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The development and status of biologically based integrated pest management in Cuba

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Abstract

This paper describes the evolution of IPM in Cuba during three pre- and post-revolutionary periods. The state of the art of IPM after the collapse of Cuba's relations with the soviet block is analyzed in detail. During this 'special period' Cuba is undergoing a major conversion from conventional agriculture dependent on external inputs to a semi-organic agriculture dependent on local resources and low external inputs. The massive production and use of microbial pesticides complemented by cultural and habitat management techniques are at the heart of this new quest of agricultural sustainability in the midst of the economic crisis. About 982,000 ha of various crops are under biological control, with savings of about US$ 30 million in pesticide imports.

Introduction

Agrochemicals were introduced in Cuba in the 1940s and eventually became a cornerstone of Cuban agriculture. Cuba, like many other developing nations, was highly dependent on imports of these products. The government promoted the ever-increasing use of pesticides in an effort to boost production of both exports and locally consumed crops. However, rising import costs as well as the development of pest resistance, pest resurgence and secondary pest outbreaks, began to reverse this trend well before the crisis of 1990 marked by the collapse of trading relations with the socialist block (Rosset & Benjamin 1994).

Cuba started shifting toward an integrated pest management (IPM) paradigm in the early 1970s through the creation of the National System of Plant Protection which consisted of a network of regional stations (Estaciones Territoriales de Proteccion de Plantas – ETPP) charged with monitoring the pest situation in various localities. The work of these stations was progressively perfected emphasizing the integrated use of biological, cultural and chemical control pest management tactics leading to a substantial reduction in pesticide imports in a 14-year period (Vazquez & Castellanos 1997). As a result, IPM became an official Cuban goverment policy as early as 1982, a policy that stimulated the use of predators, parasitoids and entomopathogens. The economic crisis of the 1990s, however, dramatically changed the scene, as Cuba had to face a major decrease in pesticide imports (63%) as well as a reduction in fertilizer and petroleum imports. Since then the country has had to meet the challenge of maintaining crop production for food security and also reasonable levels of export agriculture using low-input agricultural technologies. The result is that Cuba is undergoing a major conversion from conventional agriculture dependent on external agrochemical inputs and machinery to an organic agriculture dependent on local resources and low external inputs (Rosset 1997a). Biologically based pest control technologies are at the heart of this new quest for agricultural sustainability.

One of the keys to Cuba's new model of agriculture has been to further develop and massify the use of alternatives to insecticides for the management of insect pests in a range of important crops. This agroecological trend has been favored by recent changes in the land tenure system which has reduced the scale of production and has emphasized the formation of cooperatives, which in turn has resulted in the diversification of Cuban landscapes with a mosaic of crops (Funes *et al.* 2001).

This paper presents a brief historical background of the development of IPM in Cuba, ending with a detailed description of contemporary efforts in IPM, focusing on the production and use of insect biological control agents. The significance of the emergence of this alternative IPM model for the rest of Latin America is also discussed.

Historical Framework of Cuban Agriculture from an IPM-Context

(a) IPM before the revolution 1940–1959

Before the revolution, Cuba's agricultural system had been based on the prevailing *latifundio-minifundio* model, with sugar cane as the major export component and a mass of rural peasants either partially self-sufficient on micro holdings or with no land at all. Although agricultural production was highly dependent on pesticides, Cuba has a tradition of biological control efforts that dates back to the 1930s. Since that time, parasitoids of the sugar cane borer and the citrus blackfly were being evaluated as biological control agents and many Cuban scientists at various institutes during this period maintained an unofficial interest in biocontrol.

The citrus blackfly, *Aleurocanthus woglumi*, a major pest of citrus was introduced into Cuba in 1916. The citrus blackfly was brought under biological control after the introduction of the parasitoid, *Eretmocerus serius*, from Singapore in 1930 (Hagen & Franz 1973). During this same period the coccinellid *Rodolia cardinalis* was introduced for the biological control of the cottony cushion scale *Icerya purchasi* (Vazquez & Castellanos 1997). A program to rear and release the endemic parasitoid fly, *Lixophaga diatraeae* to regulate populations of the sugar cane borer, *Diatraea sacharalis*, was also initiated in 1930. *L. diatraeae* was introduced into the US from Cuba in an effort to bring the sugar cane borer under biological control (Fuentes *et al.* 1998). By 1954, there were 6 laboratories rearing *L. diatraea* and from 1960 to 1980 new rearing technologies were developed which led to the creation by the Sugar Ministry (MINAZ) of the National Biological Control Program. By 1995, this program had 50 centers rearing the tachinid fly at an annual rate of about 78 million flies enough to cover 1.6 million ha of sugar cane (Fuentes *et al.* 1998). In fact, today there is a whole complex of parasitoids and entomopathogens used in sugar cane to combat a series of insect pests.

(b) IPM during the revolution 1959–1989

From 1959 to 1989, Cuba closely integrated its economy with other socialist countries and became especially dependent on the USSR, which offered Cuba favorable terms of trade. Sugar was the most important crop, and Cuba traded sugar, tobacco and other exports for food, machinery, petroleum, fertilizers and pesticides. All of Cuba's citrus and starchy roots and fruits were home-grown; but the country imported substantial amounts of staple foods such as rice (49%), wheat (100%) and beans (90%) plus fats, meat, milk and livestock-feed (Rosset & Benjamin 1994).

During the 1980s, Cuba received from the Soviet Union an average price for its sugar exports that was 5.4 times higher than the world price. Cuba also was able to obtain Soviet petroleum in return; part of which was re-exported to earn convertible currency. Because of the favorable trade terms for sugar, its production far outweighed that of food crops. About three times as much land was devoted to sugar in 1989 as was used for food crops, contributing to a pattern of food dependency with as much as 57% of the total calories in the Cuban diet coming from imports. In summary, the Cuban agricultural sector was characterized by a high degree of modernization, the dominance of export monocultures over food crops and heavy dependence on imported inputs and raw materials. Pesticides accounted for an important portion of these imports until 1990 (Figure 1).

Cuba had made remarkable strides in agricultural development since its revolution in 1959. National research programs on biological control began full-force in the late 1960s (Altieri & Nicholls 1999). During this period, the longest-running biological control program involving *L. ditraeae* was massified. Also the rearing centers created by MINAZ were diversified to include the production of entomopathogens.

