A G R O E C O S Y S T E M S

Regaining the High Ground: Reviving the Hillsides of Machakos

In Machakos, necessity is the mother of conservation. Because water is scarce and rainfall unpredictable in this mostly semiarid district southeast of Nairobi, farmers have learned to husband water. They collect water from their roofs, they channel road runoff onto their terraces, they scoop water out of seasonal streams or perennial rivers, and they dig ponds to collect rain. To minimize soil erosion, farmers have adopted a system of conduits, tree planting, and terraces found nowhere else in Kenya. "These [measures] are the lifeline of the people here in Machakos," said Paul Kimeu, soil and water conservation officer for the Machakos District.

Conservation efforts, plus persistence and hard work, have enabled the people of Machakos, the Akamba, to survive in the face of drought, poverty, and land degradation. In the 1930s, severe soil erosion plagued 75 percent of the inhabited area and the Akamba were described as "rapidly drifting to a state of hopeless and miserable poverty and their land to a parching desert of rocks, stones, and sand" (Tiffen et al. 1994:3, 101). Today, once-eroding hillsides are productive, intensively farmed terraces. The area cultivated increased from 15 percent of the district in the 1930s to between 50 and 80 percent in 1978, and the land supports a population that has grown almost fivefold, from about 240,000 in the 1930s to about 1.4 million in 1989 (Tiffen et al. 1994:5; Mortimore and Tiffen 1994:11). This environmental transformation has been called "the Machakos Miracle" (Mortimore and Tiffen 1994:14, citing Huxley 1960).

But the benefits of the "miracle" have not reached everyone. Those with the least fertile land often lack the financial

(continues on p. 152)

Box 3.1 Overview: Machakos

Through innovation, cultural tradition, access to new markets, and hard work, farmers in Kenya's Machakos District have turned once-eroding hillsides into productive, intensively farmed terraces. However, economic stagnation, population growth, increasing land scarcity, and a widening income gap raise the question: Is Machakos' agricultural transformation sustainable?

Ecosystem Issues

Agriculture	Since the 1930s, the Akamba people of Machakos have terraced perhaps 60–70 percent of arable fields to protect them from erosion. Land conditions and agricultural output have also benefited from penned livestock, tree planting, composting, and other measures. Yet with decreasing arable land per capita and sluggish economic development, poverty remains a problem for some, particularly during droughts. Poverty, in turn, decreases farmers' ability to invest in sustainable technologies and management.
Freshwater	Most streams in Machakos are seasonal, rainfall is variable, and groundwater limited. Water projects and conservation activities have expanded irrigation, reduced the risk of crop failure, cultivated higher-value crops, and freed labor from fetching water. But about half the population still lacks potable water and water availability constrains industrial and urban growth.
Forests	Contrary to expectations, aerial photos suggest that the District has become more, not less, wooded since the 1930s. Small-scale tree planting efforts have been beneficial; farmers plant trees to stabilize soils and supply fruits and timber. Akamba also minimize deforestation by using dead wood, farm trash, and hedge clippings for firewood.

Management Challenges

Equity and Tenurial Rights	Some of the most severe agroecosystem degradation in Machakos emerged in the decades when the colonial government divested the Akamba of their land rights and restricted market access. By contrast, greater Akamba control over farm techniques, lands, and livelihoods have coincided with self-led, often independently funded innovations in conservation.
Economics	Improved access to markets, the growth of urban areas like Nairobi and Mombasa, and the right to grow lucrative cash crops provided incentive for farmers to implement new technologies and maximize productivity. But market access remains difficult and economic growth sluggish; decreasing farm size and labor shortfalls are additional roadblocks to further agricultural intensification.
Stakeholders	For decades, government officials and farmers disagreed about farming objectives and methods. In an atmosphere of inequality and mistrust, officials promoted or regulated technologies that the Akamba did not accept or perceive as viable. Greater environmental progress has occurred since Akamba farmers have gained a more equal voice in the decisions about agricultural management and methods.
Information and Monitoring	NGOs, government extension workers, researchers, and self-help groups have vastly improved the information and resource base available to farmers, but improvements in the information base must be ongoing. For example, researchers have emphasized the weakness of data with which to analyze change in extent and condition of Machakos ecosystems, including data on soil health, changes in land use and vegetation, and production.

Timeline

1600s–1700s Akamba first occupy the Machakos uplands.

1889 Europeans arrive.

1895 British Protectorate of East Africa is established.

1897–99 Consecutive drought seasons result in devastating famine; 50–75 percent of Akamba die.

1906 British colonial government designates the most fertile Machakos lands as "White Highlands" for European settlers; Akamba are restricted to "Native Reserves." Only Europeans are allowed to grow high-value export crops like coffee and tea.

1928–29 Drought and famine strike.

1930s Growth of human and livestock populations without room for expansion cause farmlands on Native Reserves to deteriorate. Akamba migrate out of Reserve settlements in search of work or to occupy other lands illegally.

1933–36 Successive droughts occur. Officials acknowledge the "Machakos problem" when 75 percent of inhabited area is plagued by soil erosion.

1937–38 Colonial government creates the Soil Conservation Service and attempts to impose conservation measures on Akamba, including compulsory reductions of cattle. Akamba protest.

1940–45 Conservation funding and number of available male farm laborers are limited during WWII; famine relief is required.

1946 Government makes significant investments in land development and conservation in Africa—in Machakos in particular. Emphasis is on compulsory communal work, including government-selected systems of terracing.

1949–50 Consecutive drought seasons ensue.

1950s Growth of urban areas increases demand for agricultural products, making terracing and water conservation profitable and attractive.

1952 News spreads among Akamba that cultivators who use bench terraces, rather than government-mandated narrow terraces, are making big profits, sparking voluntary construction of bench terraces.

