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Biological control and agricultural modernization: Towards resolution of some contradictions

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Abstract. An emergent contradiction in the contemporary development of biological control is that of the prevalence of the substitution of periodic releases of natural enemies for chemical insecticides and the dominance of biotechnologically developed transgenic crops. Input substitution leaves in place the monoculture nature of agroecosystems, which in itself is a key factor in encouraging pest problems. Biotechnology, now under corporate control, creates more dependency and can potentially lead to Bt resistance, thus excluding from the market a key biopesticide. Approaches for putting back biological control into the hands of farmers (from artesanal biotechnology for grassroots biopesticide production Cuban style to farmer-to-farmer IPM networks, etc.) have been developed as a way to create a farmer centered approach to biological control

Key words: Biological control, Environmental policy, IPM programs

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Introduction

Biological control was originally defined, 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" (De Bach, 1964). As such, biological control 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 portion of the population as the density of that population increases, and vice-versa (De Bach and Rosen, 1991). In a strict ecological sense, applied biological control can be considered a strategy to restore functional biodiversity in agroecosystems by adding, through classical and/or augmentative biocontrol techniques, "missing" entomophagous insects or by enhancing naturally occurring predators and parasitoids through conservation and habitat management (Altieri, 1994). As envisioned by the early proponents and practitioners, biological control was to become a self-sustaining strategy, through which farmers relied for pest control on the ecological services provided by the "restored" functional biodiversity, thus avoiding dependence on costly pesticides. Historically this has been the case worldwide, with a number of pests brought under permanent control, since the successful control of the cottony-cushion scale *Icerya purchasi* in California with the vedalia beetle, *Rodolia cardinalis*, which was imported from Australia in 1888 (van Driesche and Bellows, 1996).

The combined savings attributed to the California agricultural industry from seven major classical biological control programs conducted between 1928 and 1979 was estimated at about US$ 20 million, not accounting for inflation and/or discount (Hagen and Franz, 1973; van den

Bosch et al., 1982). Such environmental benefits, however, have rarely been accounted for in normal economic analysis of agricultural technology.

This natural phenomenon of pest population regulation created by human management through the enhancement of the interaction of biological control agents, plants, and herbivores provided the ecological basis for what in the 1970s became known as insect pest management (IPM) strategies (van den Bosch et al., 1982). Under the original IPM vision, agroecosystems were to be diversified and managed to enhance natural control and pesticides would only be used in "emergency situations." Unfortunately, such a vision slowly eroded and IPM, increasingly under pressures from the agrochemical and now the biotechnological industry, came to mean something more like Integrated Pesticide Management; that is, the justification of pesticide use only when pest populations surpass a predetermined economic threshold. The problem is that, as the monocultural structure of agroecosystems, which lacks ecological defense mechanisms, remains unchallenged, pest problems continually surpass tolerable levels, and thus require constant control interventions. Even when natural enemies are featured in IPM programs in biologically impoverished monocultures, biological control has tended to function more as a strategy to "patch up" monocultures. A totally different outcome is observed in diversified agroecosystems, where pests are more likely to remain below economic thresholds when natural enemy biodiversity is high (Andow, 1991).

In a way, classical and augmentative biological control has had an "ecologically naive" view of modern agriculture. By assuming and accepting the persistence of large scale monoculture farms, most of the time biological control specialists seek only to "balance" monocultures through the addition of natural enemies that may be key to controlling a specific pest. This narrow acceptance of the present structure of agriculture (i.e., as monocultures that are at the very root of most pest problems) as a given condition, restricts the real possibility of implementing alternatives that challenge such a structure (Levins, 1973).

It could thus be argued that while often painted as a radical alternative to chemically based control in industrial farming, biological control does not actually challenge the more fundamental bases of industrial agriculture. Biological control has often been wrongly promoted as an appropriate technology of low environmental impact whose diffusion per se could initiate broader social change. This technological determinism has to a significant extent prevented biological control specialists from understanding the structural roots of environmental degradation and the larger crisis of industrial agriculture.