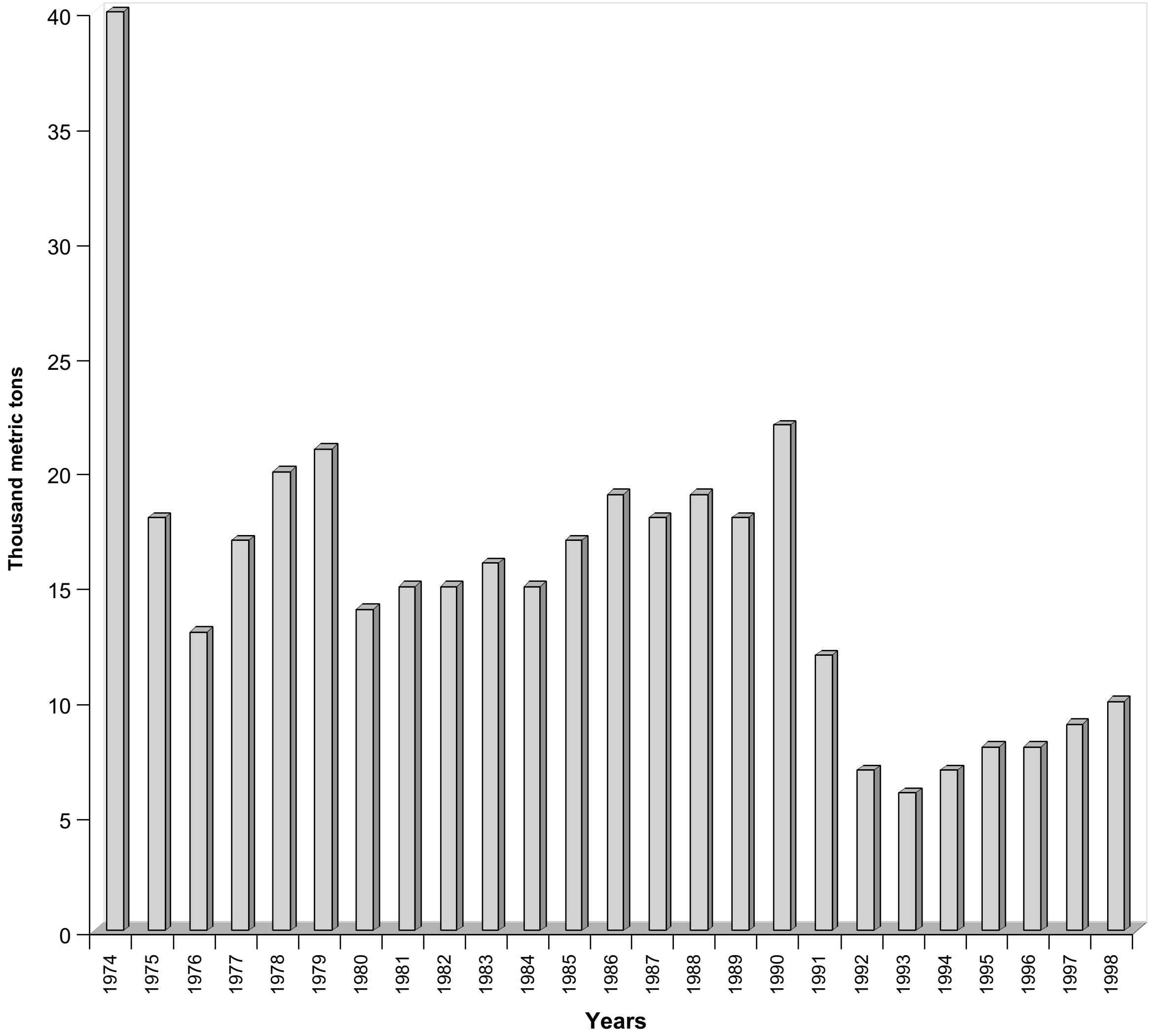

Figure 1. Pesticide imports since the creation of the Estaciones Territoriales de Proteccion de Plantas ETPPs (CNSV 2000).

In 1960, the first biological product based on imported *Bacillus thuringiensis* (*Bt*) appeared in the market which proved effective in the control of *Heliothis virescens* in tobacco and *Mocis latipes* in pastures. These successful experiences stimulated the interest for the search of native strains of *B. thuringiensis*. In 1985, after many years of research and practice, biological control began to replace pesticides as the conceptual basis for pest management. In 1988, the Ministry of Agriculture (MINAG) created the National Program for the production of Biological Agents for the period 1989–1990, which led to the widening of the rearing laboratory network (Centros de Reproduccion de Entomofagos y Entomopatogenos-CREEs) from 82 in 1992 to 227 in 1994.

(c) IPM during the special period: 1989–present

As mentioned earlier, since the 1989–1990 collapse of trading relations with the socialist bloc, Cuba had to face a substantial decrease of fertilizer and pesticide imports (Table 1). At the same time, food imports, which previously accounted for up to 57% of the caloric intake of the population, had fallen by more than half. Thus, a country with a highly industrialized agricultural system technically similar to that of California had to dramatically increase food production without significantly affecting earnings from export agriculture, all virtually without the use of chemical inputs and machinery on which it had become dependent.

Table 1. Comparison of selected Cuban imports in 1989 and 1992 (CNSV 2000)

Item	1989 imports	1992 imports	Change (%)
Petroleum	13,000,000 MT	6,100,000 MT	−53%
Fertilizer	1,300,000 MT	300,000 MT	−77%
Animal feed	1,600,000 MT	475,000 MT	−70%
Pesticides	US$ 80,000,000	US$ 30,000,000	−63%

Source: Lage 1996.

This event plunged Cuba, in 1989, into a crisis at almost all levels of society and placed the nation in what they term the ‘Special Period in a time of peace’. Within three years of the breakup of the Soviet–East European alliance, Cuba’s purchasing power decreased by 73% while by 1992 its gross national product fell by 42%. Everything had to be rethought, and agriculture was no exception as Cuba was forced to develop an endogenous path towards food security based on the substitution of local for imported technology (Rosset 1997b).

The result is that Cuba is currently undergoing a grand experiment in conversion from modern conventional agriculture to semi-organic farming on a large scale and which led to restoring food security over a 5-year period. From 1989 to 1994, the per capita intake had fallen from 2,908 to 1,863 calories. By 2000, the caloric level had risen to 2,585 (Oxfam America 2001). The strategy adopted by the government in the face of the cutoff of imports has been to mobilize Cuba’s substantial scientific infrastructure – both physical plant and human resources – to substitute autochthonous technology for the no longer available inputs. The alternative agriculture model includes: (1) the use of organic fertilizers (what Cuban now commonly refer to as ‘biofertilizers’ and vermi-compost); (2) biological control of pests; (3) adjusting crops and animals to local ecological conditions; (4) animal traction and other forms of alternative energy; (5) crop diversification in the form of rotations and mixed cropping; (6) soil conservation, reclamation of degraded lands and reforestation; (7) integrated crop–livestock systems; and (8) urban agriculture. All these technological approaches were embedded in a context characterized by the re-organization of the labor force, the use of farmers’ local knowledge and the massive training of technicians and farmers on agroecology and sustainable agriculture (Funes *et al.* 2001).

Cuban-made biopesticides and biofertilizers – the products of modern and artesanal fermentation biotechnology – are being combined with IPM, vermiculture, water recycling, rational pasture management, biological pest control, cover cropping and other ecologically sound practices in a new successful attempt to avert a catastrophic shortfall of food availability for the population. At the same time, a re-organization of production is being undertaken – including the promotion of small and medium farms, the privatization and cooperativization of the state sector and the opening of farmers’ markets.

