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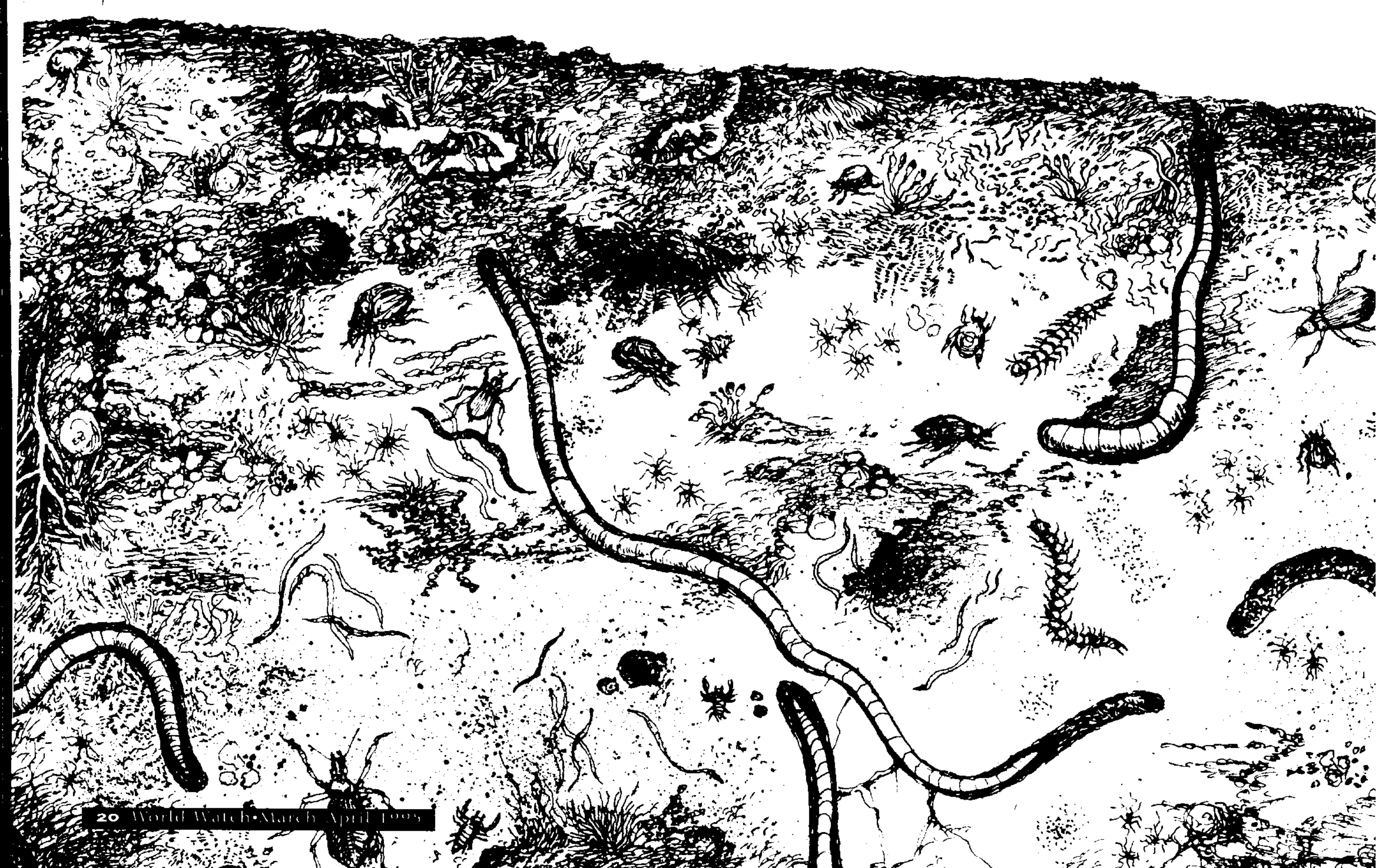
THE APPETITES OF GROWING POPULATIONS ARE SQUEEZING THE LIFE OUT OF THE EARTH'S FINITE SUPPLY OF GOOD SOIL. NOW THE QUESTION IS WHETHER WE CAN REBUILD IT FASTER THAN IT DISAPPEARS.