1954 Swynnerton Plan to revolutionize agriculture emphasizes production of crops for export. For the first time, Akamba are granted the right to grow coffee, another incentive to terrace land and a source of cash with which to purchase farm inputs.

1959–63 Akamba turn to political activity in build-up to Kenyan Independence (1963). Conservation efforts slow, as they are perceived as tainted by colonial authority.

1962 Akamba surge onto former Crown Lands. Population growth rates in some areas reach 10–30 percent per year, as people seek to escape land shortages in other areas.

c. 1965–70s Recognizing the potential for higher yields, farmers renew soil and water conservation efforts largely without government aid. New roads improve access to Nairobi, and growth of canning plants encourages fruit and vegetable production and, in turn, terracing.

1974–75 Drought returns.

1975–77 High prices for coffee inspire tripling of production and heavy investment in land conservation.

1978–80s Numerous church-led projects and national and international NGOs provide support for community development, including famine relief, food production, and water supply and irrigation.

1983–84 Drought strikes—called "dying with cash in hand" because of severe food shortages. After the drought, more terraces are rapidly constructed.

1996–98 Droughts followed by El Niño rains ruin subsistence crops and force farmers to sell livestock for food.

2000 Perhaps as much as 65 percent of farms are terraced, many farmers use additional conservation measures.

resources to tap the water below it. Higher living standards seem most achievable by those households with access to nonfarm income, but population growth and economic stagnation contribute to a shortage of jobs in towns and cities. For those farmers without access to nonfarm income, lack of capital or credit limits their ability to implement innovative agricultural practices.

On the one hand, then, Machakos offers a dramatic example of how knowledge, innovation, and respect for the vital services that soil and water provide have enabled people to restore and even increase the productivity of severely degraded lands. On the other hand, Machakos illustrates the continued vulnerability of both ecosystems and people in the face of cultural, economic, and environmental change.

A Land of Hills and Dry Plains

Machakos lies on a plateau that gradually slopes southeast from 1,700 to 700 m elevation, broken by groups of high hills. Rain has always been precious in Machakos; annual rainfall ranges from 1,200 mm in the highlands to less than 600 mm in the lowlands of the southeast and the dry plains of the extreme northwest (Mortimore and Tiffen 1994:12; Tiffen et al. 1994:18). Less than half the district has more than a 60 percent chance of getting enough rain to grow maize, the Akamba's preferred staple (Mortimore and Tiffen 1994:12, citing Jaetzold and Schmidt 1983). In most years the highlands are the only region that can support reliable agricultural harvests without irrigation.

The Akamba are believed to have settled the uplands of Machakos in the 17th and 18th centuries, when most of the area was an uninhabited thorny woodland. Evergreen forests crowned the wetter highlands and grasslands carpeted the drier plains. The Akamba raised cattle, goats, and sheep and cultivated grains, pulses, and sweet potatoes on wet hills. Close to water they irrigated small plots of vegetables, bananas, and sugarcane. They became skillful traders, providing ivory, honey, beer, ornaments, and weapons to the Kikuyu and Masai in exchange for food. Their lives changed dramatically in the late 1890s, however, after smallpox, cholera, and rinderpest decimated both human and animal populations and drought devastated the land. By 1900, 50–75 percent of the Akamba had perished in some areas; perhaps only 100,000 people were left in the district (Tiffen et al. 1994:44, citing Lindblom 1920; Tiffen 1995:4).

At about the same time, the new British colonial government gained sufficient power to impose boundaries on the Akamba and other native people in Kenya. They created several "Native Reserves" and claimed some of the best farmland for themselves in "Scheduled Areas" or "White Highlands." Though the Akamba retained most of their traditional lands, the government's policy blocked any expansion, with European ranches and farms on two sides and government-controlled "Crown Lands" on the other two.

Traditionally the Akamba had responded to drought, decreasing soil fertility, and population growth by moving to new fields or ranges. Without this mobility, shifting cultivation gave way to continuous cultivation. Although the population of both people and cattle in the Akamba reserve grew, the colonial government strictly enforced the reserve boundaries to maintain political control. By 1932, some 240,000 Akamba lived in Machakos, more than double the population at the turn of the century (Mortimore and Tiffen 1994:11). Within the reserves, soils became exhausted and crop yields fell.

For the already stressed ecosystem and its people, the return of severe drought in 1929 was catastrophic. The Akamba called the drought "*Yua ya nzalukangye*" or "looking everywhere to find food" (Tiffen et al. 1994:5). Then, from 1933 to 1936, droughts occurred during six of the eight semiannual growing seasons–the long rains from March to May, and the short rains from October to December. Locusts invaded the withering maize crops, and voracious quella birds ate the remains. Cattle denuded the parched brown hillsides, then began to starve, soon followed by the Akamba themselves. When the rains did come, the region's highly erodible red soil bled from the steep hillsides in torrents. Historical photographs reveal a landscape of treeless hillsides, deep gullies, denuded slopes, and fields stripped of topsoil.

Changing Attitudes: From Compulsory Conservation to Akamba Innovation

In reports written from 1929 to 1939, colonial agricultural officers argued that rapid population growth, surplus livestock, deforestation, and unscientific farming methods were leading to massive degradation of the region's natural resources. The Akamba recognized the worsening environmental crisis, too. "[T]his place was becoming a desert," reflected Joel Thiaka, a farmer from Muisuni, in 1938 (Tiffen et al. 1994:44).

Several factors prompted the colonial government to invest in land development: a global antierosion movement, catalyzed in part by the Dust Bowl in the United States; the increasing African populations; and the expense of providing emergency food aid to ward off massive starvation during times of drought (Tiffen et al. 1994:179). In 1937 the colonial government created a Soil Conservation Service led by Colin Maher. The Service's first efforts included the confiscation and slaughter of "excess" Akamba cattle. After Akamba protestors rallied in Nairobi, those initiatives were abandoned (Tiffen et al. 1994:181–182).