Mass Production and Use of Insect Biological Control Agents

The network of CREEs

One of the most interesting aspects of contemporary insect pest management efforts in Cuba is the ‘artesanal’ production of biological control agents in the decentralized CREES. As mentioned earlier, prior to 1988 the government approved the construction of these facilities; however, few had been built before the beginning of the economic crisis. The government has since invested its limited capital in the construction and operation of these centers. By the end of 1992, 227 CREES had been built throughout Cuba to provide services to state, cooperatives and private farm operations. In addition, 29 biopesticide plants with semi-industrial reproduction technologies and one pilot plant with industrial technology were established. Since 1997, there are 280 CREEs that together with the production capacity of the pilot plant covered most of Cuban’s requirements of biological pest control agents (Vazquez & Castellanos 1997). Fifty-three of these CREES are located in sugar cane growing areas, and produce several biocontrol agents (Table 2). The remaining 227 are located in areas under crop and fruit production within state farms or the two types of cooperatives: Cooperatives of Agricultural Production (CPA) or Basic Units of Cooperative Production (UBPC) making biocontrol agents available at low cost to at least 50% of the total population of small farmers in this island.

In the years immediately following the 1989 crisis, pesticide imports decreased thus creating a demand for biopesticides (Figure 2), all massively produced at the CREEs reaching overall levels superior to 15 million t between 1990 and 2000.

The CREEs are part of a two-pronged strategy for the production of biological pesticides. The CREEs are considered to be 'artesanal' production compared to the development of 'industrial' production techniques. The country has a network of 30 brewers yeast factories normally functioning for only 4 days per month making yeast, the remainder of the time they are idle. Some of these factories are now being devoted during idle days to mass-produce biological pesticides at an industrial scale. The goal is to produce 'commercial' products with high standards of quality control for the high-end market-state farms and large cooperatives that produce for export. The network of CREEs produces a lower-priced product for local farmers (Rosset & Moore 1997).

Table 2. Biological control agents used in sugar cane (Fuentes *et al.* 1998)

Biocontrol agent	Pest	No. of CREEs in which produced	1995
Lixophaga diatraea	*Diatraea sacharalis* *Elasmopalpus lignosellus*	50	81 million individuals
Trichogramma fuentesi	*D. sacharalis* *Mocis latipes*	3	24.6 million individuals
Eucelatoria sp.	*Leucania* spp. *M. latipes* *Spodoptera frujiperda*	6	20 million individuals
Archytas monachi	*S. frujiperda*	3	0.28 million individuals
Telenomus spp.	*S. frujiperda*	3	1.1 million individuals
Euplectrus platyhypenae	*S. frujiperda*	3	0.26 million individuals
Cotesia flavipes	*D. sacharalis*	6	Experimental production
Bacillus thuringiensis	*Lepidopteran* larvae	7	209 t
Beauveria bassiana	*D. sacharalis*	9	132 t

The CREEs are maintained and operated by local technicians with college degrees, two years of post-high school vocational training, or high school diplomas. The products produced are free of charge to the hosting cooperatives and are sold to neighboring farmers, state farms and other cooperatives at nominal cost. The centers rear entomophagous insects and a number of entomopathogens.

The CREEs are involved in a large-scale effort to mass rear and release *Trichogramma*, which parasitizes the eggs of a variety of Lepidoptera pests. The sources of the genetic stocks of the *Trichogramma* colonies are obtained by rearing adults from parasitized eggs of the target insect pests collected in the local area from the crop plants where they will later be released. The field collected *Trichogramma* are then reared on host eggs of either *Corcyra cephalonica* or *Sitotroga cerealella*, both pests of stored products. Parasitized host eggs are kept at ambient temperatures and transferred to small vials. The release method involves placing the vials in the field when approximately 50% of the adult *Trichogramma* have emerged in the CREE. Release rates range from 8,000 to 30,000 individuals per hectare depending on the crop and the density of target pests' eggs in the field. *Trichogramma* is used to combat the cassava hornworm,

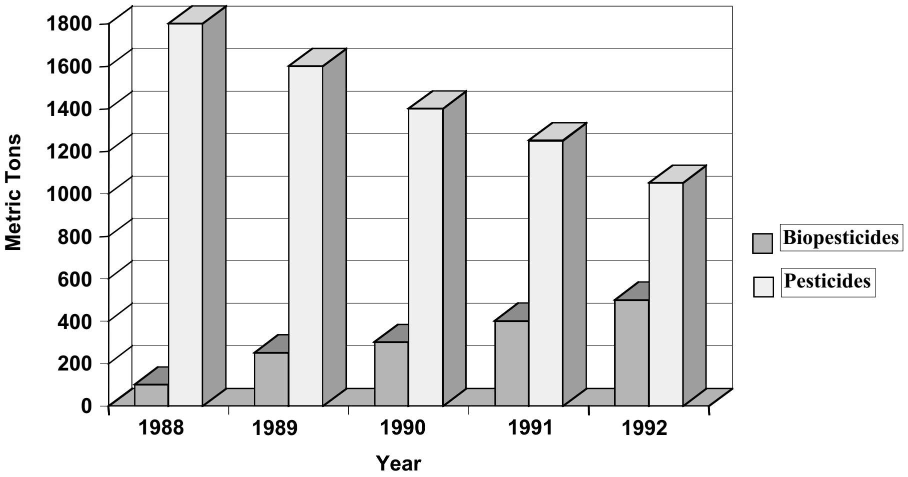

Figure 2. Consumption of Biopesticides and Pesticides in Cuba during the 4-year period before and after the onset of the special period (CNSV 2000).

Erinys ello; tobacco budworm, *H. virescens*; sugar cane borer, *D. sacharalis*; and various caterpillars including *Mocis* spp. that attacks improved pastures. With the exception of 1991–1992, production levels of *Trichogramma* have been kept constant at the MINAG's CREEs at about 10 billion wasps per year enough to cover between 300,000 and 1 million ha of cropland (Figure 3).

The successful control of Lepidoptera pests in cassava and pastures achieved with *Trichogramma* has been mainly due to the good selection of ecotypes and the rigorous quality control at the production level sponsored by the Instituto de Investigaciones de Sanidad Vegetal (INISAV).

In addition to *Trichogramma*, a number of other predators and parasitoids are mass reared and released against several pests in a range of cropping systems (Table 3).