By Elena Wilken

To be human is to be a creature of the soil: that message is contained in creation stories from all over the world. In Genesis, for instance, man is formed "from the dust of the ground." The soil's mysterious vitality is a subject for science too; in the lightless world beneath our feet, death becomes life, and the renewal of the soil itself—a process so slow it's usually indiscernible in a human lifetime—proceeds



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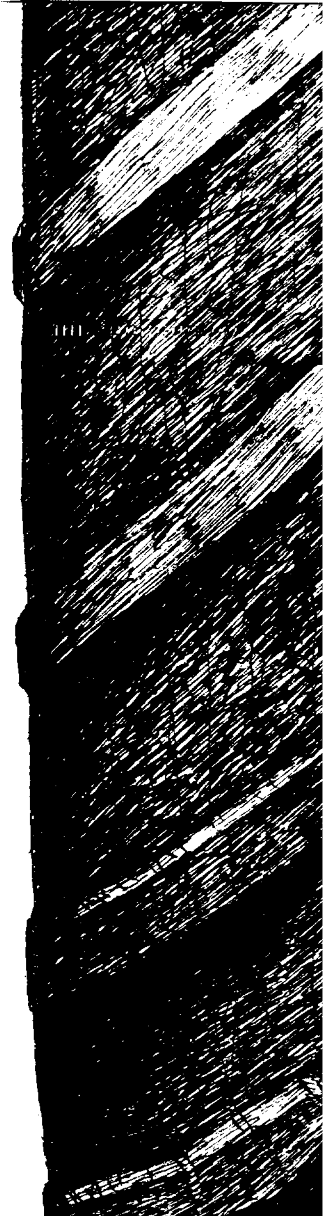


in rhythms still largely unknown. But in the developed world, at least, those creation stories seem to be lost on us. By and large, we no longer honor our relationship to the soil. Soil has become simply one more resource—a substance necessary for crop production and for holding up buildings. We take it for granted, and fail to notice that it's disappearing.

For most of human history, we could afford to remain ignorant of how the soil worked. When farmers exhausted the productivity of a field, they could usually bring another one into production. But now that human populations are pushing into every nook and cranny of the globe, we no longer have the option of moving on. Virtually all of the world's most productive cropland is already in cultivation. It's true that in many areas, some of the best land is producing cash crops instead of food for local consumption. But even so, the basic trends are clear: if the amount of land in production remains constant over the next 40 years, farmers will nearly have to double their yields to feed the growing population. And as we try to grow more and more food—by cultivating marginal cropland, by intensifying production, by using more powerful technologies—our soils deteriorate.

