguerite (*Anthemis*), dandelion, sunflower, yarrow), crimson clover, hairy vetch, grains and native grasses, butterfly weed (*Asclepias*), black locust, buckwheat, euonymus rye, hemp sesbania (*Sesbania exaltata*), soapbark tree, buckthorn (*Rhamnus*), saltbush (*Atriplex* spp.), black locust (*Robinia pseudoacacia*).
Mealybug destroyer (*Cryptolaemus montrouzieri*) (Coccinellidae family)	Mealybug	Carrot family (fennel, dill, angelica, tansy), sunflower family (goldenrod, coreopsis, sunflower, yarrow)

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Chapter 11

Chapter 11

Agroecology: Transitioning Organic Agriculture Beyond Input Substitution

Organic farming is a production system whose objective is to sustain agricultural productivity by avoiding or largely excluding synthetic fertilizers and pesticides. The original philosophy that guided organic farming emphasized the use of resources found on or near the farm. These internal/local resources include solar or wind energy, biological pest controls, and biologically fixed nitrogen and other nutrients released from organic matter or from soil reserves. The idea was to rely heavily on the use of crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes and aspects of biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to regulate insect pests, weeds, and diseases. Original adherents to the movement were typical small and/or family farmers, growing diverse enterprises for the local markets, who saw farming as a way of community life closely linked to the rhythms of nature.

Thanks to the pioneering efforts of these farmers and the advocacy work of many organic agriculture promoters, organic farming is now widespread throughout the world and is growing rapidly. Today there are about 23 million hectares of land under organic management, of which 10,6 million has and 3.2 million ha are in Australia and Argentina respectively, mostly devoted to extensive grazing land. More then 4 million hectares are under certified organic farming in Europe. In Italy alone there are about 56,000 organic farms occupying 1.2 million hectares. In Germany alone there are about 8,000 organic farms occupying about 2 percent of the total arable land. In Italy organic farms number around 18,000 and in Austria about 20,000 organic farms account for 10 percent of total agricultural output. In Latin America, organic farming accounts for 0.5% of the total agricultural land, about 4.7 million hectares. In North America about 1.5 million hectares are certified organic (45,000 organic farms) occupying 0.25% of the total agricultural landin. In the USA the organic acreage doubled between l992 and l997 and in 1999 the retail organic produce industry generated US $6 billion in profit. In California organic foods are one of the fastest-growing segments of the agricultural economy, with retail sales growing at 20-25 percent per year for the past six years. But are these new organic farmers and associated industry following the original precepts of the pioneers? Or is organic farming being incorporated into the systems of intensified production, finance, management and distribution typical of conventional agriculture? Is organic agriculture replicating the conventional model that it so fiercely opposed?

Realities Working Against Organic Farming

There is no question that demands for organic food is increasing, but seems confined to the rich and especially to populations of the industrialized world. As Third World countries enter the organic market, production is mostly for export and thus contributing very little to the food security of poor nations. As organic products are increasingly traded as international commodities, their distribution is slowly being taken over by the same multinational corporations that dominate conventional agriculture. Locally owned natural food stores and organic brands are becoming consolidated into national/ international chains.

It is possible that some of the above problems could have been minimized if the organic movement have not disregarded three important factors that now have come back to haunt them:

The Size of Farms to be Certified: By not limiting the maximum amount of land that a particular farmer or company could certify as organic, it has allowed big corporations to join the fad, displacing small organic farmers. In California, over half the value of organic production was represented by 2% of the growers who grossed over US $500,000 each; growers grossing $10,000 or less comprised 75% of all growers and only 5% of the sales.

The consolidation of multiple farms, packing plants, and regional hubs under a single corporation requires the adoption of conventional big business practices. This system is excellent for consolidating wealth and power at the apex of a pyramid, but it is antithetical to the goals of community and local control that were part of the original inspiration of the organic movement.

Inappropriate certification standards: The movement was quick to develop rules that sought to standardize practices that inevitably vary by farm or region. The high variability of ecological processes and their interactions with heterogeneous social, cultural, political, and economic factors generate local organic systems that are unique. When the heterogeneity of these systems is considered, the inappropriateness of standardized technological recipes or blueprints becomes obvious. Many guidelines proved unworkable for some farmers for technical reasons. Some farmers were offended at being told to alter their on-site proven methods, especially when they saw only higher costs as a result. Such standardization process proved particularly culturally and economically inappropriate to small farmers in the developing world whose farming rationale is rooted in biodiversity and traditional knowledge. In fact, many people in the south perceive organic standards as an imposition and as a form of protectionism from the north.

Ironically, organic standards are now under threat, and as organic standards erode, a false perception of organic integrity will be created through advertising and political control of regulatory agencies as is already happening in the USA. As a consequence, many farmers are opting out, and together with consumers, many are creating their own standards and certification procedures as well as more locally-centred marketing strategies.