Maher next launched "compulsory conservation projects." These required Akamba to plant grass and build terraces–

structures used for centuries in Asia and Africa to cultivate steep hillsides. When these activities progressed too slowly, Maher mandated the building of conservation structures with government tractors and paid-labor gangs. The Akamba again protested, fearful of another government land grab; according to Akamba tradition, anyone clearing or cultivating land had permanent use-rights to the property. Some Akamba even threw themselves in front of the tractors. The Akamba finally agreed to send one family member two mornings a week to work on forced-labor gangs building terraces and water conservation projects and planting fodder crops.

The terraces that Maher required Africans to construct during this period were narrow-based terraces, also known as contour ditches. Building these small structures required workers to dig a shallow trench and throw the soil downhill to create a small berm to capture runoff. Though easy and relatively fast to construct, narrow terraces were also quick to wash away and required significant maintenance. They soon lost favor with Akamba farmers, but not with Maher.

Although soil conservation efforts languished during World War II (1940–45), they were renewed with vigor by an expanded Department of Agriculture after the war, as wide-scale erosion and famine returned to Machakos. There was much African opposition to many of these "betterment" projects. Yet several Akamba innovations emerged in the ensuing decades from these controversial programs, innovations which laid the foundation for the "Machakos miracle," though few recognized them at the time. One was workers' experimentation with the construction of a bench terrace called a *fanya juu*.

Fanya juu terraces are constructed by digging a trench along the contour of a slope and throwing the excavated soil uphill to form a gently sloping field with an earth embankment that collects rainfall and slows runoff. Though they require considerable labor to construct, such bench terraces soon become stable and require only periodic maintenance of the berm. Maher, however, thought they were too labor-intensive for the Akamba, and thus had mandated narrow terraces.

Maize, beans, and mango and banana trees are part of this well-designed hillside terrace.

Box 3.2 Machakos Agriculture

Results from a 1998–99 survey involving several hundred farmers and 484 plots of land suggest that the efforts put into conserving soil and water in Machakos have been well rewarded. The survey shows that terracing is by far the most popular conservation measure. Farmers who use terracing often use multiple conservation measures—adopting them as a package (Zaal 1999). Other research suggests that there was a substantial increase in productivity per hectare in the Machakos District between the 1930s and 1990s (Tiffen et al. 1994:95–96).

Land and Water Conservation Measures in Machakos

About half the terraced plots also incorporated another conservation measure.

Percent of Fields Given Over to...

Terracing	86.7
Grass strips	14.0
Grass terrace border	10.7
Trash lines	6.5
Agroforestry	2.3
Cover crops	1.0
Open ridges	0.6
Stone terrace	0.4
Cut-off drain	0.2

Source: Zaal 1999.

Benefits of Terracing

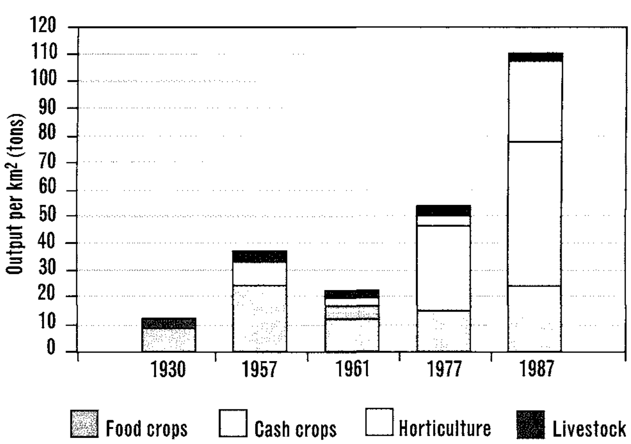
The survey showed that farmers who use terraces reap numerous benefits.

Percent of Farmers Experiencing...

Higher land value	97
Higher yield levels	94
Greater stability of yield	94
Less erosion	76
Less use of fertilizer	75
Less labor to plant	58
Less labor to weed	43

Source: Zaal 1999.

Crop and Livestock Production in Machakos



Source: Tiffen et al. 1994:95.

But the Akamba have a saying: "Use your eye, the ear is deceptive" (Tiffen et al. 1994:152). Many of the Akamba men fought as part of British forces overseas, where they saw other agricultural practices at work. In 1949, one veteran built a bench terrace patterned after one he had seen in India. He harvested a good crop of onions that he sold for a profit. Other farmers in the area soon followed his lead. After Maher's retirement in 1951, farmers were allowed to choose whether to have contour ditches or *fanya juu* in the compulsory betterment programs; more and more chose *fanya juu*.

During the 1950s, more than 40,000 ha was terraced in Machakos (Mortimore and Tiffen 1994:14, citing Peberdy 1958). One incentive for this large-scale shift to terraces was the government's decision in 1954 to allow Akamba farmers to grow coffee for the first time–a decision based on the Swynnerton Plan's emphasis on producing lucrative cash crops for export. The Akamba were eager to reap the economic benefits of growing coffee, but coffee can only be planted on steep slopes if they are terraced, to ensure that the nutrients and moisture essential to coffee's growth are retained. Other farmers used terraces to grow tomatoes and other vegetables for the expanding town of Nairobi.

Another breakthrough that would promote self-led Akamba innovation and conservation occurred in 1956. The new and mainly African-staffed community development service under a government-appointed chief replaced the hated compulsory work gang with the *mwethya*, or traditional work party, whose members chose each other and their own leaders. Normally Akamba families called a *mwethya* for a special project, such as building a hut; neighbors would help in exchange for food. With technical support from the government, *fanya juu mwethyas* were soon busy all over the district building terraces and undertaking other projects.

Since many Akamba men worked outside the district, most of the laborers who worked on the conservation projects and in the first *mwethya* were women. This was the first time in Akamba history that women were elected to leadership positions, providing them with increased status and political power and reinforcing the value of education for daughters. The traditional work group evolved, too, into self-help groups that today pool money as well as labor and are connected with organizations that provide community development, agricultural extension, and literacy services.