In this paper, we argue that to define biological control as only a technical substitute for agrochemicals inputs, without challenging the monoculture structure of agricultural systems, greatly diminishes the potential to develop a more sustainable agriculture. By only addressing environmental concerns, biological control as an input substitution approach offers little hope of either reversing the rapid degradation of the resource base for future production, or of resolving the current profit squeeze and debt trap in which the world's farmers are caught (Rosset and Altieri, 1997).

We further argue that biological control (especially classical biological control) is not free of issues relating to social equity. For over two centuries, industrialized countries have freely appropriated genetic and other biological resources from developing countries for agricultural production without compensating them for such services (Kloppenberg and Kleinman, 1987). In our view, the exchange and importation of natural enemies is liable to similar equity considerations as has been the case for crop germplasm. We also question as "false promises" corporate claims that genetic engineering is the wave of the future for biological control (Hindmarsh, 1991). We suggest that this form of biotechnology may exacerbate pest and other problems of conventional agriculture, and undermine ecological methods of farming such as biological control itself. Furthermore, numerous large-scale releases of genetically engineered organisms risk eroding genetic diversity and distorting ecological processes such as natural control in agroecosystems (Rissler and Mellon, 1996). In fact, such biotechnology may seriously threaten the food systems of Third World countries.

As an alternative, we discuss remarkable advances made in developing countries on farmer-led biological control efforts that constitute "ground-up" farmer-to farmer approaches to technology transfer and development and that represent potential avenues for reaching production autonomy. We also elaborate on how Cuba's unique and amazing advances in the artesanal and decentralized development and application of biopesticides are slowly serving to demystify the concept that biotechnology can only be high-tech and executed in sophisticated laboratories under private corporate control.

Classical biological control and social equity

Classical biological control involves the introduction of natural enemies from the center of origin of an insect herbivore that has become an exotic pest elsewhere (van Driesche and Bellows, 1996). Throughout history this has involved hundreds of exchanges between various world regions of natural enemies used against agricultural insect pests. The analysis conducted by Altieri (1991), provides a measure of the "biological control contribution" of each of six regions to world agriculture and also a measure of the "biological control dependence" of each region on non-indigenous sources of natural enemies. It is clear that the six regions are interdependent in terms of biological control agents. It is also obvious that there are countries that are disproportionately more dependent than others for natural enemies (USA and Canada) and that other regions have made more significant contributions (Asia, including India).

If the regions are clustered into industrialized countries (USA, Canada, Western Europe, and Australia) and developing countries (Latin America, Asia, and Africa), it is observed that the industrialized countries have significantly benefited from the natural enemy richness of the developing countries. Up to 1965, industrialized countries had received 49 species of natural enemies from developing countries for the control of various agricultural insect pests, whereas the developing countries received only 30 species from the industrialized countries. Asia (including India) has provided 21 different species of natural enemies to the USA and Canada, but in return have only received one species from North America.

When more recent data on the inter-regional introductions of parasitic insects against arthropods of agricultural, forestry, and medical importance are analyzed, it reinforces the point about the world's interdependence on biological control agents (Luck, 1981). When examining data from the 1970s and 1980s, the industrialized countries-developing countries dependency relationship still holds and again appears highly dependent on foreign natural enemy sources. Through 1981, developing countries donated 353 species of natural enemies to the industrialized countries, whereas the developing countries only received 260 natural enemy species from the industrialized countries. Again, Africa, Asia, and Latin America stand out as net contributors.

The data on inter-regional exchanges suggests that because there has been more transfer of natural enemies species from developing countries to industrialized countries than vice-versa, it could be argued that industrialized countries have accrued a "biological control debt" with developing countries. It could also be argued that such debt is related to the fact that the agriculture of the industrialized countries is based on introduced plant material and therefore vulnerable to exotic pests amenable for classical biological control (i.e., by 1970 there were 212 insect pests of foreign origin in the USA) or that intensive transfers were the result of a much greater financial and scientific capacity of the industrialized countries to do so. Another argument could be that given the ecological vulnerability of high-input agricultural monocultures, industrialized countries have a greater need to utilize natural enemies to patch up unstable agroecosystems than developing countries. It is possible that with the expansion of monoculture-based agroexports in developing countries, this need may also increase in all such countries. Thus far in these countries, pest problems in export agriculture have been dealt with mainly by pesticides, many of which have been restricted or banned in the industrialized countries (Conway and Pretty, 1991).