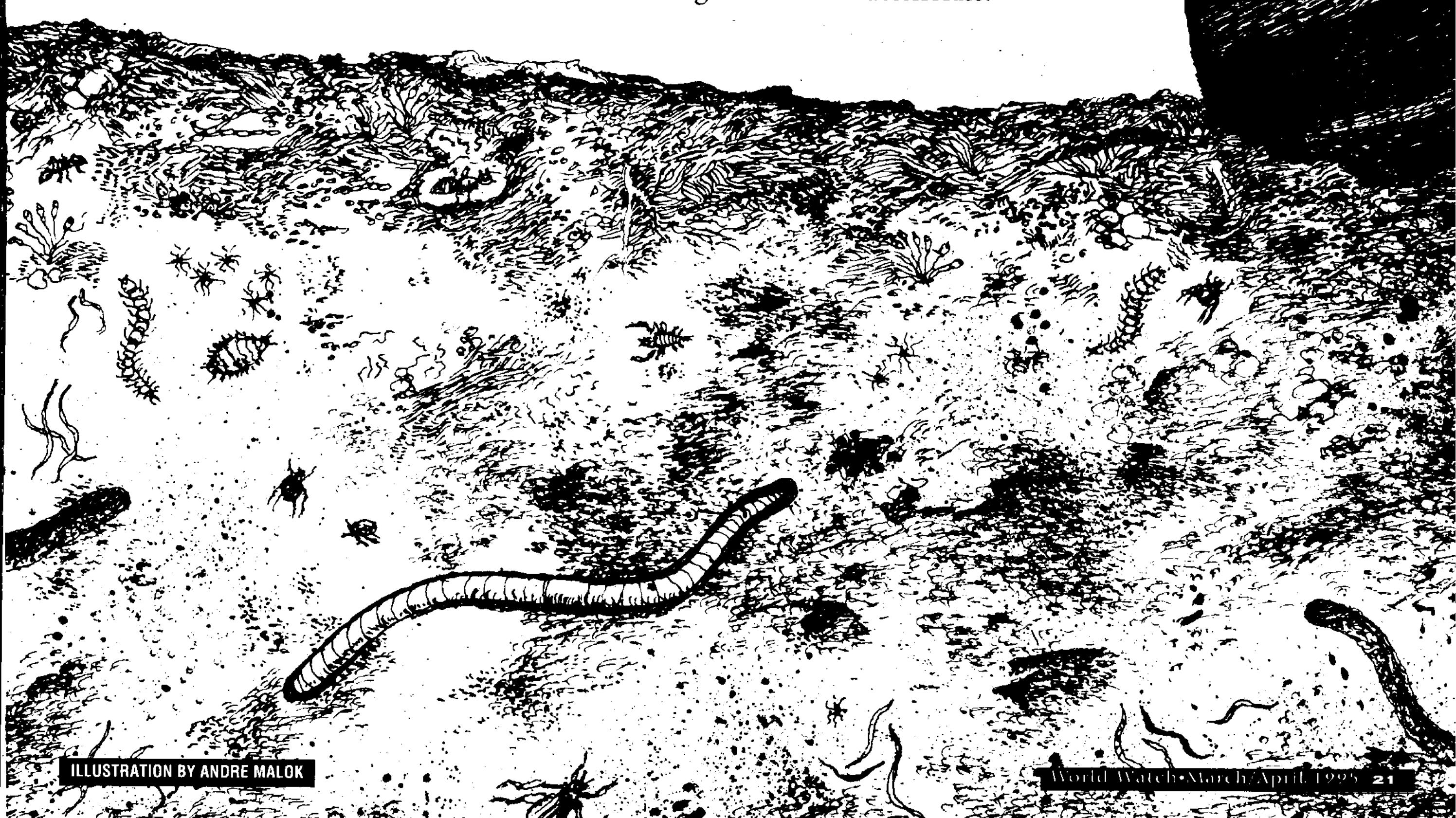


ILLUSTRATION BY ANDRE MALOK

The problem is further complicated by our ignorance of natural changes: not every form of degradation is caused by human activity, and large natural cycles are probably futile to combat. In 1984, for example, the U.N. Environment Programme claimed that the sands of the Sahara were being pulled southward by excessive livestocking, deforestation, and over-grazing around watering holes. But satellite photographs eventually showed that this instance of desertification was largely the result of a sustained drought. In marginal climates, a few centimeters of rain can make the difference between relatively lush vegetation and a barren landscape. Certainly much of sub-Saharan Africa is under increasing pressure from grazing and agriculture, and some areas are severely degraded. But the simple *appearance* of degradation is not a sufficient basis for policy.