Kenya's independence from colonial rule in 1963 spurred a surge of Akamba families onto former Crown Lands. The new government ended all funding for soil conservation, and for a few years terracing fell out of favor with the Akamba, who saw conservation efforts as tainted by the colonial regime. But soon farmers who had seen the benefits of the *fanyu juu*–for yields of staple crops like grains and beans, cash-crop production, and survival during drought–began to build them again, on their own, either through *mwethyas* or hired labor. In fact, more terraces were built from 1961 to 1978 than were built during the 1950s, and without any government aid (Tiffen and Mortimore 1992:363). The period from 1960 to 1980 was also characterized by a phase of steep growth in land productivity in Machakos (Tiffen and Mortimore 1992:365). Another 8,500 km of terraces were built annually between 1981 and 1985, half of them by farmers with no outside assistance. By the mid-1980s, aerial surveys showed that 54 percent of Machakos' arable land was protected from erosion, with more than 80 percent protected in hilly areas (Tiffen et al. 1994:198). A 1998–99 survey of 484 fields in Machakos suggests that about 60 percent are terraced; many farmers also use additional conservation measures (Zaal 1999:5).

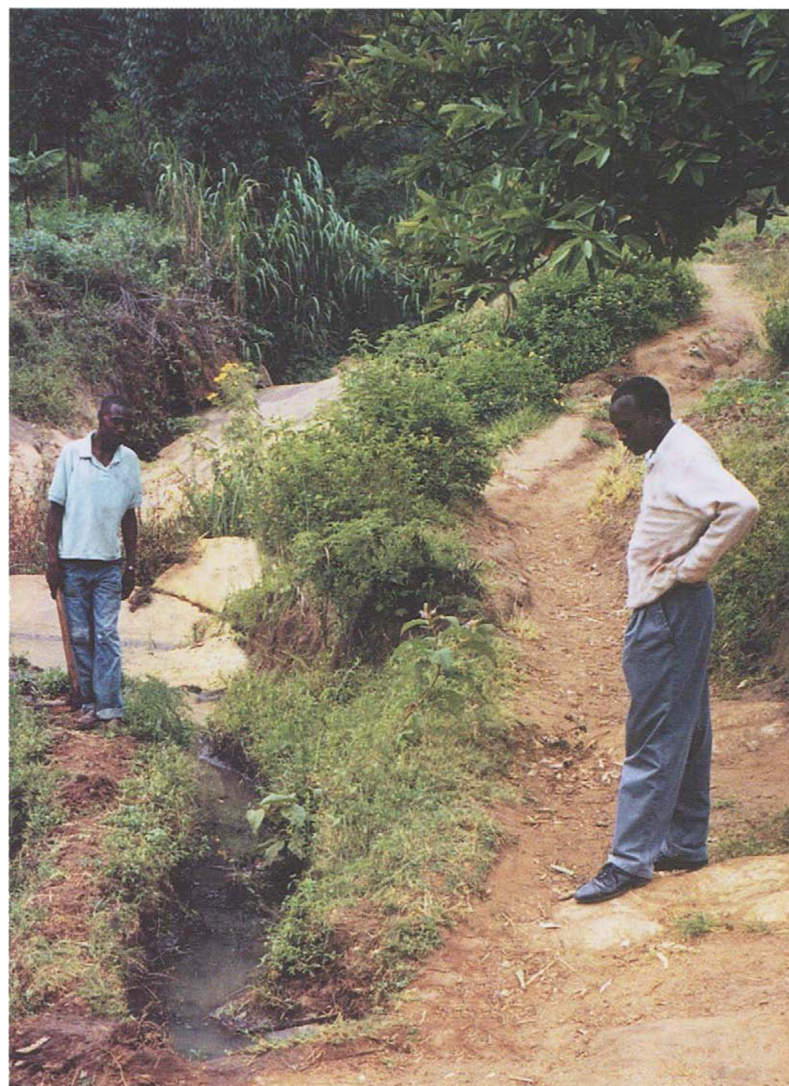
Overall, some 76 production technologies were introduced or expanded in the district between 1930 and 1990, including introduction of 35 crops varieties, 5 tillage practices, and 6 methods for managing soil fertility (Mortimore and Tiffen 1994:16). Many of these conservation and land development mechanisms were Akamba innovations.

The expansion of market opportunities clearly affected the popularity of conservation measures. The coffee boom in the 1970s, for example, increased demand for labor on the farms and in coffee processing factories and transport to markets. Coffee prices fell in the late 1980s, but large international horticultural firms in Nairobi began to encourage Machakos farmers to produce crops like French beans as export crops. Citrus, pawpaws, and mangoes have proved similarly successful with the rise of Kenya's canning industry and the growth of towns and tourist trade. According to a 1981–82 survey, 41 percent of rural income came from nonfarm businesses and wages (Mortimore and Tiffen 1994:16). For decades such income, usually earned by Akamba men with jobs outside the district, has been invested in farm improvements such as building terraces or water storage tanks and planting trees and hedges.

Farmers also began to invest in planting and protecting trees. Photographs comparing landscapes in 1937 and 1990 show a substantial increase in the density and average size of farm trees (Tiffen et al. 1994:218). Because farmers, particularly women, spent increasing time foraging for firewood after hillslopes were cleared, they developed the practice of planting woodlots to facilitate gathering. Often farmers planted trees at the bottom of their plot so as to minimize water uptake from their own crops and maximize that from their neighbors'; that location offered the added advantage of helping to keep hillside soil in place. Women farmers have favored fruit tree plantings because they offer household food supplies and an independent source of cash (Tiffen et al. 1994:221).

