Alternative Agriculture in Cuba

Cuba, having initially tied its agricultural productivity to the fate of the Soviet Union, has successfully developed and implemented an alternative agricultural model.

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In 1959, with the whole world watching, Cubans committed themselves to a new social order. A population made up of peasants, laborers, and millionaires underwent a violent shift toward a system that promised to eliminate hunger, educate the masses, and distribute resources equitably. From the beginning, the revolution was mainly about agriculture. Dating back to Columbus’ discovery of the island, Cubans had never been truly autonomous in controlling their land. Spaniards, Americans, the British, and others imposed their vision on Cuba and created great riches for themselves from Cuban sugarcane and Cuban labor. When Castro rose to power, it was with the full support of the farming classes, and his promise to return the land to the people who worked it galvanized the nation.

Sadly, a great leader is not necessarily a great manager, and the early post-revolutionary years were characterized by chaotic efforts to do good on all fronts. Although education, health care, and living conditions improved markedly, attempts to restructure Cuba’s agricultural practices were a failure. Faced with an embargo that cut off sugar sales almost overnight, Castro searched for ways to feed the country. Perhaps inevitably, Cuba eventually entered into a reciprocal trade agreement with the Soviet Union, and Soviet largesse made up for Castro’s excesses and failures in agricultural planning. Cuba supplied sugar to the Soviet bloc and in return received staple foods, petroleum, and manufactured goods (Castellanos and Alvarez 1996).

To maintain high levels of sugar production for export, Cuba adopted a developmentalist agricultural strategy similar to that seen in the United States. In this, Cuba had the full support of the USSR where high-input, heavily mechanized growing practices were well advanced. Using Russian goods and expertise, Cuba’s agriculture was transformed: poor soils were rectified with inorganic fertilizers, crop pests controlled through intense pesticide application, and human laborers replaced by machines. Central-planning techniques were adopted, and agricultural management moved from being a single farmer’s decision about what to grow, to a huge, state-run enterprise. Increased yields followed swiftly, and Cuba, although dependent upon the USSR, became the most prosperous country in Latin America. In fact, the World Health Organization’s Quality of Life Index for 1989 (WHO 1989), based on such factors as literacy, life expectancy, and caloric intake, placed Cuba eleventh in the world, with the United States in fifteenth place.

The perils of Cuba’s dependent position were revealed in 1989 as the Soviet bloc fell into ruin. Within three years, imports of food from the USSR dropped by almost 50%, and the importation of other goods was affected similarly (Castellanos and Alvarez 1996). The materials necessary to maintain Cuba’s input-dependent agricultural system were no longer available, and the danger of starvation became a reality. Cuba was, therefore, faced with a unique challenge: to simultaneously increase food production and reduce or eliminate inputs. To do so, Cuba adopted as national policy an alternative agricultural model, referred to in the United States as Low Input Sustainable Agriculture (USDA 1980).

The goals of this system were both philosophical and practical in nature. In an immediate sense, such a strategy was dictated by the scarcity of fertilizers, pesticides, and farm implements. Yet a deeper issue also was involved: along with many of the world’s scientists, Cuban researchers increasingly had become disillusioned with classical farming methods as practiced by the United States and the USSR (Levins 1993). The use of inorganic inputs was perceived as poisoning the environment, and the continual escalation of chemical requirements was regarded as both costly and dangerous. In response, Cuban scientists had for many years been exploring alternative agricultural techniques. They thus were well prepared to face the challenge of nationwide conversion to sustainable agricul-
In many ways mirrors worldwide trends. Following the developmentalist ideology described by Levins (1993), agricultural development has proceeded along a steady line from less developed to more advanced production techniques. As in North America and Europe, such progress has followed several major trends, including (1) the replacement of labor-intensive production by capital-intensive production; (2) a change from small, multiple crop production units under individual management to large-scale monocultures under centralized or corporate control; and (3) the replacement of local, grower-based agricultural knowledge with the more specialized, widely applied results of scientific research.

In Cuba, this trend began some centuries ago. Pre-Colombian Cuba was populated by the agricultural Arawak Indians, whose techniques for growing maize, cassava, and other crops were of necessity, low input. Their resource management strategies were quite sophisticated, utilizing locally adapted crop assemblies to minimize competition for soil resources and water and planting of peanuts and other nitrogen-fixing legumes to enhance soil fertility (Rosset and Benjamin 1994).

As the Spanish colonized Cuba in the wake of Columbus’ 1492 discovery of the island, they initially relied on Arawak techniques and labor to supply needed resources. Soon, however, the Spaniards began to convert to plantation agricultural practices. Large plantations, relying on indigenous and imported slave labor, produced sugar and tobacco for export to Europe. Forests were cleared to free more land for agriculture and animal production, with felled wood contributing to the shipbuilding and hardwood export trades. By the late 1700s, sugar was firmly established as the dominant crop in Cuba, a situation further intensified by the slave revolt and subsequent demise of sugar production in Haiti, at that time the world's foremost supplier of sugar (Baker 1997).

Although the political situation changed radically in Cuba from 1800 to 1959, reliance on a sugar monoculture did not. The vast profits available from exported sugar encouraged an increas-
The diversification of agriculture away from reliance on sugar was one of Castro's first goals. By 1962, however, the effects of the U.S. embargo had resulted in widespread hunger, and rationing was introduced. Faced with a starving nation, Castro abandoned attempts at diversification and turned with a new passion to sugar production.