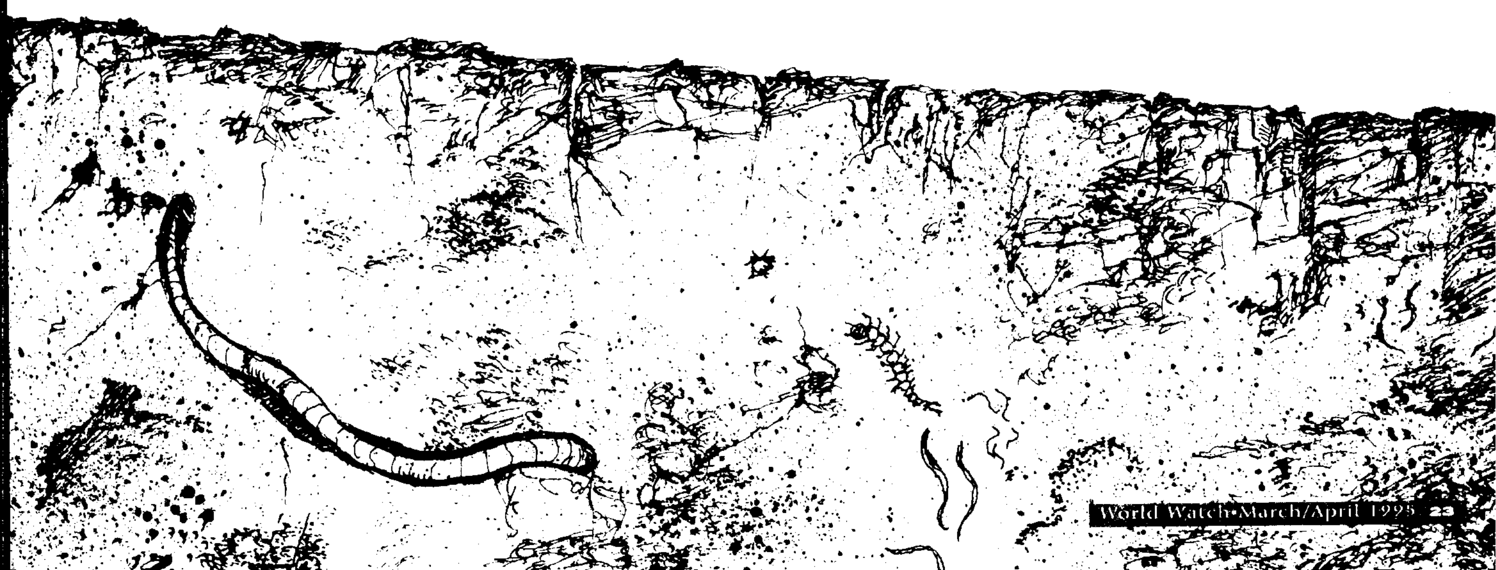
On the other hand, it would be a costly mistake to allow our uncertainty to forestall action. Conserving healthy soil is much easier and cheaper than repairing ruined soil. In the western United States, for instance, saltation is a widespread yet largely preventable problem. Saltation occurs in poorly drained fields, where irrigation raises the water table to just below the soil surface. Salts and minerals, from fertilizer and from the soil itself, are dissolved in the water and deposted at the surface as the water evaporates. The results can be dramatic: in Utah, for instance, a highway outside Salt Lake City offers a view of barren fields crusted in white. Rejuvenating such fields costs from $1,000 to $2,000 per hectare, and the effort often fails. But saltation can be prevented with just a simple set of underground pipes to draw excess water off the field.

The components of degradation are interconnected. Loss of soil structure, for instance, tends to increase erosion, which will lower nutrient levels, which will in turn decrease microbial activity. But it's often possible to approach the problem by looking at the relationship between a particular type of soil degradation and the farming practices most often associated with it.

Erosion is one of the most obvious forms of degradation. In dry climates, wind will erode unprotected, fine soils. Water erosion is a greater concern in humid climates and on steep slopes. In both cases, erosion increases with the loss of vegetative cover. Cover slows wind speed, decreases the impact of raindrops, and stabilizes soil with root systems. Just clearing a forest or plowing a grassland may drastically increase the rate of erosion.

In some parts of the Third World, erosion is part of a fundamental social problem. In Latin America, for instance, wealthy land owners are increasing their cash crop production for growing export markets. Subsistence farmers, forced off their rented plots, have no choice but to clear less arable land, often in sloping, forested highlands. Once stripped of trees and plowed, the soil in such areas erodes rapidly, forcing its tenants off in search of yet more land. Under such conditions, soil erosion exacerbates social erosion.

Although obvious in its extreme forms, most erosion is insidious. The loss of colossal amounts of material can be very difficult to detect: 6 metric tons of soil coming off of 1 hectare would reduce the topsoil level by only 1 millimeter. A complex set of factors, including rainfall, slope, and farming practices past and present, determine the rate of erosion, and variation in any of the causes may greatly affect that rate. Erosion rates can vary by a factor of 100 in a single agricultural area. In parts of Poland, erosion in a dry, windy year has been shown to be four times greater than in a wet year. In eastern Kenya, a study found that rangeland with



more than 20 percent vegetative cover erodes at a rate of 6 to 12 metric tons per hectare per year, while the rate for land with less than 20 percent cover is several times higher. Even within the same plot of earth, the forces of erosion do not act equally on all parts of the soil. Small particles—the ones most often bonded with nutrients—erode easily; large particles are more stable.