Adaptive changes in livestock management and the adoption of ox-drawn plows for weeding and cultivation have contributed to Akamba farmers' success. Since no communal grazing lands remain, animals are now fed on the farm. More than 60 percent of the district's livestock are stall-fed or tethered for all or part of the year, requiring fodder feeding, but also supplying manure for fields (Mortimore and Tiffen 1994:19, citing African Development and Economic Consultants 1986). Added advantages of "zero-grazing" systems are increased milk yield, reduced destruction of vegetation through overgrazing, decreased disease incidence, and labor savings. A transition to foddering cattle also brought the care of cattle into the female domain, further empowering women. Many women now derive useful income for themselves and the farm through milking, for example. Cutting of fodder by women, usually from napier grass on terrace edges, encourages their involvement in terracing.

Machakos' agricultural success didn't come without environmental costs. As the cultivated land in the district grew from 15 to nearly 80 percent, native plant and animal populations decreased dramatically, including some of Kenya's rarest species, such as the rhinoceros. Poaching and encroachment in Tsavo National Park and other protected areas remains a problem (Kenya Web 1999).



Small-scale, traditional irrigation in Machakos is based on seasonal streams.

Box 3.3 Ranking the Challenges in Machakos

At a 1999 conservation workshop sponsored by the World Resources Institute in Machakos, farmers unanimously agreed that lack of water was their most pressing concern, followed by farm size and land scarcity. As the population has increased, farms have been divided among heirs until the average farm size is little more than 1 ha. The high-potential lands have all been taken, so people are farming more marginal lands, either in the plains or on steep mountainsides where the government prohibits agricultural activities.

Lack of capital to invest in farm improvements and technologies and the lack of a ready labor pool were also at the top of this group's list of constraints to conservation. Because more children are in school and older children are migrating to cities to find work, women now provide most of the farm labor in Machakos—while still carrying out traditional responsibilities like raising children, keeping house, and fetching fuel and water.

Soil erosion didn't make their list of challenges. In fact, the largest contributor to soil erosion in the district today isn't farms but rather poorly constructed or unrepaired roads and sand mining from river beds by the concrete industry, which has flourished in conjunction with a building boom in Nairobi. Many roads are etched with deep gullies along steep roadsides, made worse by the El Niño rains, but repair requires public or community resources on a scale that the citizens of Machakos simply don't have. Poor roads also increase the cost of imported foods and the cost of transportation to get Machakos-produced goods to retail markets in places like Nairobi and Mombasa. Road conditions during the rainy season make it difficult for farmers to get their produce to markets before it spoils. Because the district is not completely supplied with electricity, food processing or refrigeration is not always feasible.

A road that connects Machakos Town to district hillsides. On the left is a roadside drain. Maize and bean crops and mango, banana, and eucalyptus trees are visible in the background.

An example of poorly maintained terraces near Machakos. Theses show only minimal management to reduce erosion of the unprotected terrace berms. Further up the slope this farmer has planted maize, beans, cassava, mango, and banana trees.

Machakos Today

"In Machakos today people are building soil conservation structures without being forced," says George Mbate, an economist with USAID (interview 19 February 1999). "They've come to relate production of crops with proper soil management."

The effect of drought is not as damaging today, thanks to investments in terraces; retention ditches, which encourage water seepage to the cropped area; and cut-off drains, which collect water and discharge it safely without causing erosion on the farm. The manure that farmers apply to fruit trees not only fertilizes the soil but improves water infiltration, lessening water runoff. Short-season maize varieties and early planting to allow enough time to prepare the land for the "long-rains" crops are also beneficial. These techniques, along with diversification of income from urban jobs, have made it possible to reduce food imports and famine relief, even during droughts (Tiffen and Mortimore 1992:373).

But even terraced crops are vulnerable, and the problems of Machakos are far from solved. Droughts in 1996 and 1997, followed by El Ninõ rains in 1998, ruined subsistence crops and forced some farmers to sell livestock to buy food. In the semiarid areas good harvests were achieved, but the heavy rains hit the hilly areas of Mwala division particularly hard, rotting crops, leeching nutrients from the soil, and destroying terraces, houses, and latrines.

"Most times, it's a food-deficient area," admits A.M. Ndambuki, agricultural officer for the district (interview 1 March 1999). "In a good year, there's enough food for that season. This year [1998] with the drought, we didn't harvest anything. Now almost all the food we're eating comes from outside the district." Importing food rather than producing it wouldn't be a problem if there were sufficient opportunity to earn money, but in Machakos, there is not. Many of the poorest farmers must search for alternative, often low-wage rural jobs in order to feed their families.

The farmers who fare the best are those like Samuel Milo, who grows tomatoes, maize, beans, and sugarcane on the sloping land of his 16-ha farm. He maximizes his terraces by planting napier grass for fodder on the terrace embankments, and a row of banana trees in the gullies to protect against erosion and to supply fruits. He plants trees as windbreaks between crops, too, and has a woodlot from which he sells timber and gets his firewood. His 4,200 coffee plants produce high-quality beans that he sorts, processes, and sells. By keeping his five cows penned and fed on napier grass harvested from the terrace, instead of allowing them to graze, he saves land space and has fertilizer for the soil.

But Mr. Milo is not just enterprising and conservation-minded, he is also fortunate. His farm is unusually large and a stream runs through his property. He has built an irrigation channel above the stream. Thanks to income-generating crops, he has been able to run a pipe from another stream into a large underground storage tank built on his property, ensuring a steady water supply.

Other farmers are not so lucky. For many, adaptations and conservation techniques like Mr. Milo's are too expensive or labor intensive. For the farmer with limited resources to hire help, for example, terracing can take years. In one Machakos village, researchers found that only 57 percent of farmers could afford the capital needed to produce cash crops for the market or to purchase farm inputs like fertilizer. Those were usually farmers with family members who earned money from off-farm jobs in urban areas (Murton 1999:40).