The Cuban Revolution
The existence of this vast and often hungry peasant class, together with institutionalized political corruption, set the stage for Castro's 1959 overthrow of the U.S.-supported Batista regime. Advocating bottom-up social reforms, Castro won widespread support among the lower classes, who supplied him with food, arms, and volunteers during the 2 years of armed struggle that culminated in Batista's expulsion from Cuba on 1 January 1959.

Agrarian reform was the first item on Castro's agenda. All land holdings greater than 67 hectares were repatriated as state property, driving huge numbers of upper-class landholders into exile. Further reforms allowed the state to seize control of foreign-owned oil and sugar processing plants and resulted in a retaliatory U.S. embargo on Cuban sugar. In 1961, the Trade Embargo Act was passed into law, banning all Cuban exports to the United States.

The diversification of agriculture away from reliance on sugar was one of Castro's first goals. By 1962, however, the effects of the U.S. embargo had resulted in widespread hunger, and rationing was introduced. Faced with a starving nation, Castro abandoned attempts at diversification and turned with a new passion to sugar production. A warlike effort to increase the sugar harvest to its highest level ever was begun. Tens of thousands of workers were diverted from their normal jobs and sent to the cane fields, and virtually all arable land was turned over to sugarcane production. Although a record harvest was achieved, the entire country was left in chaos (Castellanos and Alvarez 1996). Clearly, sugar exports alone were not sufficient to feed the nation.

Soviet Alliance
The reign of monoculture was strengthened in 1968 when Castro, unable to provide food security for Cuba, joined the Council for Mutual Economic Assistance (COMECON), the Soviet bloc's economic community. Cuba's role in COMECON was to supply sugar to European socialist nations in exchange for which, the island's import needs would be met. Thus, the revolution, whose goal had been Cuban independence, simply paved the way for a new outside power to prop up Cuba's unstable agricultural situation.

The formalization of trade relations with Soviet bloc countries had far reaching implications for Cuban agriculture. For all its ideological rejection of capitalist culture, the Soviet government was committed to technological progress following a Western model. Progress was measured by output, and methods that increased productivity were adopted widely. The result, for both Cuba and the USSR, was a highly industrialized farming system. In Cuba, some 75% of all agricultural lands were devoted to state-run farms, whose main task was the production of sugar for export (Castellanos and Alvarez 1996).

A Classical Model
These large, state-run enterprises exhibited many of the hallmarks of modern agriculture. Wherever possible, human labor was replaced by mechanization, resulting in an increasingly urbanized populace. Fertilizer inputs were considerable, with the soil viewed as an expendable resource. Monocultures, which are extremely vulnerable to insect pests, were protected by high levels of pesticide application, and required large-scale irrigation.

Such procedures are part of what may be termed the classical model (Vandermeer et al. 1993) of agricultural production employed by most developed countries. In the classical model, dependence on external sources of food is high. In Cuba's case, this dependence extended to external sources of almost all agricultural inputs. Food consumed in one region generally was grown elsewhere, so efficient transportation and refrigeration were essential. Reliance on imported technology was high, and involved both machinery and chemicals.

Employing this classical model of production, Cuba was far from independent in its food supply. Imports of food, machinery, chemicals and animal food were extensive. The results were good. Productivity climbed as tractors replaced animal traction, mechanization replaced human labor, and use of chemical pesticides insulated growers from the effects of insect damage and soil depletion. These technologies became fundamental to the Cuban agricultural system and were considered a sign of its increasing sophistication (Castro himself viewed escalating pesticide use as a sign of Cuba's progress [Vandermeer et al. 1993]). By the late 1980s, 82% of agricultural pesticides used in Cuba were imported from the Soviet bloc, and 42% of its fertilizers were from the same source (Deere 1992).

Such a situation, although productive, was extremely precarious. Through its dependence on Soviet bloc imports and exports, Cuba's productivity was tied inextricably to the fate of the Soviet
Union. Some 84% of all Cuban trade was with the Soviet Union and Eastern Europe, and other forms of aid from these sources totaled more than US $3 billion (Baker 1997). This dependence was intensified by the favorable terms of trade the Soviets offered Cuba. Sugar, Cuba’s main export, was purchased at a fixed price, regardless of world market fluctuations. By trading this sugar, which comprised 75% of all Cuban exports in 1988 (Pastor 1992), Cuba was able to obtain the food, chemicals, and manufactured goods needed to sustain its populace.

**Fall of the USSR**

The collapse of the Soviet bloc in 1989 dealt a catastrophic blow to Cuba’s economy. Imports from Eastern Europe fell by half from 1989 to 1990, and by 1992 plunged to a third of their former value (Castelanos and Alvarez 1996). During the same time, the U.S. embargo against Cuba was strengthened through the M ack Amendment, passed in 1992, which made it illegal for foreign subsidiaries of U.S. companies to trade with Cuba; shipment of any medicinal or food items to Cuba was forbidden.