Social standards: Most certification protocols did not include social criteria. For this reason, today in California, it is possible to buy organic produce that may be environmentally produced, but at the expense of the exploitation of farm-workers. There are no major differences in living conditions, labor practices or pay for a farm-worker working in an organic *versus* a conventional farm operation. Might this be a reason why for example, in California, the United Farmworkers have not wholeheartedly endorsed organic farming? There is no question that organic agriculture must be both ecologically and socially sustainable. For this to happen, organic techniques must be embedded in a social organization that furthers the underlying values of ecological sustainability. Ignoring the complex social issues surrounding commercial and export-oriented organic agriculture is to undermine the original agrarian vision of organic farming.

Input Substitution

Structurally and functionally speaking, large-scale commercial organic farms do not differ substantially from conventional farms. The most important difference is that organic farmers avoid the use of chemical fertilizers and pesticides in their farming operations, while conventional farmers may use them extensively. However, a large number of organic farmers do use modern machinery and commercial crop varieties and adopt monocultures. Due to their inherent low levels of functional biodiversity, these simplified systems lack natural regulatory mechanisms and therefore are highly dependent on external (organic/biological) inputs to subsidize functions of pest control and soil fertility. Adopting such practices and leaving the monoculture intact does little to move towards a more productive redesign of farming systems. Farmers following this regime are trapped in an input substitution process that keeps them dependent on suppliers (many of a corporate nature) of a variety of organic inputs, some of questionable effectiveness and environmental soundness. Clearly, as it stands today, «input substitution» has lost its «pro-sustainability» potential. It is precisely the heavy use of these inputs that has been the target of organic farming detractors (the biotech industry) who accuse organic farmers of promoting insect resistance due to continual use of Bt sprays, of contaminating soil and water with copper sulphate and eliminating beneficial insects with rothenone and other non selective botanical insecticides.

It is important however to emphasize that only a minority of organic farmers follow the input substitution model, but these are the ones that control large tracts of land and amass much capital. Most small and medium size farmers still feature legume-based rotations, use of compost and a series of diversified cropping systems such as cover crops or strip cropping, including crop-livestock mixtures. Research shows that these systems exhibit acceptable yields, conserve energy, and protect the soil while inducing minimal environmental impact. A recent study in Washington State revealed that organic apple orchards gave similar apple yields than conventional and integrated orchards. Moreover, the organic system ranked first in environmental and economic sustainability as this system exhibited higher profitability, greater energy efficiency and lower negative environmental impact. Despite the benefits, such farming systems can still improve if guided by agroecological principles.

Agroecological Conversion

The monoculture nature of organic farms can be transcended by adopting diversification schemes that feature optimal crop/animal assemblages which encourage synergisms. So the agroecosystem may foster its own soil fertility, natural pest regulation and crop productivity through maximizing nutrient recycling, organic matter accumulation, biological control of pests and constancy of production.

Promotion of biodiversity within agricultural systems is the cornerstone strategy of the system-redesign, as research has demonstrated that:

- Higher diversity (genetic, taxonomic, structural, resource) within the cropping system leads to higher diversity in associated biota.
- Increased biodiversity leads to more effective pest control and pollination.
- Increased biodiversity leads to tighter nutrient cycling.
- Increased biodiversity minimizes risks and stabilizes productivity.

Using agroecological principles to improve farm performance can be implemented through various techniques and strategies. Each of these will have different effects on productivity, stability and resiliency within the farming system, depending on local opportunities, resource constraints, and, in most cases, on the market. The ultimate goal of agroecological design is to integrate components so that overall biological efficiency is improved, biodiversity is preserved, and agroecosystem productivity and its self-sustaining capacity are maintained.

The key challenge for the 21st century organic farmers is to translate ecological principles into practical alternative systems to suit the specific needs of farming communities in different ecoregions of the world. There are already numerous examples, according to researchers at the University of Essex who examined 208 agroecological projects implemented in the developing world, about 9 million farming households covering about 29 million hectares have adopted sustainable agricultural systems. A major strategy followed by these farmers was to restore agricultural diversity by following key agroecological guidelines. Some examples are given below.

Increase Species Diversity Through Intercropping

In Africa, scientists developed an intercropping system using two kinds of crops that are planted together with maize: a plant that repels borers (the push) and another that attracts (pulls) them. The push-pull system has been tested on over 450 farms in two districts of Kenya and has now been released for uptake by the national extension systems in East Africa. Participating farmers in the breadbasket of Trans Nzoia are reporting a 15-20% increase in maize yield. In the semi-arid Suba district plagued by both stemborers and striga, a substantial increase in milk yield has occurred in the last four years, with farmers now being able to support grade cows on the fodder produced. When farmers plant maize, napier and desmodium together, a return of US $2.30 for every dollar invested is made, as compared to only $1.40 obtained by planting maize as a monocrop. Two of the most useful trap crops that pull in the borers' natural enemies are napier grass (*Pennisetum purpureum*) and Sudan grass (*Sorghum vulgare sudanese*), both important fodder plants; these are planted in a border around the maize. Two excellent borer-repelling crops which are planted between the rows of maize are molasses grass (*Melinis minutifolia*), which also repels ticks, and the leguminous silverleaf (*Desmodium*). This plant can also suppress the parasitic weed *Striga* by a factor of 40 compared to maize monocrops; its N-fixing ability increases soil fertility; and it is an excellent forage. As an added bonus, sale of *Desmodium* seed is proving to be a new income-generating opportunity for women in the project areas.