Another economic change that may undermine poor farmers' ability to apply best farm practices is a polarization of wealth and land. In 1965, the poorest 20 percent of the households in Mbooni owned 8 percent of the land; in 1996, they owned 3 percent. By contrast, the richest 20 percent owned 40 percent of the land in 1965 and 55 percent in 1996 (Murton 1999:41). This creates a group of viably large farms, but leaves very small farms struggling in poverty. Land concentration occurred as wealthier farmers, often those with a nonfarm income source, bought out farmers who sold their medium-sized or small farms. Some of the farmers who sold their farms migrated onto the former Crown Lands–the more fragile lands and drier frontier areas. There more acreage was available, but more inputs were needed to produce the same income.

Why do people bear the hardship of pioneering a new farm in difficult conditions or hang on to a tiny plot in the uplands? Because for the Akamba, owning land "is part of your identity, your value, your culture," according to Dr. Samuel Mutiso (interviewed 25 February 1999), a Kamba who heads the geography department at the University of Nairobi and is Kenya's representative to the UN Convention on Desertification. "We are torn between two worlds," he said.

Can the "Miracle" Continue?

"The changes in Machakos didn't come overnight," says Mutiso. Spurred by necessity and eventually freed from the constraints of dictatorial government land policies, the Akamba successfully intensified land use by selecting and adapting new technologies from a variety of places. They switched to more profitable crops, better staples, manure fertilizers, and systems of multiple cropping, reduced grazing, and tree cultivation. Community-level planning and leadership, such as the *mwethya* groups, and community preferences in technology and crops far more effectively increased fertility and decreased erosion than imposed conservation programs. When farmers have economic incentives to conserve soil–higher yields, the opportunity to grow more profitable crops, and access to markets–they are willing to invest more capital and labor in bench terraces. In a sample of five areas, the proportion of total area treated with soil conservation measures rose from about 52 percent in 1948 to 96 percent in the older settled areas in 1978. The areas also reflected substantial gains from soil erosion reduction and from rainfall infiltration and soil moisture retention (Tiffen and Mortimore 1992:368).

Migration to urban areas provided a flow of remittances that augmented capital for agricultural development. Income and experience from nonfarm jobs were combined with government extension efforts to dramatically facilitate the transfer of knowledge, technology, and capital to the farms.

Another important change was a shift from central government decision making about ecosystem issues to greater district-level participation, including direct engagement of local leaders in seminars. This approach afforded an opportunity to work with, rather than against, the Akamba's intimate knowledge of the land's problems and their culturally preferred agricultural methods. It also capitalized on their abiding attachment to the land. "It is not just economic," says Maria Mullei (interview 17 March 1999), an agricultural officer with USAID who also farms in Makueni, "you love the land so you protect it." In fact, much of the incentive and capital for the retreat from expected ecological disaster came from the people of Machakos themselves.

Decreasing farm size, growing land scarcity in the face of population growth, and loss of communal grazing lands also have pressured the Akamba to use their land and water as efficiently as possible. Yet no one has suggested that population growth might encourage further conservation, land intensification, and productivity. Today, population growth rates in Machakos are about 3 percent per year (Mortimore and Tiffen 1994:13). With increasing population density and high costs of raising children, however, birth rates are starting to fall.

Less encouraging are signs that without capital some erosion protection and water conservation technologies cannot be adopted even if they would improve the land. For example, more farmers would like to put in water storage tanks but face the problem of limited financial resources. On some upland farms there are too few bulls to haul plows, and terraces are too small to allow plows to turn easily.

Cyclical poverty may emerge, as Murton (1999) found in Mbooni, which was part of Machakos district prior to 1992. Those with an off-farm job, more fertile soils, or a water source fare better. Those that fare better and increase productivity are most able to switch to higher value crops, like citrus fruits and French beans, and tap commercial markets. But others abandon farming or migrate to marginal lands. Although all children complete primary school, the poorest families may not be able to afford to send their children to secondary school, which may deny them the opportunity to secure the off-farm jobs that lead to personal income.

The future of agricultural innovation and land productivity in Machakos also depends in no small part on the larger economy in which the district operates. The technologies to protect the land are in place, but the present greenness of the fields does not guarantee anyone a living. Economic and environmental sustainability also are determined by food prices, the availability of urban jobs, and external resources for improvement of roads or electrification to help farmers tap commercial markets.

Tempered by such challenges, Machakos remains an encouraging story, a place where the expected progression toward further environmental degradation has not occurred, a place where farms flourish in place of deserts. Whether such rewards and growth are sustainable will be determined in the decades to come.

Cuba's Agricultural Revolution: A Return to Oxen and Organics

The fall of the Berlin Wall in 1989 and the subsequent demise of communism in the Soviet Union occurred half a world away from Cuba. But the repercussions of that revolution directly affected Cuban soils: it transformed Cuba's agricultural lands by forcing a radical shift to organic inputs and farming methods on a scale unprecedented worldwide.

Cuban Agroecosystem Management from 1959 to 1989

From 1959 through the 1980s, being part of the socialist trade bloc significantly influenced Cuba's economic development and ecosystem management. Though a highly industrialized country that produced pharmaceuticals and computers as well as crops, sugar was the staple of the Cuban economy. By 1989 state-owned sugar plantations covered three times more farmland than did food crops (Rosset 1996:64). Sugar and its derivatives constituted 75 percent of the total value of Cuba's exports, purchased almost entirely by the Soviet Union, Central and Eastern Europe, and China (Rosset and Benjamin 1993:12). High crop yields were attained through agricultural methods that were more mechanized than in any other Latin American nation, in addition to extensive use of pesticides, fertilizers, and large-scale irrigation.