These events precipitated a crisis that affected almost all levels of society. Cuba’s sophisticated, high-input agricultural system faced an 80% drop in pesticide and fertilizer availability, and access to fuels and irrigation also fell sharply. Machine parts for transportation and agricultural devices became unavailable, rendering many mechanized processes useless. Imports of food for human consumption decreased quickly and extensively. Average caloric intake per individual declined by 30% from 1989 levels, and nutritional deficiencies led to the outbreak of new diseases such as optical neuritis (Eckstein 1997). Cuba, the only country in Latin America to have eradicated hunger, was faced with widespread malnutrition and food shortage.

The focal point of these trade losses was agriculture. “The food question,” said Castro, “has number one priority” (as quoted in Rosset and Benjamin 1994). Long dependent on outside sources for the majority of its production and produce needs, Cuba appeared ill equipped to deal with this new crisis.

**A New Model**

Within Cuba, however, as in many countries, a quiet agricultural revolution had been taking place. Even as the classical model of agriculture was being implemented, a vocal minority was decrying its dangers. The 1962 publication of Rachel Carson’s Silent Spring brought worldwide attention to the costs of the classical model. The intensive use of pesticides for pest control led to escalating cycles of pest resistance, demanding new chemicals and larger doses to achieve control. Pesticides were demonstrated to have significant and long-term health risks for humans and other organisms, causing widespread fear about their presence in foods. Huge monocultures, designed to exploit economies of scale, required constant inputs of fertilizers to compensate for declining soil fertility and erosion, and the mechanized growing techniques used in such monocultures put an entire class of rural laborers out of work.

As such trends became widely acknowledged, an alternative model of agricultural production emerged. Attempting to address the health, environmental, and social costs of the classical model, the alternative model called for a change in inputs, a reduction in scale, and new systems of production. By using organic and biological fertilizers, chemical fertilizer input would be reduced or eliminated; the introduction of natural enemies and biological pesticides would decrease reliance on chemical pesticides; strategic crop mixes would help in weed control and soil rectification; and seasonal rainfall patterns would be exploited to reduce the need for irrigation. Additionally, the substitution of human labor for mechanization, and of animal traction for tractors, would significantly reduce fuel requirements, and help reestablish viable rural communities.

This alternative model was given a boost in 1989 when the National Academy of Sciences published its report on alternative agriculture, concluding that available data gave no evidence that the classical model offered higher production levels than the alternative model. Coupled with the noneconomic benefits of the alternative model, such conclusions generated increasing support for the alternative model. Its lower cost to growers and decreased reliance on outside sources of inputs made the model particularly well suited to developing countries (Altieri and Hecht 1990), and the reduction in health-threatening chemical inputs led the United States Department of Agriculture to endorse low input sustainable agriculture (USDA 1980).

The philosophical basis of the alternative model generally is accepted throughout the developed world, yet adoption of this production system is still rare. Full conversion from conventional to alternative production methods can involve a profit-lag of up to 5 years during which productivity and profitability may suffer. This financial sacrifice, combined with the deeply entrenched interests of pesticide and fertilizer producers, has hampered the comprehensive adoption of the alternative model, and conversion generally has been limited to individual farms (Thrupp 1996).

**The Alternative Model in Cuba**

As the full implications of the Soviet bloc dissolution were realized, Cuba’s adoption of the alternative model became a matter of necessity rather than choice. A “special period in a time of peace” was declared during which Cuba’s primary goal was to be the achievement of food security and economic independence. Castro called on agricultural scientists to “produce more food without feedstock, fertilizers or fuel” (as quoted in Rosset and Benjamin 1994). The alternative model was declared official government policy, and Cuba’s scientists were expected to provide the needed biological control, biological fertilizer, soil-rectification, and production technologies.
This daunting task was not as impossible as it seemed, for Cuba's scientists have a long tradition of exploring alternative technologies (Vandermeer et al. 1993). The National Institute for Research in Citrus and Other Fruits, for example, had embarked upon a 5-year plan to reduce pesticide inputs well before the advent of the special period. Biological control of citrus pests dates back to the 1930s in Cuba. In 1930, for example, the introduction of Eretmocerus serius Silvestri, a parasitoid of Chinese origin, achieved control of the citrus blackfly, Aleurocanthus woglumi Ashby (DeBach 1974). Further successes in the same year were gained through the release of Liocophaga diatreae (Townsend), an endemic parasitoid fly, for the control of the sugarcane borer, Diatraea saccharalis (F.) (Scaramuzza 1930). Although these biological control efforts were carried out under the auspices of U.S. scientists, the 1960s witnessed the implementation of Cuban biological control research programs. Since 1968, such programs have sponsored the release of L. diatreae over 100% of the area under sugarcane seed production (DiLott et al. 1993).

Research on alternative agricultural practices gained momentum in the 1970s and 1980s as a group of Cuban scientists in various disciplines increasingly became alarmed about the long-term negative effects of classical agriculture. In the mid-1970s, scientists at the Institute of Botany refused to carry out the Forestry Department's plans for terracing mountainsides with monocultures of teak and then clear-cutting the trees, stating that the plan's risks of pest outbreak and soil erosion were unacceptable (Levins 1993). In the mid-1980s, this vocal minority of scientists in favor of the alternative model began to gain a hearing. Their suggestions were valued primarily as a means of saving money on petroleum products purchased from other countries and were, therefore, swiftly adopted (Vandermeer et al. 1993). By the late 1980s, the Ministry of Agriculture adopted biological control as national policy (Levins 1993).