Using Flowers and Other Vegetation in Annual Cropping Systems to Enhance Habitat for Natural Enemies

Several researchers have introduced flowering plants as strips within crops as a way to enhance the availability of pollen and nectar, necessary for optimal reproduction, fecundity and longevity of many natural enemies of pests. Phacelia tanacetifolia strips have been used in wheat, sugar beets and cabbage, leading to enhanced abundance of aphid-eating predators especially syrphid flies, and reduced aphid populations. In England, researchers created «beetle banks» sown with perennial grasses such as Dactylis glomerata and Holcus lanatus in an attempt to provide suitable over-wintering habitat within fields for aphid predators. When these banks run parallel with the crop rows, great enhancement of predators (up to 1,500 beetles per square meter) can be achieved in only two years.

Diversifying Perennial Systems with Agroforestry Designs Including the Use of Cover Crops in Vineyards and Orchards

In such systems, the presence of a flowering undergrowth enhances the biological control of a series of insect pests. The beneficial role of *Phacelia flowers* to enhance parasitism of key pests in apple orchards was well demonstrated by Russian and Canadian researchers more than 30 years ago. In Californian organic vineyards, the incorporation of flowering summer cover crops (buckwheat and sunflower) leads to enhanced populations of natural enemies, which in turn reduced the numbers of leafhoppers and thrips.

Increasing genetic Diversity through Variety Mixtures, Multilines and Use of Local Germplasm and Varieties Exhibiting Horizontal Resistance

Researchers working with farmers in ten townships in Yumman, China, covering an area of 5,350 hectares, encouraged farmers to switch from rice monocultures to planting variety mixtures of local rice with hybrids. This enhanced genetic diversity reduced blast incidence by 94% and increased total yields by 89%. By the end of two years, it was concluded that fungicides were no longer required.

Intensifying Use of Green Manures for Regenerating Soil Fertility and Soil Conservation

In Central America, about 45,000 families using velvet bean tripled maize yields while conserving and regenerating soil in steep hillsides. In southern Brazil, no less than 50 thousand farmers use a mixture of cover crops that provide a thick mulch, allowing grain production under no-till conditions but without dependence on herbicides.

Enhancing Landscape Diversity with Biological Corridors, Vegetationally Diverse Crop-Field Boundaries or by Creating a Mosaic of Agroecosystems and Maintaining Areas of Natural or Secondary Vegetation as Part of the Agroecosystem Matrix

Several entomologists have concluded that the abundance and diversity of predators and parasite within a field are closely related to the nature of the vegetation in the field margins. There is wide acceptance of the importance of field margins as reservoirs of the natural enemies of crop pests. Many studies have demonstrated increased abundance of natural enemies and more effective biological control where crops are bordered by wild vegetation that natural enemies colonize. Parasitism of the armyworm, *Pseudaletia unipunctata*, was significantly higher in maize fields embedded in a complex landscape than in maize fields surrounded by simpler habitats. In a two year study, researchers found higher parasitism of *Ostrinia nubilalis* larvae by the parasitoid *Eriborus terebrans* in edges of maize fields adjacent to wooded areas, than in field interiors. Similarly, in Germany, parasitism of rape pollen beetle was about 50% at the edge of the fields, dropping significantly to 20% at the center of the fields.

One way to introduce the beneficial biodiversity from surrounding landscapes into large-scale monocultures is by establishing vegetationally diverse corridors that allow the movement and distribution of useful arthropod biodiversity into the centre of monocultures. Researchers in California established a vegetation corridor that connected to a riparian forest and cut across a vineyard monoculture. The corridor allowed natural enemies emerging from the riparian forest to disperse over large areas of otherwise monoculture vineyard systems. The corridor *provided a constant supply of alternative food for predators effectively decoupling predators from a strict* dependence on grape herbivores and avoiding a delayed colonization of the vineyard. This complex of predators continuously circulated into the vineyard interstices, establishing trophic interactions that enriched natural enemies, which in turn led to lower numbers of leafhoppers and thrips on vines located up to 30-40 m from the corridor.

Moving Ahead

A key agroecological strategy to move farms beyond organic is to exploit the complementarity and synergy that result from the various combinations of crops, trees, and animals in agroecosystems that feature spatial and temporal arrangements such as polycultures, agroforestry systems and crop-livestock mixtures. In real situations, the exploitation of these interactions involves farming system design and management and requires an understanding of the numerous relationships among soils, microorganisms, plants, insect herbivores, and natural enemies. But such modifications are not enough to achieve sustainability as it is clear that the livelihood of farmers and the food security of communities is a much more complex problem determined by economic, social and political factors. How can organic farmers produce enough food in ecologically, environmentally and socially sustainable ways without adopting a specialized industrial model of production and distribution? How can advocates of organic farming promote an agriculture that is local, small-scale and family operated, biologically and culturally diverse, humane, and socially just? Is it possible to replace the industrial agriculture model with a new vision of farming deeply rooted in the original precepts of organic agriculture?