In return for its exports of sugar, tobacco, citrus, minerals, and other items, Cuba imported about 60 percent of its food as well as crude oil and other refined products, all from the socialist bloc at favorable terms of trade. Forty-eight percent of the fertilizer, 82 percent of the pesticides, and much of the fuel used to produce the sugar crops were imported as well, along with 36 percent of the animal feed for Cuban livestock (Rosset and Benjamin 1993:10, 15).

This trade regimen–though highly import-dependent–enabled Cuba's 11 million people to achieve economic equity, rapid industrialization, and advancements in quality of life. In the 1980s, Cuba exceeded most Latin American countries in nutrition, life expectancy, education, and GNP per capita. Sixty-nine percent of the population was urban, with virtually no unemployment (Rosset and Benjamin 1993:12). Ninety-five percent of Cubans had access to safe water and 96 percent of adults were literate (FAO 1999:20).

The Advent of Alternative Agriculture

The crumbling of the socialist trade bloc in 1989–91 brought upheaval to the Cuban economy and its conventional model of agricultural production. Cuba lost 85 percent of its trade (Murphy 1999). The United States tightened its already stringent economic blockade against Cuba, compounding the country's difficulties.

Cuba's access to basic food supplies was severely threatened. As food imports were halved, caloric intake dropped 22 percent, protein 36 percent, and dietary fats 65 percent (Bourque 1999). According to the FAO, Cuba endured the largest increase in undernourished people in Latin America in the 1990s–a jump from less than 5 percent to almost 20 percent (FAO 1999:8). Imports of pesticides, fertilizers, and feeds were reduced by 80 percent and petroleum supplies for agriculture were halved (Rosset 1996:64).

To avert widespread famine, Cuba had to find a way to produce twice the amount of food with just half of its previous agricultural inputs. The result is that Cuba is now in the midst of the largest conversion from conventional high-input chemical agriculture to organic or semiorganic farming in human history (Rosset 1996:64). Cuban farmers are attempting to produce most of their food supply without agrochemicals.

Cuba's prior investments in science, education, and agricultural research and development proved a great asset during these dire economic straits. In the 1980s, concerned by Cuba's vulnerability as the sugar plantation of the eastern bloc, government leaders had invested $12 billion in training scientists in biotechnology, health and computer sciences, and robotics

Cuba's Dependence on Imported Food, pre-1990

Imported foods accounted for 57 percent of Cubans' total caloric intake.

Food	Percentage of Food Imported
Beans	99
Oil and lard	94
Cereals	79
Rice	50
Milk and dairy	38
Animal feed	36
Meat	21
Fruit and vegetables	1–2
Roots and tubers	0
Sugar	0

Source: Rosset and Benjamin 1993:10.

(Rosset 1996:65). Although Cuba comprises only 2 percent of Latin America's population, it is home to 11 percent of the region's scientists (Rosset and Benjamin 1993:4).

Agricultural scientists influenced by the international environmental movement of the 1970s had begun to criticize Cuba's dependence on foreign inputs and the toll that conventional cultivation techniques were taking on the island's agroecosystems. As they noticed increasing pest resistance and soil erosion, many shifted their research in the 1980s to alternative methods of crop production, particularly the biological control of insect pests (Rosset and Benjamin 1993:21).

Most important, Fidel Castro gave his full support to the "alternative model" during this "Special Period." The government emphasized the importance of using Cuba's own scientific expertise instead of imported technology. "Cuban scientists will create resources that will one day be more valuable than sugarcane" Castro said in 1991. "Our problems must be resolved without feedstocks, fertilizers, or fuel" (Rosset and Benjamin 1993:24).

That was easier said than done. Cuban scientists had developed several alternative agricultural techniques during the 1980s but they were largely untried. Plus, the transition from chemical to organic agriculture takes time–roughly 3-5 years to regain soil fertility and re-establish natural controls of insect pests and diseases (Rosset and Benjamin 1993:25). Cuba did not have the luxury of 3-5 years.

Cuba's Access to Selected Imports in 1989 and 1992

Item	1989	1992	Percentage Decrease
Animal feeds	1,600,000 MT	475,000 MT	70
Fertilizer	1,300,000 MT	300,000 MT	77
Petroleum	13,000,000 MT	6,100,000 MT	53
Pesticides	US$80,000,000	>US$30,000,000	63

Source: Rosset and Benjamin 1993:17.

The first challenge was soil fertility. Fertilizer availability dropped 80 percent after 1989. To fill the void, Cuban farmers have employed a variety of "biofertilizers" and soil amendments, including composted animal wastes, cover crops, peat, quarried minerals, earthworm humus, and nitrogen-fixing bacteria. Though the *Rhizobium* bacterium has long been known to help legume crops obtain nitrogen from the atmosphere, Cuban scientists also have used *Azotobacter*, a free-living nitrogen-fixing bacterium, to supply nitrogen to many nonlegume crops. *Azotobacter* offers added advantages of shorter crop production cycles and reduces blossom drop, helping Cubans achieve a reported 30-40 percent increase in yields for maize, cassava, rice, and other vegetables (Rosset and Benjamin 1993:43). Similarly, the substitution of worm humus for chemical fertilizers increased yields of various crops by 12-46 percent (Monzote n.d.:9).

Intercropping, once rare in commercial scale farming, is being revived to diversify crop production and boost soil fertility. Another key component of Cuba's soil management efforts is reforestation; many forests were razed after the 1959 revolution to plant sugarcane and provide fuel for sugar manufacturing. In 1989-90, more than 200,000 ha were reforested (Rosset and Benjamin 1993:50).

The country is recycling its waste products on a massive scale, including household garbage and composted livestock and human waste. Wastewater is used to irrigate cane fields. Filter press cake, a by-product high in phosphorous, potassium, and calcium, serves as fertilizer. Bagasse, or dry pulp, is fed to livestock and burned to generate electricity for machinery in many sugar mills.