**Reforms After 1989**

Cuba's agricultural scientists thus were well prepared to face the economic catastrophes of 1989 by rapidly implementing alternative agricultural practices. Preliminary data on alternative farming techniques already existed, and this knowledge base allowed for the rapid expansion and redirection of Cuba's agricultural research program. The events of 1989 simply triggered and formalized a philosophy that long had been gaining popularity with Cuban scientists.

Yet conversion from classical to alternative agricultural processes does not come easily, no matter how much popular support is available. In Cuba, the difficulties of such a conversion were increased by the triple challenge the country faced—to simultaneously increase food production, reduce or eliminate inputs, and maintain a steady crop of export sugarcane to exchange for hard currency. To meet these challenges, Cuba not only has undertaken the largest shift to organic farming techniques the world has ever known but also has restructured its social and economic systems from the ground up (Eckstein 1997).

This reorientation of society along ecological lines required a general strategy reaching into every area of production. In accordance with the philosophy of Che Guevara, who emphasized the inseparability of social and economic development (Levins 1993), Cuba is attempting to achieve food self-sufficiency by involving the entire populace in the effort. Central planning helps to determine research and education programs, disseminating the knowledge needed to employ alternative agricultural techniques. Economies of scale are exploited and scarce resources directed to where they are needed most. At the same time, the units of production are kept as small as possible, empowering individual growers and drawing upon their specialized knowledge of local agronomic conditions. Additionally, such small-scale units of management have created numerous small research centers, allowing farmers and scientists to interact more frequently and effectively.

**National Conversion**

Introducing alternative farming techniques in an entire country involves complexities far beyond those encountered in a single farm conversion. Cuba's conversion has focused on the development, implementation, and coordination of new techniques in several key areas: insect management, plant disease management, weed management, soil management, and labor mobilization.

**Insect Management**

The massive decline in pesticide imports that followed the dissolution of the Soviet bloc in 1989 left Cuba's agriculture system extremely vulnerable to insect pests. Since the introduction of agrochemicals into Cuba in the 1940s, these inputs had become increasingly vital to Cuba's food production. Although research on alternatives was being carried out well before 1989, wide-scale implementation of alternative techniques had not been attempted.

In recent years, a countrywide shift to biological control methods has been set in motion (Table 1). This effort is overseen on a national level by Cuba's Ministry of Agriculture, which includes crop protection organizations such as the National Service of Plant Protection, the Central Research Laboratory, 14 regional research laboratories, 60 regional plant protection stations, 27 diagnostic laboratories, and 218 Centers for the Reproduction of Entomophages and Entomopathogens. Important crops such as tobacco and sugarcane have their own specialized agencies.

The Ministry of Agriculture's work since 1989 has focused on the development and application of biological control against insect pests. Traditional control methods based on peasant farming practices, such as the use of ants for the control of banana and sweet potato pests, have been intro-
Table 1. Biological control agents employed in Cuba

<table>
<thead>
<tr>
<th>Agent</th>
<th>Target pests and Crop protected</th>
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<tbody>
<tr>
<td><strong>Bacteria</strong></td>
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<tr>
<td>Bacillus thuringiensis (Berliner)</td>
<td>Heliothis spp. (Noctuidae) on tomato and tobacco; Erinnyis ello (L.); Sphingidae on papaya and cassava; Spodoptera spp. (Noctuidae) on tomato, pepper, sweet potato, and watercress; Plutella xylostella (L.) (Yponomeutidae) on cabbage</td>
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<td><strong>Fungi</strong></td>
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<td>Beauvaria bassiana (Balsamo)</td>
<td>Lissorhoptrus brevirostris Kuschel (Curculionidae) on rice; Galleria mellonella (L.) (Pyralidae) in beehives; Cosmopolites sordidus (Germar) (Curculionidae) on plantain; M ocis spp. (Noctuidae) on forage crops; Diatrea saccharalis (F.) (Pyralidae) on sugarcane</td>
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<tr>
<td>Metarhizium anisopliae</td>
<td>Lissorhoptrus brevirostris Kuschel (Curculionidae) on rice; Galleria mellonella (L.) (Pyralidae) in beehives; Cosmopolites sordidus (Germar) (Curculionidae) on plantain; M ocis spp. (Noctuidae) on forage crops; Diatrea saccharalis (F.) (Pyralidae) on sugarcane</td>
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<tr>
<td>Paecilomyces lilacinus (Thom)</td>
<td>Meloidogyne spp. (Nematoda) on coffee and guava; Radopholus similis (Cobb) (Nematoda) on plantain</td>
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<tr>
<td>Verticillium lecanii (Zimmermann)</td>
<td>Bemisia tabaci Gennadius (Aleyrodidae) on sweet potato, tomato, cucumber, beans, and peppers</td>
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<tr>
<td>Trichoderma spp.</td>
<td>Phytophthora nicotianae Breda de Haan (fungus) on tobacco; Rhizoctonia solani Kuhn (fungus) on tobacco; Fusarium spp. (fungus) on tobacco; Sclerotium rolfsii Saccardo (fungus) on peanuts and beans</td>
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<tr>
<td><strong>Parasitic Diptera</strong></td>
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<td>Lixophaga diatraea (Townsend)</td>
<td>Diatrea saccharalis (F.) (Pyralidae) on sugarcane</td>
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<tr>
<td><strong>Parasitic Hymenoptera</strong></td>
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<tr>
<td>Trichogramma spp. (Trichogrammatidae)</td>
<td>M ocis spp. (Noctuidae) on forage crops; Erinnyis ello (L.) (Sphingidae) on yucca; Diatrea saccharalis (F.) (Pyralidae) on sugarcane</td>
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<tr>
<td>Telenomus minimus Ashmead</td>
<td>Spodoptera spp. (Noctuidae) on legumes</td>
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<tr>
<td><strong>Predatory Ants</strong></td>
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<tr>
<td>(Formicidae)</td>
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<td>Pheidole megacephala (F.)</td>
<td>Cylas formicarius elegantulus (Summers) (Curculionidae) on sweet potato; Cosmopolites sordidus (Germar) (Curculionidae) on plantain</td>
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<tr>
<td>Tetramorium guineense Bernard</td>
<td>Cosmopolites sordidus (Germar) (Curculionidae) on plantain</td>
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<tr>
<td><strong>Nematodes</strong></td>
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<tr>
<td>Heterorhabditis heliothidis (Khan, Brooks &amp; Hirschmann)</td>
<td>Cylas formicarius elegantulus (Summers) (Curculionidae) on sweet potato; Plutella xylostella (L.) (Yponomeutidae) on cabbage</td>
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The reintroduction of traditional peasant practices for management of insect pests also has proven fruitful in Cuba. Additionally, modern technologies have been utilized for the mass rearing and release of natural enemies and for the development, mass production, and application of entomopathogenic organisms.