A closer look at biological control programs judged to be "agronomically successful" may show that they are not so successful in social terms. For example, the vast majority of the classical biological control efforts conducted in developing countries (many of which were sponsored by the governments of industrial countries) have been primarily directed at commercial, industrial and export tree crops such as coffee, coconut, citrus, cocoa, and banana and not local food crops (Hansen, 1987). This trend was particularly notorious in British Commonwealth sponsored projects during colonial times. Given the structural realities of developing countries, it is obvious that these efforts were mostly for the benefit of large-scale commercial farmers, and not for the large masses of peasants and the rural poor in these countries (Murray, 1994). Notable exceptions are the biological control programs against wheat aphids in Brazil and Chile, against rice pests in southeast Asia and against cassava pests in Africa. These projects, in addition to targeting crucial food crops, also emphasize building indigenous capabilities to implement pest management programs, encouraging the use of simple and low-cost techniques easily adaptable by small farmers (Hansen, 1987; Thrupp, 1996).

Another issue that illustrates inequities in the inter-regional exchange of biological resources and that is compounded by the contradictory nature of the contemporary structure of the world economy, is the fact that while developing countries were supplying biological control agents to industrialized countries, chemical companies from the industrialized countries were engaged in a massive export of pesticides to developing countries. From 1974 to 1978, imports of pesticides by developing countries increased from $641 million to almost $1 billion. Up to the late 1970s, 38 percent of the international trade in pesticides occurred in developing countries (Weir and Shapiro, 1981). In a period of just two years, US companies increased their pesticide exports from $615 million to $1 billion. Tragically, 30 percent of all pesticides exported from the USA were unregistered, that is, not approved for use in the USA by the Environmental Protection Agency (EPA). In other words, developing countries became a kind of dumping ground for the USA and other industrialized countries (Murray, 1994). Similarly, UK pesticide exports (mostly to developing countries) grew by 211 percent in value over the 1975–79 period, reaching about 66,000 tons by 1979 (Conway and Pretty, 1991). Latin America's share of the global pesticide market, currently around 10 percent, is steadily increasing. Brazil alone accounts for nearly 50 percent of the total sales in the region, followed by Mexico, Argentina, and Colombia. From 1980 to 1986, pesticide sales rose dramatically in Brazil and Argentina. If current trends continue, the cost to Latin America of chemical pest control is expected to reach $3.97 billion by the year 2000 (Belloti et al., 1990).

In many developing countries, governments until recently subsidized pesticide production and sales. The median level of subsidy was about 44 percent of total retail costs. Such subsidies make pesticides considerably cheaper, thus encouraging farmers to use more chemicals than they would if they had to pay the full costs (Murray, 1994). These subsidies undermine efforts to promote more ecologically-sound pest control methods such as biological control. International assistance agencies based in industrialized countries, including the World Bank and US Agency for International Development (USAID), have in the past been involved in promoting pesticide use in developing countries, either directly through agricultural development loans, or indirectly though support for local agricultural credit programs or technical assistance programs (Repetto, 1985). Although international agencies have announced new policy guidelines governing pesticide use in development projects, such guidelines have been unjustifiably slowly implemented. Such sponsored assistance hinders biological control in developing countries and promotes use of pesticides, while these countries continue supplying beneficial organisms to industrialized countries. Such a situation is unethical and suggests a type of "ecological imperialism." It should be noted, however, that many biological control workers in the industrialized countries actively oppose such policies, and are working hard to develop and promote more equitable alternatives.

Further inequities may arise with the emergence of biotechnology, financed mostly by private interests in the industrialized countries. As interest in genetically-engineered biological control agents increases, it is possible that developing countries may be caught in purchasing "patented natural enemies" at a high cost. The final irony is that such novel biotic agents be based on genetic resources originally obtained at no cost from developing countries (Kloppenburg and Kleinman, 1987).