Production and use of entomopathogens

Research and development efforts in Cuba have led to simple but effective techniques for the production, formulation, application and quality control of numerous entomopathogenetic bacteria and fungi, including *B. thuringiensis*, *Beauveria bassiana*, *Metharizhium anisopliae* and *Verticillium lecanii*. The production of the fungi *Nomuraea rileyi* and *Paecelomyces lilacinus* as well as the nematodes of the genus *Heterorhabditis* and *Steinernema* have been added to the list of artesanal microbial insecticides. These nematodes are used almost exclusively for the control of the blue green weevil in citrus nurseries (Maura 1994). The technology used in the CREEs for the reproduction of *Bt* is liquid fermentation in static culture. Most fungi are reproduced using a solid culture or biphasic method (liquid/solid), however such methods are more expensive than the *Bt* method, mainly because fungi exhibit longer production cycles. Quality control and monitoring are carried out through three mechanisms: standardized dose rates, direct test of pathogen virulence and monitoring field effectiveness by collection and observation of exposed pests. For each bacterial or fungal formulation, 2% of the harvested materials are sampled and the concentration and viability of spores and/or crystals recorded. The application rate is determined by

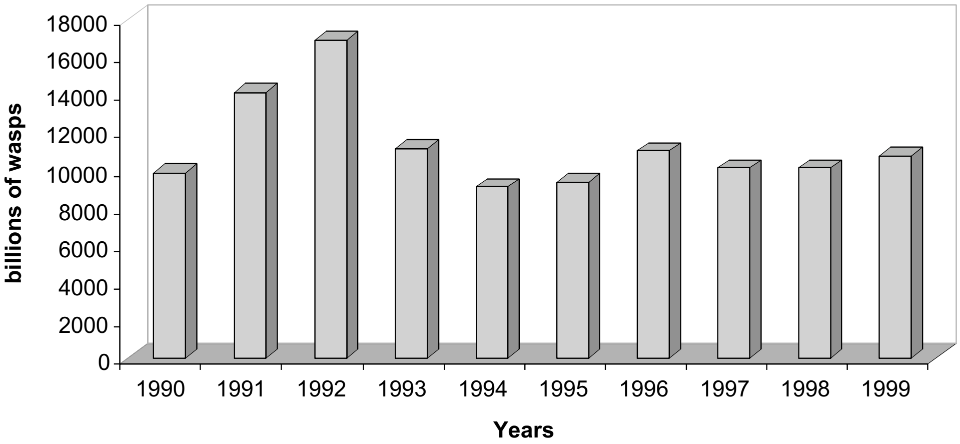

Figure 3. Production of *Trichogramma* spp. in MINAG's CREEs (CNSV 2000).

Table 3. Entomophagous insects used in Cuba (Pérez & Vazquez 2001)

Crop	Natural enemy	Pest	Area (ha)
Ipomoea batata (sweet potato)	*Pheidole megacephala*	*Cylias formicarius*	15,300
Manihot esculenta (cassava)	*Trichogramma* spp.	*Erynis ello*	110,408
Saccharum sp. (sugar cane)	*Trichogramma* spp. *Lixophaga diatraea*	*Diatraea sacharalis*	>100,000
Pastures	*Trichogramma* spp.	*Mocis* spp.	563,068
Several crops	*Trichogramma* spp.	Lepidopteran	10,497
Nicotiana tabacum (tobacco)	*Trichogramma* spp.	*Heliothis virescens*	>5,000

calculating the number of spores or organisms per unit volume and adjusting the rate of material applied in the field to standardize the dose per area. Virulence is tested by recording the incidence and severity of infection in pests exposed to field rates of entomopathogens that have been recently applied. Quality control is enforced at the state level through a network of provincial laboratories (Laboratorios Provinciales de Sanidad Vegetal – LAPROSAV) and the ETPP which monitor field effectiveness under the methodological advise of the INISAV, organization that supplies all CREEs with certified inoculum.

Specific application rates have been developed for each entomopathogen. Information on the production methods, application rates and target pests for the common entomopathogens used in Cuba are presented in Table 4.

B. thuringiensis is by far the most widely used microbial insecticide and as observed in Table 5 four strains are used against a range of insect pests (Carbajal 1995; Fernandez-Larrea 1999).

B. bassiana is used in combination with pheromone traps for the control of the sweet potato weevil (*Cylas formicarius elegantulus*). In large areas, this fungus has been used to control the weevils *Cosmopolites sordidus* in bananas and *Pachnaeus litus* in citrus. *B. bassiana* combined with *M. anisopliae* have also been used against *Thrips palmi* in a range of crops. *V. lecanii* has been successfully employed in preventive programs against whiteflies (*Bemisia tabaci*) in tomatoes and beans. The antagonist *Trichoderma* is also mass reared in Cuba and effectively used in the biological control of various soil-borne plant diseases and for seed treatment. *T. harzianum* is used in horticultural crops against *Phytopthora capsici*, *P. parasitica*, *Rhizoctonia solani, Pythium aphanidermatum* and *Sclerotinia rolfsii*. There is also an unidentified *Trichoderma* species used in tobacco against *P. nicotianae* (Rodriguez *et al*. 1997).

Biopesticides are produced using flexible methodologies that take advantage of the most adequate but locally abundant substrate. For example, fruit juices are recommended for *Bt* production. These can be from orange, grapefruit, carrot, cucumber, tomato and sugar cane according to the availability. For fungi reproduction, a rice production waste is used. The use of by-products or wastes from agroindustrial production as substrates for mass production reduces production costs. For example, 1 t of the fungus *B. bassiana* produced in solid culture (rice wastes) can cover up to 100 ha. Using such simple methods, high levels (a yearly average of 2,132 t) of production of a series of biopesticides against insects, plant diseases and plant parasitic nematodes have been achieved nationally (Figure 4). Approximately 600,000 ha were treated

Table 4. Production methods, application rate and target pests of entomopathogenic fungi in Cuba

Entomopathogen	Production method	Application rates	Target pests
Bacillus thuringiensis	*Bt* strains collected from endemic populations in Cuba are being cultured on static medium made from a rice based product with the addition of juice from locally available sources, including, citrus, tomato, or cucumber juice	10^8–10^9 bacteria per hectare	Diamondback moth, *Plutella xylostella*; Cassava hornworm, *Erynis ello*; Tobacco budworm, *Heliothis vires*cens; *Mocis* spp.; and several other important Lepidopteran pests
Beauveria bassiana	*B. bassiana* is cultured on static medium	Between 1–3 × 10^9 spores per hectare in 10–40 l per hectare of liquid formulation	Banana root borer, *Cosmopolites sordidus*; sweetpotato weevil, *Cylas formicarius elegantulus*; rice water weevil, *Lissorhoptrus brevirostris*; and sugar cane borer *Diatrea sacharalis; Atta insularis; Thrips palmi*
Metarhizium anisopliae	*M. anisopliae* is produced on static medium. The spores are harvested and applied to the pest	Between 10^{11} and 10^{12} spores per hectare	Banana root borer, *Cosmopolites sordidus;* rice water weevil, *Lissorhoptrus brevirostris; Mocis* spp.; *Plutella xylostella; D. sacharalis;* and the greater wax moth *Galleria mellonella; Monecphora bicincta fraterna*
Verticillium lecanii	*V. lecanii* is cultured on static medium	10^{11}–10^{12} spores per hectare applied as a liquid preparation	Sweetpotato white fly; *Bemisia tabaci; Myzus persicae*

with these formulations in 1999 reaching 982,000 ha under biological control when adding areas undergoing *Trichogramma* releases.