The first step in applying any biological control method is to monitor for the presence of crop pests. The system now in place in Cuba is among the world's most comprehensive. Monitoring was first developed in the 1970s, when it was used as a means of tracking and delaying insect resistance to pesticides. Today, each of the 60 research stations overseen by the Ministry of Agriculture includes a monitor plot. These plots are planted with the important crops and varieties of their regions, and on-site weather stations constantly record climate conditions. Scientists regularly evaluate crop phenology, pest population levels, disease onset and development, and crop yield data. Additionally, several fields in each region are selected as test plots, and data on crop threats are collected. When potentially dangerous climatic conditions, diseases, or pests are discovered, local farmers are advised of the threat. Control measures employed in response to such a situation depend upon local production and availability of biological control agents.

The mass production of biological control agents was an early goal of Cuba's shift to alternative agricultural practices. Lack of currency meant that such agents could not be purchased from other countries, and, in fact, large-scale production of biological control organisms is rare. In Cuba, the Centers for the Rearing of Entomophages and Entomopathogens (CREEs) are responsible for producing the needed numbers of organisms. These centers function as artisanal (i.e., staffed by skilled laborers rather than scientists) production centers, which are located on collective farms and operated by members of the collective. Operation of these centers by local residents, whose education levels range from Ph.D. scientists to high school graduates, has helped destroy the myth that biotechnology requires high-tech, sophisticated laboratories and personnel to achieve success. The entomopathogens and entomophages produced are available free of charge to cooperative members and are sold for profit to others.

Biological control agents produced at the CREEs are varied, and are targeted to meet local pest control needs. Entomophage production has focused primarily on Trichogramma, a hymenopteran egg parasitoid. Trichogramma colony stocks are collected from the region's target pests, ensuring a high level of host preference and adaptation by the parasitoid. These field-collected Trichogramma are reared in the laboratory and allowed to oviposit in the eggs of either the rice moth, Cercyra cephalonica (Stainton); or the Angoumois grain moth, Sitotroga cerealella (Olivier); which are stored product pests. Parasitized eggs are collected in vials and transported to pest-infested fields when 50% emergence has occurred. Release rates are determined by the intensity of pest infestation and range from 8,000 to 30,000 Trichogramma per hectare of agricultural land. To date, Trichogramma releases have been used successfully to control the sugarcane borer; the cassava hornworm,1 Erinnyis ello (L.); the tobacco budworm, Heliothis virescens (F.); and several Mocis spp.; which are lepidopteran forage pests (Diott et al. 1993).

Entomopathogenic fungi and bacteria are also mass-produced at local CREEs. Cuba's production and deployment of these biological control agents are among the most highly developed in the world and have allowed for control of a great variety of pests. Agents employed include Bacillus thuringiensis (Berliner), Pasteuria penetrans (Thorne), Beauvaria bassiana (Balsamo), M etarhizium anisopliae (M. etchnicoff), Paecilomyces lilacinus (Thom), and Verticillium lecanii (Zimmerman). Organism efficacy is ensured by constant quality control and monitoring; for each formulation of bacteria or fungi, virulence is evaluated in the laboratory prior to deployment. Application rates are determined by evaluating pests exposed to standardized doses of entomopathogens; spores per pest organism per application volume are evaluated and adjusted for maximum benefit. After wide application of a formulation, treated crops are scouted frequently to determine incidence and severity of entomopathogen infection. In 1995, some 500,000 hectares of agricultural land were treated with biological control agents, up from 77,000 hectares in 1990 (F. F. Monzote, personal communication). Good control of nematodes, lepidopterans, and weevils has been achieved through use of locally manufactured biological pesticides.