Biological control and input substitution

The goal of the sustainable agriculture movement is to generate major technological adjustments in conventional agriculture to make it more environmentally, socially, and economically viable (Vandermeer, 1995). The main focus has been to substitute less noxious inputs for the agrochemicals that are blamed for so many of the problems associated with conventional agriculture. Emphasis is now placed on purchased biological inputs such as *Bacillus thuringiensis*, a microbial pesticide that is now widely applied in place of chemical insecticides, and is marketed by major chemical companies under brand names like Dipel® and Javelin®. This type of technology pertains to a dominant technical approach we have called "input substitution" (Rosset and Altieri, 1997). The thrust is highly technological, with the "limiting factor" mentality that has driven conventional agricultural research in the past. Agronomists and other agricultural scientists have for generations been taught the "law of the minimum" as a central dogma. According to this dogma, at any given moment there is a single factor limiting yield increases, and that factor can be overcome with an appropriate external input such as a chemical or biological insecticide (Rosset and Altieri, 1997).

There are several problems with this approach. It focuses on the most superficial level of integration in the agroecosystem, that of a single species, the crop, with a single limiting factor, such as an insect pest. It denies the rich, scientific basis provided by the science of ecology for the importance of higher levels of interaction, including synergism, antagonism, and multiple-species interactions such as those of herbivores and their natural enemies. From a practical standpoint, the outcome of the "limiting factor" approach inevitably is that as a farmer "solves" the problem of one symptom, he or she is confronted with another, "unexpected" problem. If he or she uses urea to overcome nitrogen as a limiting factor, for example, they are all to often then confronted with an outbreak of insect pests such as aphids or whiteflies, whose numbers are dramatically increased by the greater availability of free nitrogen in the plants' sap upon which they feed (Altieri and Rosset, 1996). This perpetuates a process of treating symptoms rather than the real causes that evoked the ecological imbalance.

In this context, we find the prevalence of input substitution in alternative or "sustainable" agriculture to be alarming. Essentially, the capital-intensive, monoculture-based system of conventional agriculture is left intact. All changes are relatively minor. A toxic pesticide is removed and a biological product is substituted. While these changes may suggest a more environmentally benign direction, they leave in place the key forces that are driving the agricultural crisis; extensive monoculture, excessive use of machinery, input control by agribusiness, dependence of fossil fuels, and very high capital requirements. This approach neither addresses the debt trap that farmers are caught in because of high costs of machinery and inputs, nor the ecological basis of declining yields – the reduction of functional biodiversity of agroecosystems (Altieri and Rosset, 1996).

Evidence for the increasing dominance of this faux-sustainable approach is everywhere. Organic farming, commonly viewed as a holistic concept, is now heavily commodity and capital oriented. Publications directed at organic farmers are filled with advertisements for expensive biological pesticides, commercial compost, insectary-produced natural enemies, botanical extracts, microbial and other soil amendments, etc., increasing their dependence on "green" suppliers (Lampkin, 1990).

Throughout the world, an input substitution industry is emerging and internationally funded IPM programs, government extension agents, and commercial sales representatives urge farmers to use new, safe, and effective biological products, like Javelin®, which may cost as much as $150 a liter, or even Avermec®, which may cost more than $400. These products are indeed safer, and in many cases more effective, than methyl parathion. Nevertheless, a question must be asked. In its crudest form this question is, “What is more injurious to the health of a farm family whose annual income may be well under $1000 per year – exposure to the occasional whiff of methyl parathion or having to pay an additional $393 for an essential production input?” More generally, if alternative products raise production costs for First and Third World farmers already caught in a cost/price squeeze, and increase their already excessive dependence on off-farm suppliers of inputs, then input substitution biological control does not offer a way out of the crisis (Rosset and Altieri, 1997).

The dependence of farmers is further exacerbated as multinational companies attracted by the commercial opportunities presented by agricultural biotechnology develop genetically engineered plants that exhibit “biological control” properties. A case in point is the development of transgenic Bt-containing crops, which corporations claim will be environmentally clean and more effective than existing insect control strategies. Not only will these transgenic crops be more expensive, but just like chemical pesticides, transgenic crops can be expected to exert strong selection pressure in favor of pests with a resistance to the natural biotoxins that are used (Rissler and Mellon, 1996).

