Modern Agriculture:

Ecological impacts and the possibilities for truly sustainable farming

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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.

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

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.

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

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.

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.

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.

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.

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.

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.

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 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.

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 $16 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 year. 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.

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.

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, 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.

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. 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.

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 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.

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:

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. 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 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.

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.

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

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. 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.

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.

References

Altieri, M.A. 1992. Agroecological foundations of alternative agriculture in California. Agriculture, Ecosystems and Environment 39: 23-53.

Altieri, M.A. 1995. Agroecology: the science of sustainable agriculture. Westview Press, Boulder

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.

Audirac, Y. 1997. Rural sustainable development in America. John Wiley and Sons, N.Y.

Buttel, F.H. and M.E. Gertler 1982. Agricultural structure, agricultural policy and environmental quality. Agriculture and Environment 7: 101-119.

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

Gliessman, S.R. 1997. Agroecology: ecological processes in agriculture. Ann Arbor Press, Michigan.

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

Krimsky, S. and R.P. Wrubel 1996. Agricultural biotechnology and the environment: science, policy and social issues. University of Illinois Press, Urbana.

Liebman, J. 1997. Rising toxic tide: pesticide use in California, 1991-1995. Report of Californians for Pesticide Reform and Pesticide Action Network. San Francisco.

Mc Guinnes, H. 1993. Living soils: sustainable alternatives to chemical fertilizers for developing countries. Unpublished manuscript, Consumers Policy Institute, New York.

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

Pimentel, D. and H. Lehman 1993. The pesticide question. Chapman and Hall, N.Y.

Rissler, J. and M. Mellon 1996. The ecological risks of engineered crops. MIT Press, Cambridge.

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.