Surely, technological or environmental intentions are not enough to disseminate a more agroecologically-based agriculture. There are many factors that constrain the implementation of sustainable agriculture initiatives. Major changes must be made in policies, institutions, markets and research and development agendas to make sure that agroecological alternatives are adopted, made equitably and broadly accessible, and multiplied so that their full benefit for sustainable food security can be realized. It must be recognized that major constraints to the spread of truly sustainable form of farming are the powerful economic and institutional interests that are trying to de-rail and control the organic industry and its regulations.

The evidence shows that throughout the world, there are many organic agricultural systems that are economically, environmentally and socially viable, and contribute positively to local livelihoods. But without appropriate policy and consumers support, they are likely to remain localized in extent. Therefore, a major challenge for the future entails promoting institutional and policy changes to realize the full potential of a truly organic approach. Necessary changes include the following:

- Increase public investments in agroecological research methods with active participation of organic farmers, thus replacing top-down transfer of standardized technology model with participatory technology development and farmer-centred research and extension, emphasizing principles rather than recipes or technological packages.
- Changes in policies to stop subsidies of conventional technologies and to provide support and incentives for agroecological approaches.
- Appropriate equitable market opportunities including fair market access and expand local farmers markets and CSAs (Community Supported Agriculture or subscription farming) with pricing systems accessible to all.
- Create policies that intervene in the market by opening opportunities for local organic producers (i.e. ordinances that mandate all food served in school and university cafeterias should be organic).
- Democratize and provide flexibility to the certification process, encouraging emergence of solidarious (no-cost certification, based on mutual trust) locally adapted certification.
- Include farm size and social-labour considerations in organic standards, and limit certification against operations that leave a large ecological footprint.

In summary, major changes must be made in policies, institutions, markets and research to scale-up organic agriculture. Existing subsidies and policy incentives for conventional chemical approaches must be dismantled. Corporate control over the food system, including the organic industry must also be challenged. The strengthening of local institutional capacity and widening access of farmers to support services that facilitate use of accessible technologies will be critical. Governments and international public organizations must encourage and support effective partnerships between NGOs, local universities, and farmer organizations in order to assist and empower organic farmers to achieve success. There is also need to increase rural incomes through local and equitable market opportunities emphasizing fair trade and other mechanisms that link farmers and consumers more directly. The ultimate challenge is to scale-up forms of organic agriculture that are socially equitable, economically viable and environmentally sound. For this to happen, the organic movement will have to engage in strategic alliances with peasant, consumer and labour groups around the world and with the anti-globalization movement. It also needs to secure political representation at local-regional and national levels so that the political will is present in municipal or state governments to implement and expand the goals of a truly sustainable organic agriculture.

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Chapter 12

Chapter 12

A Rapid, Farmer-Friendly Agroecological Method to Estimate Soil Quality and Crop Health in Vineyard Systems

Introduction

One of the reasons why many vineyard farmers decide to convert from a conventional monoculture system to a more diversified organic system is to achieve stable production without dependence on external inputs, thus lowering production costs while maintaining and/or enhancing the natural resources of the farm, such as soil, water and biodiversity (Thrupp, 2003). On the other hand, the main goal of researchers involved in the development and promotion of organic vine management techniques is to design agroecosystems that exhibit high resilience to pests and diseases, good recycling and nutrient retention capacities, and high biodiversity levels (Altieri, 1995; Gliessman, 1998). A more diversified system (usually vines with cover crops) with a biologically active and organic rich soil, may be considered a non-degrading, robust and productive system (Ingels et al 1998). In other words, a vineyard rich in biodiversity, exhibiting a series of biotic interactions and synergisms, which in turn subsidize soil fertility, plant protection, and productivity, is said to be *sustainable and healthy* (Locke, 2001).

One of the challenges that farmers and extentionists face involves knowing when an agroecosystem is healthy, or better yet, knowing how healthy the system is after the conversion towards agroecological management has been initiated. Various researchers working in sustainable agriculture have designed a set of *sustainability indicators* to assess the condition of particular agroecosystems. Unfortunately, few of the proposed methods are farmer-friendly (Gomez *et al.,* 1996; Masera *et al.,* 1999). The few practical methods available offer a set of proposed indicators consisting of observations or measurements that are done at the farm level to assess soil fertility and level of degradation and whether crop plants are healthy, strong and productive. In other words, the proposed indicators are used to *check the pulse* of the agroecosystem.

In this article we describe a practical methodology to rapidly assess the soil quality and crop health of vineyard systems using simple indicators. Although the indicators are specific to wine grapes in northern California, with some modifications this methodology is applicable to a broad range of agroecosystems in various regions. The indicators described herein were selected because:

- they are easy to use by farmers;
- they are relatively precise and easy to interpret;
- they are practical for making new management decisions;
- they are sensitive enough to reflect environmental changes and the effects of management practices on the soil and the crop;
- they possess the capability of integrating physical, chemical and biological properties of the soil;
- they can relate to ecosystem processes, for example the relationship between plant diversity and pest population stability and/or disease incidence (Altieri, 1994).