There is general concern that widespread use of Bt-containing crops could accelerate the development of insect pest resistance to Bt. Already, eight species of insects have developed resistance to Bt toxins, either in the field or laboratory (Hruska and Pavón, 1997). The problem with transgenic Bt plants is that they will increase the exposure of pests to Bt, especially where the Bt is continuously expressed in a plant throughout its growing season. This is significant because long-term exposure to Bt toxins promotes development of resistance in insect populations. This kind of exposure could lead to selection for resistance in all life stages of the insect pest on all parts of the plant for the entire season (Rissler and Mellon, 1996). Such concerns have recently materialized according to the Union of Concerned Scientists (1996), who affirm that during the 1996 growing season, Monsanto’s Bt cotton failed to control cotton bollworm on thousands of acres, raising questions about the adequacy of the resistance management plans that the US EPA had approved for Bt cotton.

Unless effective resistance management strategies are developed and implemented, growers may soon lose the benefit of reduced synthetic insecticide use that Bt-crops and sprays could bring. With the loss of Bt’s efficacy, farmers – particularly organic farmers who depend on Bt – will be faced with decisions on how to reduce resurgent damage by insect pests. Also, the widespread use of transgenic varieties will further decrease within and between field genetic variability, already the source of the great susceptibility of “modern” agriculture to novel pest and disease outbreaks (NAS, 1972).

An alternative to the input substitution approach and future dependence on biotechnology packages is an agroecological strategy to achieve sustained agricultural productivity by breaking the monoculture structure and dependence on off-farm inputs through the design of integrated agroecosystems (Altieri, 1995; Altieri and Rosset, 1996). Agroecology states that the health and performance of agroecosystems depends on how well established is a diverse assemblage of natural enemies and antagonists. By assembling a functional biodiversity, it is possible to potentiate synergisms that 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 spectrum of biodiversification practices and technologies available that are of a preventative nature and act by reinforcing the robustness of the agroecosystem. The impacts of many of these practices have been scientifically documented (Vandermeer, 1995). Legume based crop rotations, one of the simplest forms of biodiversification, improve yields by the known action of interrupting weed, disease and insect life cycles. They also can have subtle effects such as enhancing the growth and activity of soil biology, including vesicular arbuscular mycorrhizae (VAM), which allow crops to more efficiently use soil, water, and nutrients and also to remain healthy.

On the other hand, field 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 and references therein). Factors involved in pest regulation in diversified agroecosystems include among others: increased parasitoid/predator populations, available alternative prey/hosts for natural enemies, and optimum synchrony between pests and natural enemies (Altieri, 1994).

Research has shown that by adding plant diversity to existing monocultures, it is possible to exert changes in habitat diversity that in turn favor natural enemy abundance and effectiveness. This information can be used to design intercropping and cover cropping that enhance predator and parasitoid diversity and abundance, thus resulting in lower pest loads than in monocultures (Andow, 1991). 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. Hedgerows and other landscape features have received significant attention in Europe regarding their effects on beneficial arthropod distribution and abundance in adjacent crop fields (Fry, 1995). In California, the egg parasite *Anagrus epos* was effective in controlling the grape leafhopper *Erythroneura elegantula* in vineyards adjacent to wild blackberries, which harbor 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 can also allow early-season buildup of *Anagrus epos* and early benefits of parasitism are promoted in vineyards with prune trees plants upwind from the vineyard (Flint and Roberts, 1989). Researchers now recommend that as many prune trees as possible should always be planted upwind from the vineyard.

From the perspective of farmers' independence, the advantage of the agroecological approach, which emphasizes the use of biodiversity, is that corporations cannot appropriate the workings of a balanced agroecosystem. In other words, the agroecological approach offers minimal profit to agribusiness corporations; on the contrary, it encourages farmers' productive self-reliance.