On the other side of the cycle, soil formation is just as difficult to measure. Depending on a host of conditions, it takes between 200 and 1,000 years to form 1 inch (2.5 centimeters) of topsoil. Under natural conditions, at least, soil is practically a non-renewable resource.

Agriculture has developed several stock responses to this problem. One is to enhance the rate of soil formation. Farmers cannot affect the rate at which minerals are ground out of bedrock, but they can increase the amount of organic matter in a soil by amending their fields with manure and field waste. Unfortunately, many farmers in developing countries depend on field waste for fodder, and on manure for fuel. Removing this material from the agricultural cycle exacerbates the problems that erosion is already causing. As yields drop, farmers are forced onto ever more marginal, more erodible land.

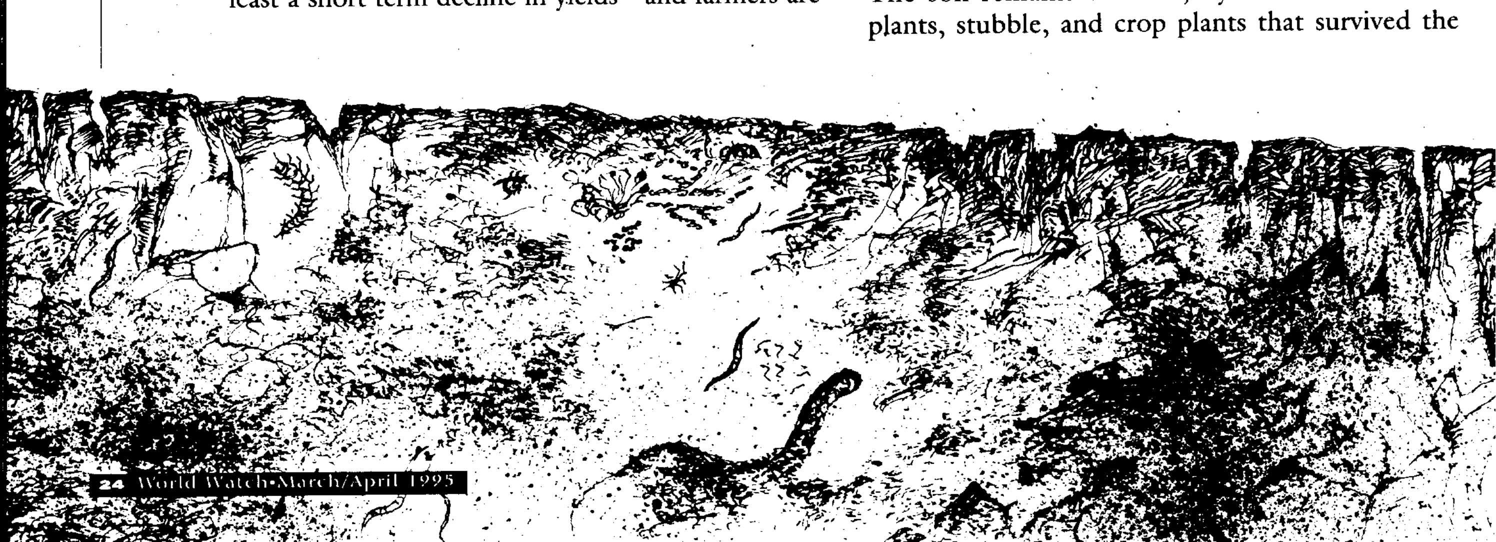
Another remedy is to make up for nutrients lost to erosion by increasing fertilizer applications. In China, some 30 percent of the nitrogen and 22 percent of the potassium applied each year on cropland goes to replace nutrients that have eroded out. Still, research has shown that fertilizing eroded soil does not fully restore lost productivity: it will improve yields, but not enough to match those of uneroded fields.

Despite the obvious need for a more aggressive approach to erosion, conservation techniques have not generally been brought into play on a scale that would allow for real progress. A major obstacle to conservation is that many of the techniques cause at least a short term decline in yields—and farmers are generally reluctant to take the loss. Converting to a different regime may also require capital or technical expertise that can by hard to come by. Such problems have plagued even the most ambitious attempts to counter erosion.