Insecticidal Plants

As part of a broad IPM strategy, work on the cultivation and production of two species of plants with known insecticidal qualities, Neem (*Azadirachta indica*) and Paradise (*Melia azedarach)*, has been initiated. Small plantations of Neem and Paradise have been started and research on formulations and applications methods is advancing (Estrada 1994).

A project in progress for the industrial development of these two plants includes the sowing of 15, 12-ha microforests of each species, the establishment of four processing plants (semi-industrial) with a productive capacity of 200 t/year and a pilot plant for industrial production. Presently, in the country there are more than 300,000 Neem trees of which 25% are in production. It is calculated that in 1999 they produce about 2,500 t of seeds per season (Estrada *et al.* 1998).

One of the advantages of the use of Neem extracts is that small-scale artesanal production is possible and it can be used directly by farmers, since no complex extraction techniques are needed. Neem preparations can be prepared by farmers and applied against a series of insects and mites of horticultural crops. Table 6 provides a list of Neem-based products elaborated by INISAV used in 14 crops against a series of pests (Estrada & Lopez 1998).

Table 5. Bacillus thuringiensis: uses in Cuba

Strain	Pest	Crop	Dose (l/ha)
Btk (LBT-24)	*Plutella xylostella*	Vegetables	4–5
	Trichoplusia ni	Food crops	
	Erynis ello		
	Spodoptera frujiperda		
	Spodoptera spp.		
	Ascia monuste eubotea		
	Diaphonia hyalinata		
Btk (LB-21)	*Heliothis virescens*	Tobacco	5–10
	Plutella xylostella	Cabbage	1–5
Bt (LB-13)	*Phyllocoptruta oleivora*	Citrus	20
	Polyphagotarsonemus latus	Potatoes	3–5
	Tetranychus tumidus	Banana	5–10
Btk (LBT-1)	*Plutella xylostella*	Cabbage	5–10
	Mocis latipes	Pastures	1–2

The artesanal production technology consists in the cleaning and drying of the seed, and its preservation in a fresh and dry place. Later, the seeds are grounded to produce a powder, which is applied as an aqueous extract. For this 20–25 g/l of water must be mixed and left to rest between 6 and 8 h, at the end of which it is filtered. The application of the extract is done in

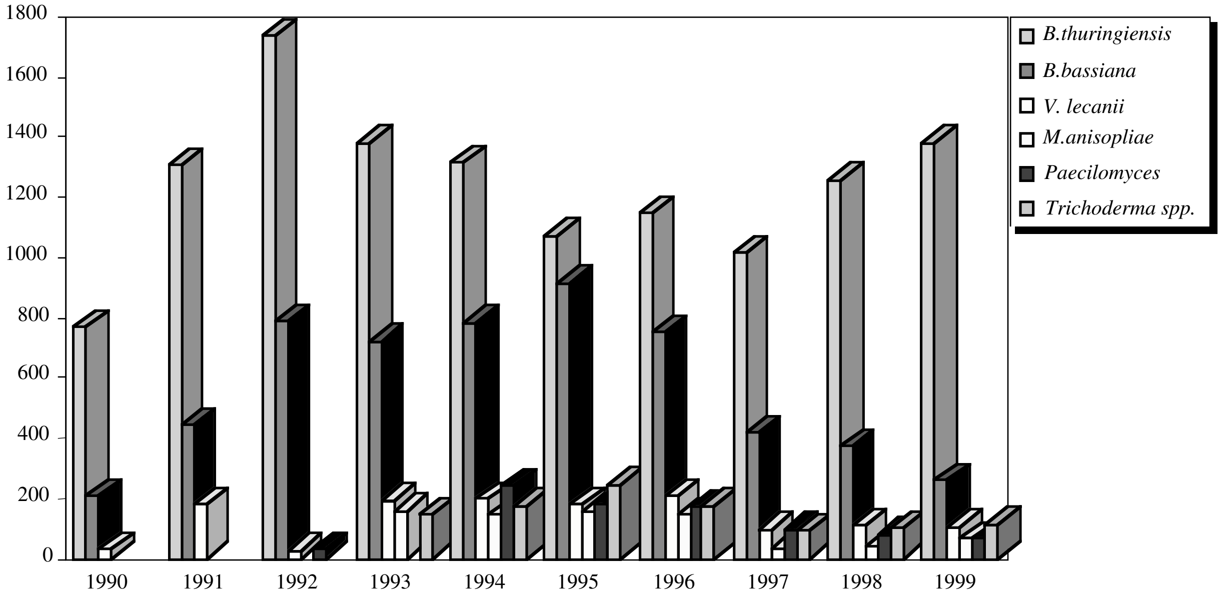

Figure 4. National production figures for biopesticides in Cuba (metric tons) (Pérez & Vazquez 2001).

Table 6. Natural products derived from Neem to control insect pests (Estrada & Lopez 1998)

Crop	Pest	Natural product	Dose
Avocado	*Selenothrips rubrocinctus*	OleoNim 80 CE	3 l/ha
	Psudacysta persicae	CubaNim-SM	7.5 l/ha
Chile pepper	*Bemisia tabaci*	OleoNim 80 CE	1.5 l/ha
	Aphis gossypii	CubaNim-SM	6 kg/ha
	Helicoverpazea		
Garlic	*Eryophyes tulipae*	OleoNim 80 CE	1.5 l/ha
	Thrips tabaci	CubaNim-SM	6 kg/ha
Rice	*Nezara viridula*	OleoNim 80 CE	1.5 l/ha
	Spodoptera sunia	OleoNim 50 CE	3 l/ha
	Diatraea lineolata		
Eggplant	*Thrips palmi*	CubaNim-Sm	6 kg/ha
Onion	*Thrips tabaci*	OleoNim 80 CE	1.5–3 l/ha
	Eryophyes tulipae	CubaNim-Sm	6 kg/ha
Citrus	*Phyllocnistis citrella*	OleoNim 80 CE	1.5–3 l/ha
	Toxoptera aurantii	CubaNim-Sm	6 kg/ha
	Aphis spiraecola	CubaNim-T	7.5 kg/ha
	Phyllocoptruta oleivora		
Cabbage	*Plutella xylostella*	OleoNim 80 CE	1.5 l/ha
		CubaNim-Sm	6 kg/ha
		CubaNim-T	7.5 kg/ha
Beans	*Bemisia tabaci*	OleoNim 80 CE	1.5–3 l/ha
	Empoasca kraemeri	CubaNim-Sm	6 kg/ha
	Diabrotica balteata	CubaNim-T	7.5 kg/ha
Maize	*Spodoptera frujiperda*	OleoNim 80 CE	1.5 l/ha
	Aphis maydis	OleoNim 50 CE	3 kg/ha
	Helicoverpa zea	CubaNim-Sm	6 kg/ha
		CubaNim-T	7.5 kg/ha
Water melon	*Diaphania hyalinata*	OleoNim 80 CE	1.5 l/ha
		OleoNim 50 CE	3 l/ha
		CubaNim-Sm	4.5 l/ha
Cucumber	*Diaphania nitidalis*	OleoNim 80 CE	1.5 l/ha
		OleoNim 50 CE	3 l/ha
		CubaNim-Sm	4.5 l/ha
Tobacco	*Heliothis virescens*	OleoNim 80 CE	1.5 l/ha
	Bemisia tabaci	OleoNim 50 CE	6 kg/ha
Tomato	*Bemisia tabaci*	OleoNim 50 CE	1.5 l/ha
	Keiferia lycopersicella	OleoNim 50 CE	3 l/ha
	Helicoverpa zea	CubaNim-SM	6 kg/ha
		CubaNim-T	7.5 kg/ha

the afternoon using a volume for the final solution of 300–600 l/ha; for which about 6 and 7.5 kg of powder are required. In soil treatments for nematode control, 100 g/m^2 are applied (Estrada 1995).