Cuba has a history of using biological controls for insect pests that dates back to 1928, when growers began releasing mass-reared parasitic flies (*Lixophaga diatraeae*) into sugarcane fields to control cane borers. Since the food crises, however, use of biological controls has intensified. Growers have been releasing predatory ants (*Pheidole megacephala*) to control the sweet potato weevil (*Cylas formicarious*), a method that has proven 99 percent effective (Rosset 1996:66).

Cuban researchers have focused also on the use of entomopathogens–bacteria, fungi, and viruses that infect insect pests but are nontoxic to humans. *Bacillus thuringiensis*, Cuba's first commercially produced biopesticide, is a soil bacterium widely used to control lepidopteran pests in pasture, cabbage, tobacco, corn, cassava, squash, and tomatoes, as well as mosquito larvae that transmit human diseases. The fungus *Beauveria bassiana* has also been used successfully against sweet potato and plantain weevils (Rosset 1996:67). In contrast, prior to 1989 the most common pesticide used in Cuba was methyl parathion, one of the most acutely toxic pesticides in the world (Gellerman 1996). By the end of 1991, an estimated 56 percent of Cuban cropland was treated with such biological controls, representing savings of US$15.6 million per year (Rosset and Benjamin 1993:27).

Overall, nonchemical weed control has been less successful than pest controls in Cuba, as elsewhere. Nevertheless, researchers continue to develop methods that hold promise—crop rotations based on mathematical modeling, methods involving weed densities, and traditional methods used by peasants before the advent of herbicides.

Perhaps the most striking change in the agricultural landscape was the return to the use of oxen in the fields while Russian tractors, lacking parts and fuel, were idle. Though more labor-intensive, ox traction actually provides advantages to Cuban farmers. Oxen are cheaper to operate, do not compact the soils, can be used in the wet season long before tractors, and their fodder provides much-needed organic fertilizer. New ox-powered plows, planters, and cultivators were developed, and the government encouraged oxen breeding programs to expand the herd.

Promotion of Small Farms and Urban Gardens

Alternative farming methods alone couldn't bring Cuba out of its agricultural slump. Huge Soviet-style state farms controlled 80 percent of the nation's agricultural land. The vast monocultures of sugarcane, pineapples, citrus and other crops they once produced with chemical fertilizers and pesticides were incapable of developing the natural pest controls or soil fertility produced by smaller, more dynamic organic systems. As a result, the state farms became extremely vulnerable to pests and disease (Rosset 1996:65, 69).

By contrast, *campesinos* were quick to adapt the new technologies, and their productivity soared. Many were descendents of generations of small farmers with long family and community traditions of low-input farming, and they remembered techniques that their parents and grandparents used

In the 1980s, Cuba used highly mechanized agricultural methods. After the economic crisis, oxen teams were substituted for tractors on both small and large farms. The number of oxen teams has tripled in the last decade. There is also a growing network of small workshops producing implements for farming with oxen teams.

such as intercropping and manuring. Even before the country-wide emphasis on organic agriculture in the 1990s, the small farmers had proven their efficiency: they worked only about 20 percent of the land but produced more than 40 percent of the domestic food supply (Rosset 1996:65, 68-69).

In 1993 the Cuban government broke up the unproductive state farms into Basic Units of Cooperative Production–worker-owned cooperatives that controlled about 80 ha each. Although the government still owns the land and sets production quotas for key crops, coop members own everything they produce above the quotas and can sell it in new farmer's markets. Sales at markets flourished and severe food shortages disappeared by mid-1995 (Rosset 1996:69-70).

Another factor that helped stave off hunger was the promotion of urban agriculture by the Cuban government on private and state land, which gardeners can use at no cost. Today, Havana alone has more than 26,000 self-provision gardens (Moskow 1999:127) that produced an estimated 541,000 tons of fresh organic fruits and vegetables for local consumption in 1998. Some neighborhoods were producing 30 percent of their food. Price deregulation provided another incentive, enabling urban farmers to earn two to three times as much as urban professionals (Murphy 1999).

Intensive, raised-bed agriculture is the model for urban agriculture in Cuba. These farms, called *organoponicos*, are approximately 1 ha and produce, on average, 20 kg of vegetables per square meter (Bourque 1999). Farmers rely on large applications of organic fertilizers from local sources and only use biologically based pest controls when absolutely necessary.

Will the Organic Revolution Be Overthrown?

In the 1996-97 growing season, Cuba recorded its highest-ever production levels for 10 of the 13 basic food items in the Cuban diet, largely because of small farms and backyard production (Rosset 1998). But FAO data suggest that total Cuban crop production in 1996-98 was still 40 percent lower than in 1989-91 (World Bank 2000:122), perhaps in part because sugar crop yields have not yet recovered. Furthermore, pest and disease outbreaks continue. Many of the biopesticides require critical timing of applications to work, and the quantity and quality of materials produced by the cooperatives vary widely. At one point a shortage of glass jars needed to grow fungal spores held up production (Rosset 1996:72).

Such stumbling blocks have led outside observers to speculate that the organic revolution in Cuba may dissolve after the economy improves and trade barriers come down. The topic is a subject of debate among Cuban agricultural scientists and farm managers, many of whom remain dedicated to high-input chemical agriculture common in the West (Mueller 1999).

Whatever the outcome, Cuba's ongoing experiment with alternative agriculture has left a powerful mark. Even though Havana now enjoys increased food availability, urban agriculture is stronger than ever (Murphy 1999). In a recent survey, 93 percent of gardeners interviewed affirmed their commitment to producing food in urban areas and once vacant lots even after the "Special Period" ends (Moskow 1999:133). Cuban scientists are already exporting their expertise, working with Mexico, Bolivia, Brazil, Laos, and other countries to develop and export biological controls for the coffee weevil and other pests (Bourque 1999). Moreover, Cuba has succeeded in feeding its people without the high inputs of conventional agriculture, providing a model that other countries can follow.