There is no doubt that most viticulturalists possess their own indicators to estimate soil quality or the health condition of their crop. For example, some farmers recognize some weeds as indicative of certain soil conditions (i.e. as growing only on acidic or non-fertile soils). Other indicators of quality or health may be the presence of earthworms, signaling a living soil, or the color of the leaves, reflecting the nutritional status of the plants. In northern California, it is possible to compile a long list of local indicators used by farmers. The problem with many of the indicators is that they are site-specific and may vary according to the knowledge of the farmers or the conditions of each farm. It is difficult to make comparisons between farms if the analysis is based on results derived from sitespecific indicators interpreted in various ways by farmers.

In order to overcome this limitation, we selected qualitative indicators of soil and crop health which are relevant to farmers and the biophysical conditions of vineyards typical of Sonoma and Napa counties. With these already well-defined indicators, the procedure to measure the sustainability is the same from site to site, and independent of the diversity of situations found in the different farms on the studied region. *Sustainability* is defined as a group of agroecological requisites that must be satisfied by any farm, independent of management, economic level, or landscape position. As all the measurements made are based on the same indicators, the results are comparable and it is possible to follow the evolution of the same agroecosystem along a timeline, or make comparisons between farms in various transitional stages. Most importantly, once the indicators are applied, each farmer can visualize the conditions of his or her farm, noticing which of the soil or plant attributes are sufficient or deficient compared to a pre-established threshold. When the methodology is applied to various farms simultaneously, it is possible to visualize which farms exhibit low or high values of sustainability. This is useful for farmers as it allows them to understand why some farms perform ecologically better than others. It also helps to stimulate thinking about management modifications that may improve the functioning of farms exhibiting lower values.

Sustainability Indicators

The indicators were initially discussed with professional viticulturists and farmers at a field workshop organized by the Napa Sustainable Winegrowing Group in the summer of 2002, and later validated on two farms (Benziger Vineyards and Cain Vineyards) by the authors of this article in collaboration with respective vineyard managers. Once the desired sustainability requirements were defined by the participants, ten soil quality and ten crop health indicators that best reflected the discussion were selected (see Table 1).

Table 1. Soil quality and crop health indicators in grape systems, with corresponding characteristics and values (values between 1 and 10 can be assigned to each indicator).

Indicators of soil quality	Established value	Characteristics
Structure	1	Loose, powdery soil without visible aggregates
	5	Few aggregates that break with little pressure
	10	Well-formed aggregates – difficult to break
Compaction	1	Compacted soil, flag bends readily
	5	Thin compacted layer, some restrictions to a penetrating wire
	10	No compaction, flag can penetrate all the way into the soil
Soil depth	1	Exposed subsoil
	5	Thin superficial soil
	10	Superficial soil (> 10 cm)
Status of residues	1	Slowly decomposing organic residues
	5	Presence of last year's decomposing residues
	10	Residues in various stages of decomposition, most residues well-decomposed
Color, odor, and organic matter	1	Pale, chemical odor, and no presence of humus
	5	Light brown, odorless, and some presence of humus
	10	Dark brown, fresh odor, and abundant humus
Water retention (moisture level after irrigation or rain)	1	Dry soil, does not hold water
	5	Limited moisture level available for short time
	10	Reasonable moisture level for a reasonable period of time
Soil cover	1	Bare soil
	5	Less than 50% soil covered by residues or live cover
	10	More than 50% soil covered by residues or live cover
Erosion	1	Severe erosion, presence of small gullies
	5	Evident, but low erosion signs
	10	No visible signs of erosion
Presence of invertebrates	1	No signs of invertebrate presence or activity
	5	A few earthworms and arthropods present
	10	Abundant presence of invertebrate organisms
Microbiological activity	1	Very little effervescence after application of water peroxide
	5	Light to medium effervescence
	10	Abundant effervescence

Table 1 (continued). Soil quality and crop health indicators in grape systems, with corresponding characteristics and values (values between 1 and 10 can be assigned to each indicator).

Indicators of crop health	Established value	Characteristics
Appearance	1	Chlorotic, discolored foliage with deficiency signs
	5	Light green foliage with some discoloring
	10	Dark green foliage, no signs of deficiency
Crop growth	1	Uneven stand; short and thin branches; limited new growth
	5	Denser. but not uniform stand; thicker branches; some new growth
	10	Abundant branches and foliage; vigorous growth
Disease incidence	1	Susceptible, more than 50% of plants with damaged leaves and/or fruits
	5	Between 25–45% plants with damage
	10	Resistant, with less than 20% of plants with light damage
Insect pest incidence	1	More than 15 leafhopper nymphs per leaf, or more than 85% damaged leaves
	5	Between 5–14 leafhopper nymphs per leaf, or 30–40% damaged leaves
	10	Less than 5 leafhopper nymphs per leaf, and less than 30% damaged leave
Natural enemy abundance and diversity	1	No presence of predators/parasitic wasps detected in 50 random leaf sampled
	5	At least one individual of one or two beneficial species
	10	At least two individuals of one or two beneficial species
	1	Crops stressed, overwhelmed by weeds
Weed competition and pressure	5	Medium presence of weeds, some level of competition
	10	Vigorous crop, overcomes weeds
Actual or potential yield	1	Low in relation to local average
	5	Medium, acceptable
	10	Good or high
Vegetational diversity	1	Monoculture
	5	A few weeds present or uneven cover crop
	10	With dense cover crop or weedy background
Natural surrounding vegetation	1	Surrounded by other crops, no natural vegetation
	5	Adjacent to natural vegetation on at least one side
	10	Surrounded by natural vegetation on at least two sides
Management system	1	Conventional
	5	In transition to organic with IPM or input substitution
	10	Organic, diversified with low external biological inputs