The use of Neem extracts is not limited to agricultural pest control. They are effective in the control of ectoparasites in cattle such as ticks (*Boophilus microplus*) and as an anthelmintic in laying hens for mites (*Megninia gynglimara*) and poultry lice (*Menopon gallinae*). Lice, fleas and other ectoparasites of rabbits and pigs have also been controled with excellent results (Estrada & Lopez 1998).

Cultural Management and Habitat Manipulation for IPM

The main thrust of the transition to sustainable agriculture has been the substitution of environmentally benign and locally available technologies for conventional technologies such as pesticides or fertilizers. In other words, Cuban production systems are increasingly relying on 'input substitution', while largely retaining the structure and function of monoculture based agricultural systems.

In many crops, however, Cuban scientists and farmers have complemented biocontrol through designed cultural practices directed at creating less favorable environmental conditions for the development of harmful organisms while encouraging diversity and abundance of natural enemies (Vazquez & Almaguel 1997). Many of these practices are being rapidly adopted by an increasing number of farmers. One such practice is crop rotation, which has been, used effectively against the weevil *C. formicarius*. However, crop rotation has been more widely used against weeds and nematodes. In the case of nematodes there are 53 different varieties among 28 crop species that are not susceptible to various species and races of *Meloidogyne*, which are recommended for use in rotations in infected fields (Cea & Fabregat 1993; Fernandez *et al.* 1998). Table 7 lists several rotations that have proven effective both in experimental trials and farmers fields in the regulation of a number of nematode species.

In many weed-suppressive rotations (see Table 8), sweet potato is used as a proceeding crop to the main crop (i.e. potatoes or beans), since sweet potatoes develop a dense canopy, 'closing' the furrow ridge and thus shading out aggressive weed species such as *Sorghum halepense*, *Cyperus rotundus* and the parasitic plant *Orobanche ramosa.*

Diversification strategies in the form of polycultures represent a challenge to researchers and farmers since the basis of Cuban agriculture has been the monoculture. Historical records, however, show that associated crops were somewhat common in the sugar cane areas of small landholders, which needed to maximize the use of the available land. Crop associations

Table 7. Effective crop rotations for the control of nematodes

Principal crop	Crop in rotation	Pest regulated	References
Tobacco	Peanut Corn Millet Vetch	*Meloidogyne incognita* *M. arenaria*	Fernandez *et al.* 1990
Tomato	Oil crop (ajonjoli)	*M. incognita*	Fernandez *et al.* 1990
Potato	Sweet potato–bean–corn/ bean–corn–sweet potato Corn or sorghum Cabbage–sweet potato		Gandarilla 1992
Corn	Peanut	*M. incognita*	Rodriguez *et al.* 1994
Vegetables	Onion or beans	*M. incognita*	Rodriguez 1998
Beans	Corn with vetch	*M. incognita*	Cea & Fabregat 1993

Table 8. Recommended crop rotation schemes to control weeds in Cuba (Paredes 1999)

Weeds	Rotation schemes
Annual grasses and certain other perennial grasses such as Johnson grass, *Sorgum halepense* and *Rottboellia exaltata*	Sweet potato–potato–peas–beans Sweet potato–potato–sweet potato–Potato Sweet potato–bean–sweet potato–potato Sweet potato–potato–sweet potato–potato Sweet potato–bean–sweet potato–bean Sweet potato–potato–peanut–potato Sweet potato–peanut–sweet potato–potato
Nutgrass, *Cyperus rotundus*	Corn–potato–sweet potato–bean Corn–pea–sweet potato–bean Corn–bean–sweet potato–potato Corn–sweet potato–potato–bean Sorghum–peanut or velvet beans–sweet potato–beans
Feverfew or Mugwort, *Parthenium hysterophorus* other Dicotyledonous annual weeds	Corn or sorghum–potato–corn or sorghum

were used by medium and large producers, for the payment of agricultural workers for labor such as the weeding of sugar cane plantations. In this way, the worker was authorized to plant beans and/or peanuts in the spaces between sugar cane furrows and they were only paid with money for the additional weeding after they harvested (Pérez 1998).

Ros (1998) conducted and ethnoecological study of polycultures in agricultural communities of the mountainous municipality 'El Salvador', in the province of Guantanamo to identify the crop associations with the best productive and environmental performance and of greater acceptance by producers. He documented 39 associations used by the farmers of the region. Among the most common were the coffee agroforestry system and the polyculture of maize–beans and cassava–beans. According to this author pest populations are kept at low levels in such systems and therefore do not constitute a problem for agricultural production in the region. Various other researchers have documented the pest suppressive performance of various polycultural arrangements (Table 9). In most polycultures the regulation of insect pest densities has been attributed to enhanced abundance and activity of predators and parasitoids (Pérez *et al.* 1998). Despite these studies much more information is needed in Cuba about the dynamics of insect pests, weeds and pathogens in diversified cropping systems.

Weed incidence has been shown to be lower in mixed crops. In general, an increase in the density of crops decreases weed populations, reaching greater suppression in associations with species of rapid growth and dense canopies where there is greater light interception early in the crop phase. This has been demonstrated in associations of cassava–maize, sugar cane–soybean, maize–bean and cassava–sweet potato (Leyva 1993). In polycultures of maize–sunflower weeds such as *Brachiaria extensa*, *Digitaria decumbens* and

Table 9. Selected examples of multiple cropping systems that prevent insect outbreaks in Cuba

Multiple cropping system	Pest(s) regulated	References
Sweet potato/corn	*Cylas formicarius*	Suris *et al.* 1995
Corn/vetch	*Meloidogyne* spp.	Cea & Fabregat 1993
Cassava/bean	*Erynis ello*	Quintero 1999
Cassava/corn	*Lonchaea chalybea*	Mojena 1998
Cassava/corn/beans	*Erynis ello* *S. frujiperda*	Pérez 1998
Potato/corn	*Trips palmi*	Vasquez *et al.* 1997b
Corn/sunflower	*Empoasca kraemeri* Defoliators/Chrisomelids	Alvarez & Hernandez 1997
Beans/sunflower	*Empoasca kraemeri* Chrisomelids defoliators	Alvarez & Hernandez 1997
Corn/tomato	*Bemisia* spp. *Liriomyza* spp.	Murguido 1995, 1996 Pérez 1998
Tomato/oil crop Cucumber/oil crop	*Bemisia tabaci*	Vasquez *et al.* 1997a
Suquini/corm	*Diaphania hyalinata*	Castellanos *et al.* 1997
Corn/suquini/oil crop Corn/cassava/cucumber	*Spodoptera frujiperda*	Serrano & Monzote 1997
Cabbage/tomato/sorgum/oil crop	*Plutella xilostella*	Choubassi *et al.* 1997
Water melon/corn Cucumber/corn	*Trips palmi*	Gonzalez *et al.* 1997
Cabbage/oil crop	*Bemisia tabaci*	Vazquez 1995
Cabbage/Tagetes	*Brevicoryne brassicae*	

Echinocloa colona are effectively controled (Paredes 1999).