The United States has perhaps the world's most comprehensive erosion control program. A monitoring system combines satellite photographs with ground-level measurements to estimate local rates of erosion and monitor change over time. In 1985, the Conservation Reserve Program (CRP) was enacted to counter excessive erosion, much of it caused by the agricultural boom of the 1970s: in response to lucrative subsidies and high commodity prices, American farmers had expanded their cropland by 20 million hectares between 1972 and 1981. Much of this land was highly erodible, and the national rate of topsoil erosion rose to over 3 billion metric tons a year. The first phase of the CRP paid farmers to convert almost 40 million hectares of cropland to grass and trees. Erosion declined by as much as 25 percent in some regions.

But the target rate for soil loss, set at 12 tons per hectare per year for deep soils, and at 2 tons for shallow soils, has yet to be achieved on land still under production. The CRP's second phase requires farmers to implement conservation practices such as no-till cultivation, contour plowing, or residue management (the practice of leaving crop debris on the field after harvest), on especially erodible cropland still in production. This phase has proven more difficult to monitor and evaluate, since the conservation incentive is poorly connected to the profit incentive.

The biggest problems usually involve a reduction in yield, but productivity can be as difficult to evaluate as erosion. It's clear, for example, that no-till cultivation decreases yields at least over the short term. In no-till regimes, farmers plant seeds in holes punched into the field's surface, instead of plowing. The soil remains covered, by a mixture of wild plants, stubble, and crop plants that survived the



previous year's harvest. Weed control is accomplished only with herbicides: no mechanical cultivation is used. Canadian field tests comparing crop performance on a no-till and a conventionally tilled field found the no-till yield 20 percent lower during a year of average rainfall. But the following year happened to be dryer than usual; yields from both fields fell, but the conventionally plowed field suffered the greater drop, and the two yields were equal.

Given the thin margins on which farmers operate, many see any drop in productivity as an unacceptable cost, no matter what the long term trend may be. That kind of reluctance is making the economics of conservation as difficult as the science. Part of the problem is that farmers do not generally account for the full effect of erosion on yields. Some of the decrease in soil productivity is usually compensated for by non-organic fertilizers, but fertilizers are expensive. Some types of conservation farming, like low-input production, eliminate non-organic fertilizers, thereby lowering yields, but lowering production costs as well. No-till methods greatly reduce machinery requirements, another major operating expense. In the United States, farmers have used no-till practices to cut production costs by 25 to 30 percent, mostly by scaling back on machinery use.

Some farmers are managing to make the economics of conservation work, but many farmers and policy makers are concerned that widespread adoption of low-input systems would greatly reduce U.S. grain exports. That would force up global grain prices and could cause food shortages in importing countries. They're right in a broad sense: mass conversion to new agricultural systems would be very disruptive. But that objection does not take into account the long term costs of soil erosion.

In the United States, farm subsidies would be an obvious place to begin accounting for those costs, and recent developments hold out some promise of constructive change. American farmers have generally been subsidized in proportion to the amount of grain they produce—an arrangement that has encouraged maximum production. But in 1985, the policy began to shift: that year's Farm Bill began requiring conservation plans from every farmer tilling highly erodible land and receiving subsidy payments. Bill Richards, a former Ohio farmer and now chief of the U.S. Soil Conservation Service, estimates that a quarter of the country's cropland is now under some conservation system, from simple residue management to the more complicated no-till cultivation. That percentage is expected to increase during the current year. By encouraging farmers to conserve soil without losing income, Richards claims the legislation is causing a revolution on the farm. "It is beyond science and technology," he says. "It is a cultural revolution." Unfortunately, the program is under fire in Congress, and this year's budget threatens a 50 percent funding cut. Even if funding isn't lost, a rise in grain prices—a likely prospect over the long term—would undercut the program's effectiveness by providing a strong incentive to increase production. And of course, few other countries have the resources to subsidize farming to the degree that the United States does. Even where conservation technologies exist, economics may block their widespread adoption.