Each indicator is valued separately and assigned with a value between 1 and 10, according to the attributes observed in the soil or crop (1 being the least desirable value, 5 a moderate or threshold value and 10 the most preferred value). For instance, in the case of the soil structure indicator, a value of 1 is given to a dusty soil, without visible aggregates;

a value of 5 to a soil with some granular structure whose aggregates are easily broken under soft finger pressure; and a value of 10 to a well-structured soil whose aggregates maintain a fixed shape even after exerting soft pressure (Burket *et al*.,1998). Values between 1 to 5 and 5 to 10 can also be assigned accordingly. When an indicator is not applicable for the particular situation, it is simply not measured or if possible, replaced by another indicator the farmer and researcher deem more relevant.

As the user gets more familiar with the methodology, the observations become more accurate and can be refined using additional, but simple instruments. For example, in the case of soil quality indicator 2 (compaction) a wire flag is pushed vertically into the soil at various locations in the field, and users record the depth at which it bends due to resistance in the soil. In the case of soil quality indicators 9 and 10 (relating to earthworms and biological activity), users may apply small amounts of water peroxide to a soil sample to observe its effervescence (amount of bubbles produced). If there is little or no effervescence, this usually indicates a soil with little organic matter and poor microbial activity. When there is significant effervescence, the soil is usually rich in organic matter and microbial life (USDA-NRCS, 1998).

The crop health indicators refer to the appearance of the crop, the level of pest and disease incidence, tolerance to weeds, growth of the crop, and potential yield. Insect pest densities are determined and in the case of grape leafhoppers, obtained values are interpreted based on known thresholds (Flaherty, 1992). A value is then assigned to crop health indicator 4 (insect pest incidence). The observations on plant diversity levels (number of cover crop and weed species), diversity of surrounding natural vegetation, and system management types (i.e. organic system in conversion with many or few external inputs) are conducted to evaluate the ecological infrastructure of the vineyard. The assumption is that a vineyard under a diversified management, with low external inputs, and diverse vegetation margins, should benefit by the synergies of biodiversity and thus exhibit a higher level of sustainability (Altieri and Nicholls, 2003).

Once the values are assigned to the indicators they are added and divided by the number of measured indicators. A mean value for soil quality and another for crop health is recorded. Farms with an overall value lower than 5 in soil quality and/or crop health are considered *below the sustainability threshold,* and rectifying measures should be taken to improve the low indicators on these farms.

The indicators are more easily observed by using an *amoeba*-type graph as it allows one to visualize the general status of soil quality and crop health, considering that the closer the amoeba approaches the full diameter length of the circle the more sustainable the system (a 10 value). The amoeba shows which indicators are weak (below 5) allowing farmers to prioritize the agroecological interventions necessary to correct soil, crop or system deficiencies. At times it may be possible to correct a set of deficiencies just by intervening on one specific attribute. For instance, increasing the species diversity or the soil organic matter will in turn affect other system attributes. By adding organic matter one is increasing the soil's water carrying capacity, augmenting soil biological activity, and improving soil structure.

The average values of various farms can be plotted, allowing researchers and farmers to visualize how each farm fares in relation to the threshold level (5) of soil quality and crop health (Figure 1). This graph clearly depicts the "above-average" farms, which may be considered *agroecological lighthouses.* The idea here is not for farmers to copy the techniques that *lighthouse farmers* use, but rather to emulate the processes, synergisms and interactions that emerge from the ecological infrastructure of the lighthouse farm, which are assumed to determine the successful performance of such systems in terms of soil quality and crop health. Simply copying the practices used by successful farmers does not work for diffusing principles underlying the performance of lighthouse farms. Agroecological performance is linked to processes optimized by diversified systems and not to specific techniques (Altieri, 1995). The synergy associated with diverse vineyards makes it difficult to evaluate individual practices (i.e. one or two cover crop mixes) effectively, because experimental tests of individual practices or subsets of practices are unlikely to reveal the true potential of a complex vineyard system. A more productive line of research is to understand the processes and mechanisms at play in successful systems, and indicators provide guidance in this direction.