The reintroduction of traditional peasant practices for management of insect pests also has proven fruitful in Cuba. Based on input from farmers, Cuba has pioneered the use of generalist ants against the sweet potato weevil, Cylas formicarius, against the tobacco budworm, Heliothis virescens (F.); and the sugarcane borer, COER P. Thaliana (F.). Previous research in other countries (Carroll and Risch 1990) had indicated that the bigheaded ant, Pheidole megacephala (F.), could not provide effective pest control in annual crops, but Cuban farmers, observing the voraciousness of this ant against the sweet potato weevil, felt that the potential for control existed. Preliminary data from the 1980s were promising, and today this system is employed in the entire Pinar del Rio province, a prime growing region.

Directed research on the use of the bigheaded ant has generated an effective management system. Reservoir colonies of this ant are created in areas with high natural populations, and all pesticide applications are prohibited. At critical infestation periods, ants are transported to sweet potato fields via a labor intensive method of inducing them to colonize banana or plantain pseudostems liberally dosed with sugar. After colonization, the pseudostems are transported to target field where subsequent desiccation induces the ants to move...

1 Common name not currently among common names of insects and related organisms approved for use by the ESA Committee on Common Names of Insects.
to the ground and begin feeding on the sweet potato weevil. Efficacy rates of up to 99% have been achieved in some regions, and use of the bigheaded ant has replaced chemical pesticides in sweet potato crops, producing higher yields at a lower cost (Dlott et al. 1993). Currently, biological control using ants is being extended to plantains for the control of the banana root borer, Cosmopolites sordidus (Germar).

**Plant Disease Management**

The biological control of plant pathogens has lagged behind the development of biological control of insects. Cuban research on plant disease traditionally has focused on the epidemiology of poorly understood diseases, and fungicides and other chemicals have been relied upon for disease control. In recent years, the emphasis of plant disease research in Cuba has shifted to methods of disease diagnosis and reduction, both fairly new research disciplines. Until the early 1980s, diagnostic tests did not exist at Cuba’s research stations, and development of biological agents for disease control did not begin in earnest until 1990.

Disease detection has been enhanced by the incorporation of techniques from veterinary and human health research. The Cuban National Animal and Plant Health Center has developed diagnostic protocols employing electron microscopy, dot blot tests, immunofluorescence, and serological tests (ELISA). The production of ELISA kits has proven so successful that Cuba now exports these tests worldwide for the detection of important plant diseases. Additionally, the local pest monitoring stations maintained by the Ministry of Agriculture are used to track the development and spread of plant diseases, and local farmers are alerted to any worrisome trends.

As fungicide availability has declined, Cuban researchers have begun to seek alternative means for coping with plant diseases. On banana plantations, the fungus *Mycosphaerella musicola* (Leach) causes yellow sigatoka disease and is responsible for large reductions in yield. This fungus kills banana leaves, and a linear relationship exists between the number of leaves killed and the degree of yield reduction. Monitoring plots to track the incidence of yellow sigatoka infection have been established at all major growing sites and until 1989 were used to determine the optimum timing of pesticide application. More recently, however, sigatoka-tolerant cultivars have been discovered, and these now are widely planted (Shishkoff 1993). When infections do arise, treatment consists of leaf stripping and the application of mineral oils, which appear to inhibit infection.

The discovery of microbial antagonists for the control of plant disease has become a major aim of Cuban research since 1989. Prior to that time, the exhaustive screening and evaluation procedures required for such research were not regarded as cost effective. In 1990, however, the Institute of Plant Health began to investigate microbial antagonists for the control of tobacco root diseases. Soil samples were collected from both infected and disease-free fields, and 25 colonies of *Trichoderma* spp. fungi were isolated for evaluation as antagonists against a variety of root-disease pathogens. Paired tests of antagonists and targets were carried out to evaluate antagonist efficacy, and four highly effective *Trichoderma* spp. isolates were discovered. These were then tested in greenhouse conditions against heavily infested tobacco seedlings. These isolates have proven so effective that fungicide use in tobacco seedbeds has been eliminated almost entirely. *Trichoderma* now is mass-reared at several CREEs, and streamlined regulatory processes have facilitated its widespread use. Although biological control agents for agricultural use must meet regulatory guidelines modeled on those of the U.S. Federal Drug Administration and the European Community, this process is reported to be extremely rapid in comparison to U.S. procedures (Rosset and Benjamin 1994).

**Weed Management**

The control of weeds within an alternative farming system can be extremely challenging. A major component of the alternative model of agriculture is the reduction of tillage to improve soil health, but this reduced tillage allows weeds to flourish. In developing countries employing low-till or zero-till techniques, selective herbicide applications are used to combat weeds. In Cuba, the reduced availability of herbicides following the collapse of the Soviet bloc made the development of alternative weed management strategies a necessity. The resulting focus of Cuban weed control science is twofold: (1) to reintroduce the traditional methods of weed control employed by farmers prior to the modernization of Cuban agriculture and (2) to scientifically evaluate the basis for the success of these methods and implement these methods for widespread application.

Weeds are evaluated in the context of the complex ecological systems they inhabit. Monitoring of test sites is used to generate data on weed species and densities from year to year, the composition and viability of seed banks, the type of crop to be planted and its competitive relationship to the

![Crop rotation for weed control: beans planted after a year of corn cultivation.](image-url)
weeds present, the effectiveness of herbicides against those weeds, and the degree of similarity between crop and weed growth habits (Dlott et al. 1993). These data are then incorporated into a mathematical model to predict what weed problems will arise in each year and location and to devise planting schemes to alleviate the effects of those problems.