Putting biological control back in the hands of farmers

Throughout the world, more and more farmers upset with the high economic, environmental, and health costs of the pesticide treadmill, are engaging in efforts to replace chemical-intensive pest control methods with alternative agricultural approaches (Thrupp, 1996). The emergence of such local initiatives has taken many forms: from community organizations to farmer-to-farmer networks, at times supported by non-governmental organizations (NGO) or even local governments. In many cases, IPM technologies developed or diffused by NGO technicians have taken advantage of farmer-initiated activities to further scale-up the spread of IPM technologies useful to small farmers (Altieri, 1993).

Historically in China, large-scale production of the microbial insecticide *Bacillus thuringiensis* occurred in communes through solid or liquid fermentation in tanks. Wheat bran, corn meal, soybean, defatted cottonseed cake, and peanut bran are the main media components used in Bt production. In the pilot plant at Hubei Academy of Agricultural Sciences, production grew from 26 tons in 1983 to 90 tons in 1984, and to 900 tons in 1990. Under government sponsorship, Bt is now widely used in 30 provinces for the control of various pests of agriculture and forests (Entwistle, 1993).

Since Cuba's trade relations with the socialist bloc collapsed in 1990, pesticide imports dropped by more than 60 percent, fertilizers by 77 percent, and petroleum for agriculture dropped by 50 percent. In order to deal with such shortages, massive efforts were initiated to find ways to reduce chemical use and to develop alternatives for management of plant diseases, insect pests, and weeds. The production of biopesticides and biological control agents are at the heart of this new quest with the creation of about 220 Centers for the Production of Entomophages and Entomopathogens (CREEs) where decentralized, "artesanal" production of biocontrol agents takes place (Rosset and Benjamin, 1994). The centers produce a number of entomopathogens (*Bacillus thuringiensis*, *Beauveria bassiana*, *Metarhizium anisopliae*, and *Verticillium lecanii*), as well as one or more species of *Trichogramma*, depending on the crops grown in each area. In 1994, production levels *of B. thuringiensis* and *B. bassiana* reached 1300 and 780 metric tons respectively. CREEs are maintained and operated by local technicians, many of them sons and daughters of owners of companies, which produce and distribute these products to local, state, cooperative, and private farmers. CREEs are thus biofactories that produce low priced microbial products for local use (Rosset and Benjamin, 1994). Opening Latin America and other developing countries' markets to Cuba's biotechnology products and expertise can provide poor and dependent countries access to alternative and cheaper technologies. In fact, Cubans are willing to train people from Lesser Developed Countries (LDC) in biotechnology, thus enabling them to develop their own appropriate biotechnology and to escape the technological control and treadmill imposed by multinationals. As rural communities within LDCs benefit from Cuban technological advances, a parallel technological path to the prevailing corporate model can be developed, thus providing farmers with more options, and even with the possibility of becoming technologically independent through the creation of simple community managed insectaries, microbial insecticide, and biofertilizer manufacturing facilities.

In another political context, in southern Brazil, farmers quickly took advantage of the identification by Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) scientists of a highly specific Nuclear Polyhedrosis virus (NPV) to control the velveteen caterpillar in soybean. Farmers realized that they could readily mass-produce the virus by themselves, by just collecting infected caterpillars, grinding them up, and then mixing them with water to produce a suspension that could be sprayed. If the suspension is kept frozen, it will retain its viral activity for longer than a season. In essence, farmers can "manufacture" their own pesticide, thus effectively bypassing the need to depend on government or industry for the supply of the virus (Hansen, 1987). In a nearby zone in Paraná, organic farmers have noticed the disease suppressing effect of a fermented compost preparation that contains naturally occurring *Trichoderma* and other antagonists, which they spray on citrus and other fruit trees to control *Oidium* and *Botrytis*, thus obviating the use of chemical fungicides (personal observation).