It may be that in a *lighthouse farm* the key is high soil biological activity or live soil cover, but this does not mean that the neighboring farmers have to use the same type of compost or cover as the *lighthouse*

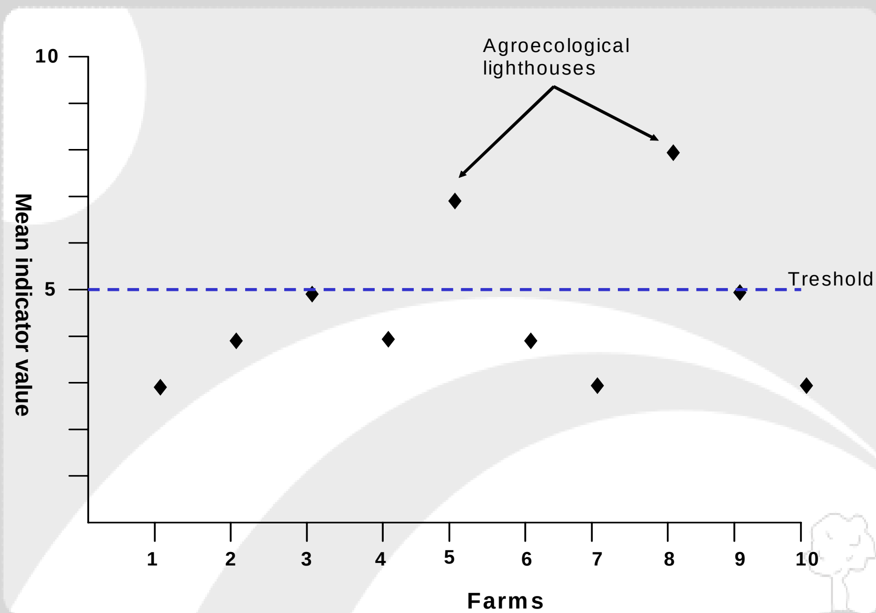

Figure 1. Hypothetical comparison of combined averages of soil and crop health indicators in several vineyards in Napa and Sonoma counties, featuring farms exhibiting high indicators values (agroecological lighthouses).

farmer; rather they should use techniques that are within their reach but which optimize the same key processes operating in the lighthouse farm.

Case studies

In September of 2003 our group visited Benziger vineyard, near Sonoma, for a four-hour period. The group applied the methodology to assess the soil quality and crop health indicators in two Cabernet Sauvignon blocks of the farm. The vineyard is managed using biodynamic methods of production, which emphasize cover cropping in the fall and winter and the use of a series of eight herbal-based preparations applied to the soil to promote soil health and vitality (www.benziger.com). This farm system exhibited an average value of 5.3 for soil quality and 7.4 for crop health (see Table 2).

Table 2. Assigned soil quality and crop health indicator values in an organic-biodynamic vineyard (Benziger) and a transitional vineyard (Cain) in northern California

	Indicators	Benziger vineyard (organic/biodynamic)	Cain vineyard (in transition)
Soil quality	Structure	7	3.5
	Compaction	7	5
	Soil depth	6	5
	Status of residues	6	5.5
	Color, odor, and organic matter	5	6
	Water retention (moisture level)	5	6
	Soil cover	5	7
	Erosion	8.5	10
	Invertebrate presence	1	4
	Microbiological activity	2.5	5
	Average of soil quality	**5.3**	**5.7**
Crop health	Appearance	8.5	6.5
	Crop growth	8.5	8
	Disiease incidence	9	10
	Insect pest balance	9.5	10
	Natural enemy abundance & diversity	1.5	2
	Weed competition & pressure	9	10
	Actual or potential yield	8	6
	Vegetational diversity	4	3.5
	Natural surrounding vegetation	9	8
	Management system	7	4
	Average of crop health	**7.4**	**6.8**

In the afternoon of the same day, the group assessed the indicators in Cain vineyards, located uphill from St. Helena, Napa. This eighty-four-acre terraced farm is under transition to organic management, and is located between 450- 750 meters above the sea level (www.cainfive.com). Cover crop residues are left in the field during the summer. Average soil quality reached a value of 5.7 and 6.8 for plant health. Table 2 presents the assigned values of all twenty indicators on both farms. Average values for soil quality and plant health observed in the two vineyards are quite similar.

The amoeba for soil quality (Figure 2) allows one to compare all relevant indicators on both farms, showing that the biodynamic farm

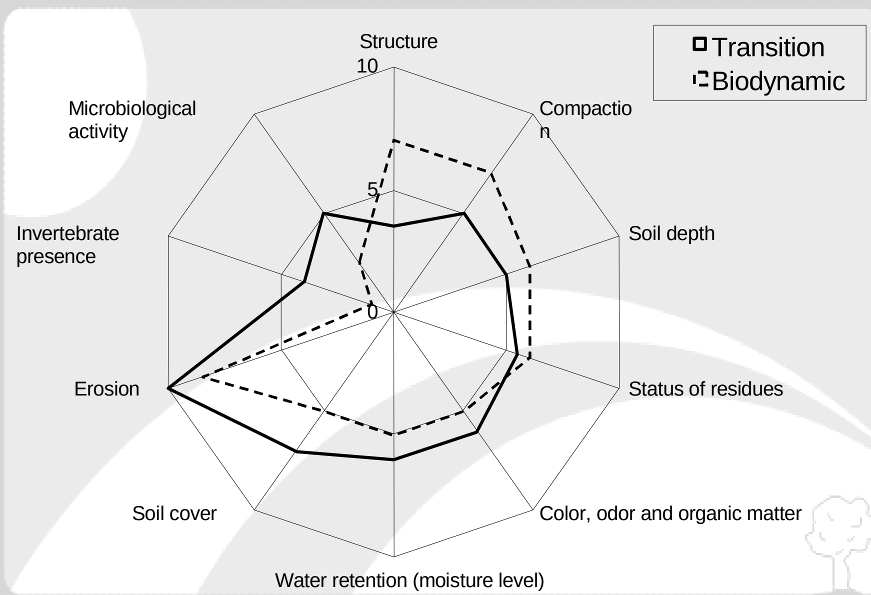

Figure 2. Amoeba representing the soil quality status of two vineyards systems (Cain – transition and Benziger – biodynamic) in northern California.