Crop rotation is one of the most important traditional techniques now being applied based on model predictions. Crops with high competitive ability against a given weed community are employed, and a single year of planting a highly competitive crop can provide nearly weed-free growing conditions in the following year. Corn, for example, can shade out low growing weeds, allowing beans to be planted the following year. Regions with particularly severe weed problems may be planted with a dense cover crop such as sweet potato, which smothers out any competing weeds. Further, selective rotation can allow the application of herbicides at a time when herbicide-tolerant crops are present, paving the way for weed-free growing of herbicide-susceptible crops in subsequent growing seasons.

Soil cultivation techniques also have a strong impact on weed control. Incorporation of tillage for weed control with a minimum-tillage philosophy has called for creative solutions on the part of Cuban growers. One such solution is the multiplov designed by Cuban agricultural engineers. Unlike roto-tillers and discs, this device lifts and opens the soil without turning it. Thus, subsoil cultivation occurs without exposing weed seeds for germination; more importantly, any weeds present are essentially sliced off at the root.

**Soil Management**

Sustainable agriculture under the alternative model is dependent completely upon high quality soil resources. Prior to the crisis of 1989, Cuba's soil management practices were similar to those employed in most developed countries, relying heavily on inorganic inputs of fertilizer to maintain high productivity levels. Production-oriented practices contributed to significant fertility loss, erosion, and salinization of Cuba's already poor soils, and addressing these problems has been an important part of Cuba's agricultural conversion.

The first task carried out by Cuba's soil scientists was the classification of all the island's soils. Mapping on a 1:250,000 scale was carried out, and soil productivity potential evaluated. A mere 8% of Cuba's soils were rated as having very high potential productivity (Gersper et al. 1993), whereas most soils fell into the low or very low categories. Existing productivity levels could not be expected to meet Cuba's food needs, and an ambitious program of soil management involving minimum tillage, recycled and biological fertilizers, green manure, reforestation, and vermiculture was undertaken.

The low organic matter content of Cuba's soils is being addressed through the addition of organic and biological fertilizers. The introduction of nitrogen-fixing microorganisms into agricultural soils helps increase the amount of nitrogen available to crops. Rhizobium bacteria are mass-produced for use on leguminous crops, and inoculation with these bacteria is estimated to supply 80% of the crops' nitrogen needs (Gersper et al. 1993). A zotobacter, free-living nitrogen-fixing bacteria, are used on nonlegumes. The large-scale production and use of Azotobacter is a technique unique to Cuba, and is estimated to supply more than half of the nitrogen needed by nonlegumes (Perfecto 1994).

Another uncommon technology employed in Cuban agriculture is the widespread use of Bacillus bacteria. Many Cuban soils are high in aluminum and iron oxides, which bind with phosphates into insoluble complexes. Phosphorus, although present, then becomes unavailable for plant uptake. In the past, this situation was rectified through artificial inputs of phosphates. Bacillus organisms, however, function as phosphosolubilizing bacteria, breaking down these complexes and freeing phosphorous for absorption by plants.

Finally, investigations of vesicular arbuscular mycorrhizae (VAM), a group of symbiotic fungi that function as auxillary roots, currently are underway. Fifty-three species of VAM native to Cuba have been identified, and arrangements for mass-production are underway (Perfecto 1994).

Green manure is another important source of soil nutrients. By growing and then plowing under plants with high nutrient-uptake capabilities, soil fertility can be increased. One particularly useful green manure is Sesbania. This saline-tolerant legume can produce up to 60 tons of green manure in 45 days (Gersper et al. 1993), providing some 75% of the nitrogen required for crops planted subsequently. The ability of Sesbania's to grow in saline soils is especially important in Cuba, because the long, narrow geography of the island subjects almost all soils to saline stress.

Cultural techniques also are used to increase the health of Cuba's soils. Exhaustive surveys of crop/soil productivity have been carried out, iden-
tifying the crops best suited to a region’s soils. Crop rotations are designed to maximize the effects of green manure, and crop residues commonly are plowed under to contribute nutrients to the soil. Intercropping practices also have been studied and employed. Although traditional peasant farming made extensive use of intercropping, the practice fell away with the introduction of large-scale monoculture production. Today, the value of intercropping is twofold: field productivity is increased, as in the intercropping of soybeans for animal food with sugarcane for export; and soil erosion is prevented, particularly through the use of leguminous intercrops. Additionally, the replacement of tractor power by animal traction has reduced erosion threats to soil significantly.

Many of the plant nutrition needs not met by these techniques are addressed by the use of vermiculture. Vermiculture, the large-scale use and production of earthworm humus, has grown rapidly in Cuba, from 2,000 metric tons in 1987 to 96,000 metric tons in 1992 (Gersper et al. 1993). Earthworm humus stimulates plant growth, increases nutrient uptake, and helps protect plants from soil-borne diseases (Gersper et al. 1993). Earthworm humus is an efficient fertilizer, and 4 tons of humus are reported to provide as much nutrition as 40 tons of cow manure (Werner 1994).