Erosion is not the only problem affecting the soil. The topsoil houses countless micro-organisms and small invertebrates—one teaspoon of fertile soil may contain over a million of them. Biologists know little about these creatures. At the current rate of study, it would take eight centuries just to complete an inventory of them. Most have not been isolated because they cannot be kept alive outside their soil habitats. We do know, however, that many are decomposers, converting the "death, dung, and detritus," as soil scientists call it, to humus and nutrients that can be taken up by other organisms. Others play a direct role in nutrient uptake by plants, performing a useful chemical reaction in exchange for a share of the energy that plant metabolism stores. It's generally agreed that the vast diversity of microbial life enhances soil productivity, but there is as yet no way of quantifying the level of diversity that is necessary for crop produc-

tion. Nor do we know what effect various agricultural techniques have on microbial life.

But in South and Southeast Asia, recent trends point to a suppression of soil life that is as ominous as the erosion in the American midwest. The International Rice Research Institute (IRRI), a research organization devoted to increasing rice production, maintains a string of carefully managed test plots throughout the region. Test plot yields have begun to decline, in part, researchers believe, because of decreased microbial activity. It is possible that the IRRI test plots have hit some sort of ceiling for rice production.

The problem has its roots in the mid 1960s, when IRRI released a set of new rice varieties that had shorter maturation times. In Indonesia, Thailand, the Philippines, India, and Japan, farmers responded to increasing demand by using the new varieties to grow two or even three crops a year. Initially, at least, this approach also seemed to make sense as a soil conservation measure: concentrating production in the fertile lowlands reduced the pressure on the highly erodible and less fertile highlands.

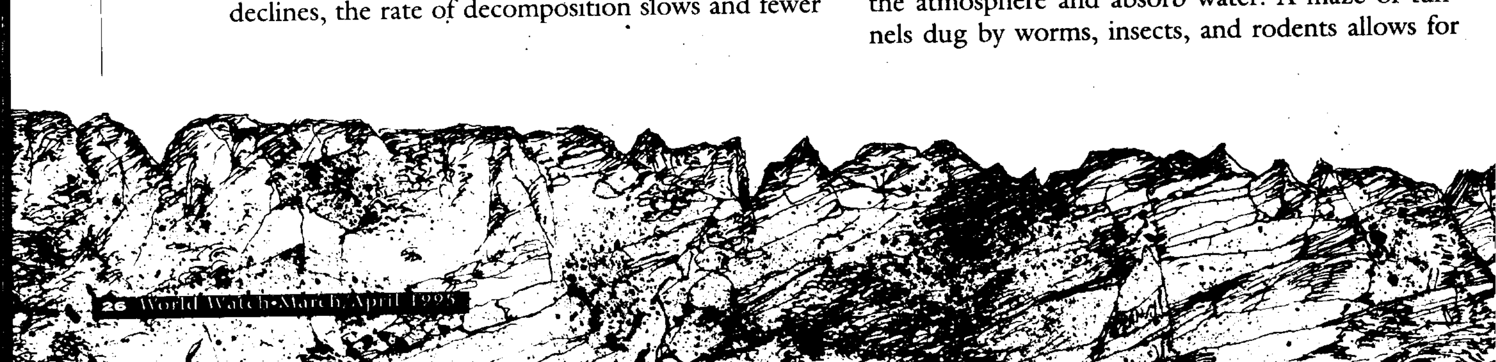
For 20 years or so, the strategy worked. Southeast Asia's rice yields rose from 1.1 metric tons per hectare in 1961 to 1.8 tons in 1982. Production increased at 2.7 percent annually, edging out the region's 2.1 percent population growth. Since then, however, increases in yields have slowed. And in the IRRI test plots, where yields regularly surpassed what most farmers achieved, production has begun to decline—in some cases, by as much as 15 percent. Farm and test plot yields are converging: about a third of the region's farmers can now match the test plots. The trend looks ominous to many researchers, who worry that the test plot declines might mean the farm yields have peaked as well.