A striking example of wide area adoption of polycultures in Cuba, has been the use of maize strips within vegetable and row crops for the regulation of *T. palmi* populations. Of Asian origin this insect pest appeared in Cuba in 1997, and attacks 20 different types of crops leading to losses of more than 29,000 t of tubers, grains and vegetables. Although the major biological control strategy against *T. palmi* has centered on the use of entomopathogenic fungi, strip cropping is complementary as maize plants affect the distribution of the pest across fields, and tasseling maize provides pollen for *Orius* sp. an important predator of thrips (Vazquez *et al.* 1997b; Gonzalez *et al.* 1997).

As a result of the suppressive effects of polycultures on pest and other complementary interactions typical of these complex systems, data shows that polycultures overyield corresponding monocultures. Quintero (1999) evaluated a number of crop associations in the Cooperativa Gilberto Leon and found LER (Land equivalent ratio) values above 1.6 in associations of cassava with maize, bean and tomato.

One of the few examples of conservation and management of natural enemies in Cuba is the enhancement of the predaceous ant *Pheidole megacephala* for the control of *C. formicarius* in sweet potato fields. This is an important achievement as most uses of *Pheidole* have proven successful only in perennial crop systems. The management system consists in the identification of reservoir areas where the ant is naturally abundant. In these areas, usually forested patches or areas with perennial crops, all pesticide applications are prohibited. *P. megacephala* colonies are transported from the reservoirs to the fields where sweet potatoes are planted. Colony transfer occurs in a variety of ways. A common technique, requiring high labor, is the use of banana stems. Banana stems are cut into several pieces, which are placed on the ground in the reservoir area. Stems are baited with honey or sugar solution and covered with a wet cloth or with banana leaves. The honey and humidity attract the ants, who proceed to move their colonies to the stems. Colonized stems are then transferred to sweet potato fields where they are exposed to the sun, causing the stems to dry out and forcing the ants to relocate and construct their nests in the ground. Once there, *P. megacephala* prey on *C. formicarius* larvae.

This method has provided close to 99% control of the sweet potato weevil in the Pinar del Rio Province, lowering crop production costs and enhancing yields per hectare (Castiñeiras 1986). So successful has the method been that the Ministry of Agriculture prohibited the use of any chemical insecticide in sweet potato fields where this method is being employed. In 1999, the ant was used in 8,470 ha planted with sweet potatoes across the island.

Cuba is the first country in Latin America in establishing the practical procedures for the use and dissemination of ants for insect control in a range of annual and semi-perennial crops. Ants are now also used in banana plantations to control de weevil *C. sordidous*, complementing the predatory activity of *Pheidole* with another predaceous ant, *Tetramonium guinese*.

The Integration of Pest Management Practices

The 'special period' IPM strategy involves the use of biological control tactics (mostly use of biopesticides) complemented by a range of ecologically sound management tactics for various classes of pests (arthropods, diseases, nematodes and weeds). The strategy involves substitution of pesticides by non-pesticidal methods of control, namely microbial control, but complemented by cultural control and habitat management. Table 10 lists the various pest management practices integrated in a series of important crops. As observed, there are crops such as coffee, sugar cane, cassava, sweet potato and pastures where the use of chemical insecticides has been completely eliminated. In crops such as rice, maize, potatoes, tomatoes and beans the use of agrochemicals is very low.

As mentioned above, the arrival of *T. palmi* has encouraged even further the redesign of farms (i.e. strip cropping) aimed at providing habitat and alternate resources necessary for a faster build-up of beneficial insects while discouraging colonization, distribution and increase of pest species. Also land from inefficient sugar cane production, has been redirected to producing crops which are currently imported (rice, oil and milk) or which show greater export potential (citrus, tobacco and coffee).

In many orchard systems, the encouragement of leguminous cover crops (*Crotalaria, Mucuna*, etc) are now extensively used to enhance within – orchard populations of beneficial predators and parasitoids. Cover crops also have many other effects in the orchard such as supplying nitrogen, conserving soil and suppressing weeds (Altieri 1994).

IPM in Urban Agriculture

Since the beginning of the 'special period' urban agriculture has rapidly become a significant source of fresh produce for the urban and suburban populations. A large number of urban gardens in Havana and other major cities have emerged as a grassroots movement in response to the economic crisis. These gardens are helping to stabilize the supply of fresh produce to Cuba's urban centers. During 1996, Havana's urban farms provided the city's urban population with 8,500 t of agricultural produce, 4 million dozens of flowers, 7.5 million eggs and 3,650 t of meat. In fact, urban farms provide enough fresh produce to meet the 300 g daily portion of vegetables recommended by UN-FAO. This system of urban agriculture, composed of about 8,000 gardens nationwide has been developed and managed along agroecological principles, emphasizing biocontrol and cultural practices such as crop diversification, recycling and the use of local resources (Altieri *et al*. 1999).

Through participatory research and extension methods, urban gardeners have been trained to design diversified gardens using a series of agronomic practices aimed at preventing or reducing pest incidence (Table 11).

Table 10. Principal IPM strategies used in a series of crops in Cuba (Vazquez & Almaguel 1997)

Crops	Resistant varieties	Cultural practices	Biopesticides	Natural enemies	Insecticides
Sugar cane	High	Medium	None	High	None
Tobacco	Medium	Medium	High	Low	Low
Coffee	High	High	Medium	High	None
Rice	High	High	High	Low	Low
Banana	Medium	High	High	Low	Low
Corn	None	Low	Medium	Medium	Medium
Bean	None	Low	Medium	None	Medium
Tomato	Medium	Medium	High	Low	Medium
Potato	Medium	High	Medium	Medium	None
Sweet potato	Medium	Low	High	High	None
Cassava	Low	Low	High	High	None
Cabbage	None	Low	High	Medium	Low

Table 11. Botanical pesticides and biological agents used in the control of insect pest outbreaks in Cuban urban agriculture (Fernandez *et al.* 1996)