Humus production in Cuba is state of the art. Fresh animal manure is fermented for 30 days, then mixed with soil and seeded with earthworms. The worms feed on the top layer of manure and deposit castings into the lower layers. Compost is added continuously for 90 days, then the worms are removed and the humus is ready for agricultural use. Several regional research stations have mass-production facilities for earthworm humus, and these stations are responsible for educating people in their region on vermiculture techniques. Annual vermiculture conferences further spread knowledge, and vermiculture is encouraged for household and community use as well as on farms. Organic materials from livestock manure, food waste, human waste, and sugarcane production are recycled as vermiculture substrates.

Waste recycling also is common for uses other than vermiculture. Sugarcane is the best example of effective waste recycling in Cuba, and some sugar mills are run entirely on energy from their own waste (Kaufman 1993). Sugarcane production involves extremely high levels of waste byproducts including bagasse, wastewater, and filter press cake. Bagasse, a dry pulp, is used both for animal feed and as biomass for energy production; wastewater is diverted to local farms for irrigation; and filter press cake, a processing byproduct high in calcium, phosphorous, and potassium, is used as a crop fertilizer. The extraction of steam energy from bagasse has been so successful that excess energy often is available for the local municipal power grid.

Cuba’s efforts at soil rectification have produced one of the world’s most impressive reforestation programs. After the 1959 revolution, Cuba began replanting thousands of hectares of forestland felled by Spanish and American sugarcane growers. Cuban revolutionaries have a long-standing appreciation of trees, dating back to Jose Marti, who said “A region without trees is poor. A city without trees is sickly, land without trees is parched and bears wretched fruit.” Even before the events of 1989, Cuba had increased tree cover from 14 to 20%. In the years since, the reforestation program has been intensified, and under the Manati Plan seeds are provided to all interested people for the reforestation of degraded lands. As a result, Cuba has added 697,000 hectares of forest in the last 8

Plows drawn by oxen such as these have largely replaced gasoline-powered tractors in Cuba.
years, making it one of the very few countries in the world to have increased the amount of forested land in recent decades (Baker 1997).

**Labor Mobilization**

Over the past 40 years, Cuba's population has become more urban. As farm work became increasingly mechanized, this flight to the cities was exacerbated, so that today an estimated 30% of Cuba's population lives in Havana or its environs. The advent of the special period following the dissolution of the Soviet bloc, therefore, gave rise to a crisis in labor because petroleum was no longer available to carry out mechanized production. Moreover, nationwide conversion to alternative agricultural techniques demands a huge labor pool. Although 30 years of progress under Soviet guidance were aimed at reducing human inputs in agriculture, the events of 1989 have made a reversal of this trend imperative.

Many alternative growing techniques are not amenable to mechanization; the harvesting of intercropped fields, for example, must be done manually. Although some practices may be carried out by machine eventually, such technology is in its infancy. As a result, any large-scale implementation of sustainable agriculture depends upon the mustering of a vast agricultural work force.

Cuba is attempting to redirect labor in several ways. In the short term, incentive plans have been instituted to encourage city dwellers to volunteer their services as agricultural laborers for periods ranging from 2 weeks to 2 years. These workers are guaranteed a salary at least equal to their real job's wages and receive somewhat better food and housing than is standard. Their city jobs are held for them, and, should they choose to remain in the country, they are provided with permanent housing. Another form of volunteerism is the Plan Turquina whereby young people can substitute 2 years of agricultural work for their required military service. By targeting young people at the threshold of marriage and childbirth, Cuba hopes to reestablish rural communities.

The division of labor on state farms also has been restructured to increase rural satisfaction. Previously, workers were sent to various parts of the farm as their specialized tasks needed to be performed; now, it is standard for each cohort of laborers to be associated with a particular tract of land, generally about 80 hectares in size (Rosset 1996). The same group carries out all growing operations on this tract, from sowing to harvest. Simultaneously, productivity incentives have been established in which the base pay is augmented according to production levels. Management responsibilities have been decentralized similarly, and many land parcels are managed by those who farm them.

The call to agricultural productivity has not been limited to rural populations. City dwellers increasingly are encouraged to plant organoponicos (urban gardens) with the aim of decreasing dependence on food from rural sources. The loss of petroleum imports has resulted in severe problems with the refrigeration and transport of food, and urban gardens are seen as a way of shifting the burden. Unused land parcels are available free of charge to anyone who will grow food on them, and the grower is entitled to keep all produce. There now are more than 2,000 small gardens in the city of Havana, and growers range from individual families to entire neighborhoods, workplaces, and schools.

**Conclusions**

The quiet revolution in Cuba is well on its way to success. For the first time in post-Colombian history, Cuba is approaching economic independence. That such gains have been made using sustainable agricultural practices is a lesson we should all note. Although many scientists around the world have lamented the persistent spread of agricultural practices based on the classical model of production, nowhere else has a large-scale conversion to alternative techniques been attempted.

By making agriculture essentially a small-scale endeavor on a national level, Cuba has drawn upon local and individual knowledge in designing solutions to problems such as soil fertility and insect management. Revolutionary to their core, Cubans have adopted alternative agriculture as swiftly and passionately as they did the Revolution of 1959. Rather than excluding the populace, the new model in Cuba integrates all areas of society in a common struggle for food self-sufficiency. By asking not if sustainable agriculture is possible, but rather how it can best be carried out, Cuba has paved the way to a more rational form of food production.

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