exhibits better soil quality values for structure, compaction, status of residues, and soil depth, while the transition farm exhibits higher values for biological activity, soil cover, water retention, and organic matter, probably reflecting the positive effects of maintaining the dry cover as mulch. On the measured attributes, one farm has more desirable physical characteristics while the other seems to have a more biologically active soil, features that may differentially influence vineyard performance.

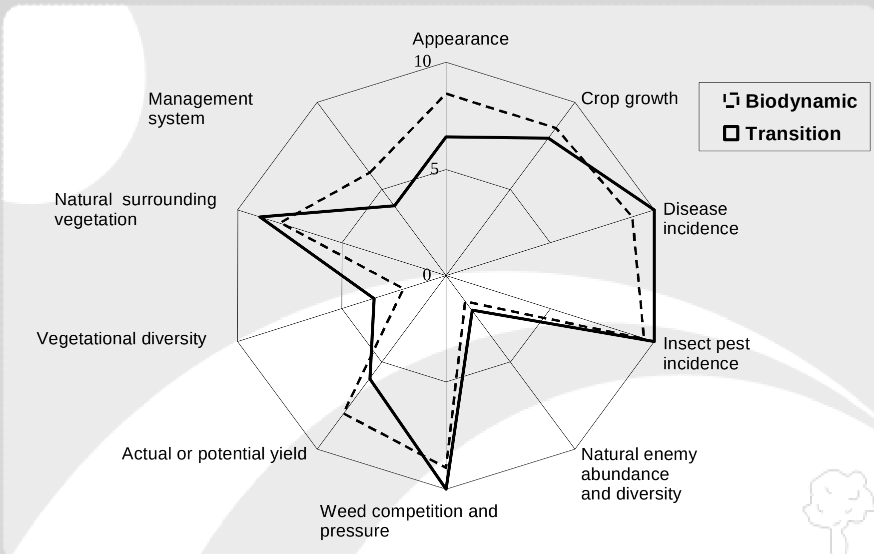

Figure 3. Amoeba representing the crop health status of two vineyard systems in northern California.

In terms of plant health, both systems exhibited very low levels of pest and disease incidence, and good rates of vine growth and appearance (Figure 3). Although within-field plant diversity was low (cover crops were dead in summer) both systems are surrounded by natural vegetation, which enhances the overall biodiversity and the environmental opportunities for natural enemies. The biodynamic farm contains an island of flowers in the middle of the vineyard; such flowers are constantly visited by predators and parasites that continually move back and forth between the island and the vineyard. For this reason the group gave this farm higher values for plant health indicators (vegetational diversity, natural surrounding vegetation, and management system).

After the diagnosis, our group discussed with the farm managers the problems that they considered most critical and in need of attention in both vineyards, and the types of interventions needed to overcome the limitations implied by the indicators. The biodynamic farm requires improvements in soil cover and other edaphic conditions to optimize root development and activate soil biological activity. In terms of crop health, both agroecosystems require key interventions to increase plant species diversity, as this in turn can enhance diversity and abundance of natural enemies (Altieri and Nicholls, 2003). The transitional «system» requires additional practices to improve vine vigor and appearance.

Conclusions

How to assess agroecosystem sustainability is today an important challenge for many farmers and researchers. Many lists of indicators that can be used to estimate the productivity, stability, resilience, and adaptability of agroecosystems have been proposed (Masera *et al.,* 1999), but few methodologies exist that allow farmers to use a few simple indicators to rapidly observe the status of their agroecosystems. Such tools would permit them to make management decisions directed at improving the attributes that are performing poorly, and thus improve agroecosystem functions.

The methodology presented is a step in this direction, and consists of a preliminary attempt to assess the sustainability of vineyards according to values assigned to relevant indicators of soil quality and crop health. The methodology involves a participatory activity and is applicable to a wide assortment of agroecosystems in a series of geographical and socio-economic contexts, as long as some indicators are replaced by others more relevant for each particular situation.

The methodology allows farmers to measure the sustainability in a *comparative or relative way,* either by comparing the evolution in time of the same agroecosystem, or by comparing two or more agroecosystems under different management practices or transitional stages. The comparison of various systems allows a group of farmers to identify the *healthier* systems, *lighthouses,* where farmers and researchers can together identify the processes and ecological interactions that explain the good performance of these lighthouses. This information can afterwards be translated into specific practices that promote the desired agroecological processes in the «vineyards» that exhibit indicator values below the threshold level.

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