The FAO-initiated IPM program for rice in south and southeast Asia has become a major model for how to establish farmers' networks to implement participatory IPM and it is touted as one of the most sustainable crop protection options for the future. The program emphasizes an innovative approach of farmers' learning about IPM, natural enemies, and rice agroecology through practical experience and in "Farm Field Schools" that enhance farmers' knowledge about beneficial biodiversity and scientific crop-management skills. By 1986, about 17,000 farmers had been trained per season in Sri Lanka. In Kasakolikasan, Philippines, 3,800 farmers have been trained, and their use of pesticides dropped between 60–98 percent and rice yields had increased between 5–15 percent (Thrupp, 1996). The BIOS (Biologically Intregrated Orchard Systems) program in California implemented by dozens of almond and walnut growers, demonstrates that biologically integrated systems (orchards with an undergrowth of selected cover crops), encourage natural control and thus reduce the reliance on pesticides and can be profitable (Thrupp, 1996).

Conclusions

There is no question that biological control can reduce production costs and can ameliorate some direct environmental impacts of agriculture, such as pesticide residues and resistance, but it does not reduce the fundamental vulnerability of monocultures. Furthermore, when used in the mode of "input substitution" (i.e., inundative releases or biopesticides), it replaces cheap, ecologically harmful inputs with expensive and benign ones, thus increasing costs and failing to address the economic crisis faced by the world's farmers.

We have also argued that the disproportionate quantity of natural enemies that industrialized countries have appropriated from developing countries raises questions of equity in biological control inherent to the global patterns of exchange of and access to natural enemies. At issue is the substantial ecological debt that industrialized countries accrued with developing countries in the form of insect biodiversity, and which has remained largely uncompensated. With increasing involvement of private corporations in bioprospecting, this question may become even more critical.

Industrialized countries should accept that a system of compensation may provide the basis for a stable mechanism for future exchange of biological control agents, and if properly administered by developing country governments or other international institutions such as UNFAO, those financial resources could be used to expand research and development in biological control that truly benefits all farmers, while simultaneously helping to regenerate and preserve the already degraded environments of developing countries (Altieri, 1991).

It will be of utmost importance for biological control scientists and practitioners to oppose the expansion of corporate hegemony in crop protection and production. As corporations make capital available, universities and research institutions are exposed to new and increased pressures to serve private interests at the expense of the public good. The danger inherent in this issue is that publicly funded agricultural research, like corporate research, is already being targeted toward the development of profitable products to sell to farmers, rather than toward research to help farmers cut inputs and costs, and thus to decrease their overall dependency.

This is why an agroecological approach that encourages biointensive IPM must be emphasized. By taking advantage of the integration of plant and animal biodiversity to enhance complex interactions and synergisms, it is possible to design agroecosystems that sponsor their own pest control without the need for external chemical or biological inputs. Diversified cropping systems, such as those based on intercropping or cover cropping of orchards, have been the target of much research recently. This is largely based on the newly emerging evidence that these systems are more sustainable and more resource-conserving (Vandermeer, 1995). Much of these attributes are connected to the higher levels of functional biodiversity (including natural enemies) associated with such complex farming systems. The key is to identify the type of biodiversity that is desirable to maintain or enhance in order to sponsor ecological services, and then to determine the best practices that will encourage the desired biodiversity components. 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 through enhanced biological pest control, thus freeing farmers from the heavy burden of external input dependency (Altieri and Rosset, 1996).

If input substitution is required, as is often the case during the transition toward organic production, then the local, decentralized, and low cost Cuban-style biofactories offer the best hope to farmers who are able to organize and cut the umbilical cord to the external suppliers of technology. Also the creation of farmer-to-farmer networks that implement participatory IPM programs are the most appropriate strategy to achieve an environmentally friendly, socially sound, and economically viable agricultural production.

Recent experiences in the Third World suggest that an agroecological-grassroots development is possible, especially when implemented at the local level. A number of grassroots rural development programs in Latin America working in peasant communities are broadening the base of participation in the production process under an agroecological paradigm, and daring to create equitable arrangements for distributing the benefits from sustainable production increases (Altieri, 1995). Through local participation, local technologies are developed based on local knowledge and resources, and used as instruments of empowerment and social organization. This allows peasants to meet their basic needs without increasing dependence on external assistance. The objective is to build upon the best of the local initiatives to ensure and support self-reliance and local adaptation.

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