Maintaining garden health	
Location	Choose a location free of harmful insects and inoculum Know local pests and choose crops with high resistance to them
Plant varieties	Plan a yearly cycle with uses seasonally adapted plants Keep diversity both within the plot and throughout the growing year. Combining plants with different levels of susceptibility to diseases
Planting	Ensure quality seeds which are healthy and without disease Timing of planting should be during ideal weather conditions, when yearly relevant pests cycles are at a minimum
Soil	Maintain optimal soil quality and fertility
Equipment	Wash equipment brought from one plot to another in order to prevent propagation of pathogens
Preventing and controlling pest outbreaks	
Soil treatment	Solarisation under a thin layer of transparent plastic sheeting; inversion of topsoil to expose soil pathogens; mulching with straw or sawdust
Protective plants	Incorporate insecticidal plants into the garden plots; make solutions from plants with insecticidal qualities to apply to infected crops or roots
Repellent fungi	Cultivation of mushrooms that control soil nematodes; application of solutions made from insecticidal mushrooms
Natural enemies	Release of parasitoids and predators of variety of insect pests; avoid the use of chemical pesticides which could inhibit the presence of beneficial insects and make pests more resistant
Entomopathogenic microorganisms	Application of various bacteria, fungi, and viruses for the control of a wide variety of pests
Traps	Yellow traps: Metal or wooden boards, painted a vibrant yellow, are coated in a sticky substance to attract and trap insects Light traps: To combat nocturnal insects a lamp is placed in the garden over a mixture of water and oil into which the insects fall Mollusk traps: Apply a mixture of water and boiled slugs to the plants, which repels with its odor, or set out trays of beer and salt which attract then drown snails and slugs

In the case of insects, IPM strategies are tailored according to crop susceptibility (Table 12). Strategies for vulnerable crops such as tomato, beans, pepper, cucumber and celery, differ from those used for more tolerant crops such as radish, carrot, lettuce and Chinese cabbage. However, whatever the crop mix, biological controls are a fundamental component of the IPM strategy in urban agriculture (Vazquez 1995). For example application of the fungus *V. lecanii* at a rate of 1 kg/ha can quickly achieve a 50% reduction in whitefly densities. Similarly, low-dosage applications of *B. thuringiensis* and the nematode *Steinernema carpocapse* are quite effective in suppressing *Plutella xylostella*, a caterpillar attacking cruciferous crops. Many bacterial and fungal plant diseases are controlled using *Trichoderma harzianum*, especially in seedbeds and as a 'dip' when transplanting seedlings. Nematodes are controlled using the fungus *Paecilomyces lilacinus* (Fernandez *et al.* 1996).

Table 12. Crops and their pest susceptibility in urban agriculture

Category	Crops	Approach
High susceptibility	Tomatoes, beans, peppers, celery	Preventive: spraying of biologicals
Medium susceptibility	Cabbage, beets, chard	Spraying of biologicals according to pest levels
Tolerant or pest free	Radish, carrot, lettuce, Chinese cabbage	No spraying

Conclusions

When the 'Special Period' was declared in 1991, Cuba was still importing US$ 80 million in pesticides per year. With adjustments that came with the 'special period', pesticide imports were reduced to US$ 30 million. More than US$ 10 million in savings accrued from pesticides such as Thiodan, Carbaryl, Carbofuran and Tamaron, substituted by biological controls in various crops (Maura 1994). Eleven years of increasingly intensive research and field implementation of biological control and other alternatives has allowed Cuba to undertake one of the most ambitious and successful programs of IPM in the history of any country.

After 1990, Cuba moved on an accelerated basis to replace agrochemicals with locally produced and in most cases biological substitutes. Using sustainable production methods, Cuba's agriculture recovered (production of tubers, vegetables, cereals and beans almost doubled from 1994 to 1998) while imports of pesticides and herbicides actually dropped. In the area of pest management, this meant the wide use of biopesticides (microbial products) and natural enemies to combat insect pests, resistant varieties, crop rotations and microbial antagonists to combat plant pathogens, and rotations, cover cropping and integration of grazing animals to manage weeds in pastures. The reliance on artesanally produced biocontrol agents has saved Cuba about 6.2 million dollars in pesticide imports (Maura 1994). Additional savings also accrue through the massive employment of biofertilizers, compost, natural rock phosphate, green manures and other products for soil fertility enhancement (Rosset & Benjamin 1994).

Undoubtedly, the area in IPM that has received the most attention is the mass rearing and release of natural enemies and the development, mass production and application of biological insecticides based on insect pathogens. Cuba is one of Latin America's largest producers of biological control agents. While the European Union's annual use of biopesticides reaches about 700 t per year, Cuba applies some 2,000 t, all produced nationally. The production of natural biopesticides based on plant extracts is particularly Neem, is also another important development.

There are various factors that account for the success of Cuban IPM programs:

- High level of education and significant numbers of IPM professionals directly involved in research and implementation.
- Organized nature of rural Cuban society, especially the spread of cooperatives.
- Broad collaboration, exchange and partnerships among institutions, researchers and farmers.
- Supportive governmental policies.
- Extensive infrastructure of CREEs.

Cuba's agriculture has partly moved beyond 'input substitution' by implementing conservation biological control programs such as the use of ants for the control of sweet potato and banana pests and the wide use of crop rotations, polycultures and cover cropping to enhance beneficial biodiversity in agroecosystems.

Cuba's success IPM stories have gained much attention in the rest of Latin America countries, and Cuban experts continuously train and advise personnel from universities, farmers associations and non-governmental organizations on artesanal methods for mass production of biological control agents. In the last 10 years, thousands of farmers, agricultural technicians and rural policy specialists from the Americas, have travelled to the island to learn first hand about Cuba's new agriculture. Cuba also supplies through a growing international market many other countries with biopesticidal preparations.

Whether the Cuban agricultural reform model can be replicated will depend on the willingness of countries to invest in human capital, agricultural research, land reform and change in the rural infrastructure and social organization to the degree Cuba has.

Despite the advances in IPM in Cuba, the academic and farming community are divided on a very key issue regarding the future agricultural technology path: whether after the 'special period' is over Cuba should further develop its agriculture along agroecological lines, or as capital and market constraints are overcome Cuba should return to the agrochemical technology which characterized Cuba prior to 1989 (Montano *et al.* 1997). The actual IPM policy in Cuba as stated in the new 1997 environmental law, article 132 (Sections b and d) says:

(b) promote the rationale use of biological and chemical means, according to local conditions and resources, especially these that reduce environmental pollution
(d) the preventive and integrated management of insect pests and diseases, with special attention to the use of biodiversity related resources.

There is no doubt that the current Cuban policy scenario encourages biologically based IPM. In practice many farmers are transcending 'input substitution' by moving towards an agriculture that maximizes the use of ecological services. In the light of these facts it is very difficult to envision Cuba returning to pesticide calendar spraying characteristic of the 60s and 70s or to the dependency on foreign inputs typical of the 80s. Cuba, as many other developing countries facing a strong economic crisis should, will most likely continue supporting its agricultural model that is not only cost saving but also environmentally and health expanding (Pérez & Vazquez 2001). Then maybe however limits to growth of the ecological model. Cuba has the land, but may not have the labor free, for full-scale transformation to agroecologically-based production (Oxfam America 2001).

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