New rice strains continue to be developed, but none have reversed the test plot declines. Careful testing has ruled out problems with the genetic potential of the strains, and with the input regimes, which means that the problem must involve environmental degradation. No one knows exactly what is happening, but scientists theorize that the community of soil micro-organisms is ill-adapted to the continually flooded soil. As microbial activity declines, the rate of decomposition slows and fewer nutrients are available for plant growth. The irrigation water is richly furnished with nitrogen by the algae growing in it, but the soil is not supplying that nitrogen to the rice. Attempts to inoculate the test plots with foreign microbes have been largely unsuccessful: apparently, the paddies are no more hospitable to foreign microbes than to native ones.

Meanwhile, the demand for rice is increasing, driven by expanding populations and incomes, and the region's governments face an ugly dilemma. Persisting at current levels of production will likely lead to a decline in yields, which could force farmers onto the more fragile highlands. Yet farmers are loathe to cut back to one harvest per year, which would allow soils to dry out and rejuvenate. For the present, the remedy seems worse than the disease. Nor does crop rotation offer an obvious way out. Planting the paddies in wheat or legumes during the dry season has yielded indifferent results, because continually flooded soils form a hard layer of clay below the topsoil, decreasing water absorption. Rice plants thrive in such an environment, but the dry season crops do poorly, since they prefer deeper root space and better drainage.

One of the first lessons in a typical soil science class is a demonstration with two handfuls of soil, one from a field that hasn't been plowed in five years, the other from a field subjected to at least eight tractor crossings a year for several years. Eight crossings is typical in conventional agriculture—two for plowing, one for seeding, two for fertilizing, two for weeding, and one for harvesting. The plowed handful of soil is dense and breaks up into hard chunks; a cup of water thrown on top runs off the surface. The fallow sample is looser and clumps together. It absorbs the water, which runs out the bottom in a few seconds. The differences are a matter of structure.

In undisturbed soil, it's mainly the top layer that stores nutrients, sustains microbial life, and supports roots. Most of the soil's organic matter is found here. Humus is light and bulky—it's measured at only 6 percent of the soil's mass, but up to 25 percent of its volume. Structure determines a soil's ability to "breathe" and drink. The surface is pocked with tiny pores that exchange gasses with the atmosphere and absorb water. A maze of tunnels dug by worms, insects, and rodents allows for



drainage and aeration. But plowing collapses the pores and tunnels. Water absorption drops and the gas exchange—an important part of the soil's ecology—slows. Soil can repair itself in time, but not if repeated compaction with heavy tilling equipment decreases its resiliency.

The communal farms of the former Soviet Union may have taken this process to an extreme. The communes averaged 5,000 hectares and were supplied with the world's largest tractors—considerably heavier than the largest American models, which weigh as much as 20 tons. Continual use of these machines compacted the country's most productive soil. Commune harvests also usually removed all the crop residues for fodder, further undermining soil structure by depriving the soil of its organic component. The effects of this assault on the land were partly masked by extremely heavy applications of non-organic fertilizer: from 1975 through 1991, the region's farmers had the world's highest rate of fertilizer use.

The communes were privatized after the collapse of the Soviet state, and the average size of a farm is now under 50 hectares. The huge tractors are no longer necessary, and farmers are demanding more appropriate technology. Fertilizer use has decreased by 50 percent since 1988, because the cost of inputs is rising faster than farm profits. Although yields have not changed noticeably during this transition, farmers will be dealing with the legacy of Soviet agriculture for years to come. An eventual decline in yields is probable unless farmers address the extensive compaction that their soils have suffered.

The cure for compacted soils is relatively simple: planting perennial crops, such as alfalfa and legumes, makes annual tilling unnecessary, so the soils have a chance to rebuild. But Russian farmers want to continue producing wheat and other annuals, because those are the crops that have well-defined markets. Selling an alternative crop requires a capitalist's skill, which is still hard to come by on the Russian farm. In the meantime, additions of organic material—manure, or just crop residues—could boost the soil structure immediately. To farmers struggling with unfamiliar markets and economic instability, any soil management plan more elaborate than that might seem like a luxury.

The task of rebuilding the world's cropland must be done by the world's farmers, but it's up to governments to set the policies that will make that effort possible. Policy specifics may vary as widely as the soils themselves. Formulating them will require a great deal more research and planning, but some basic principles are clear. Broad conservation standards—for erosion, say, or for drainage—could encourage change while allowing flexibility in the methods used to achieve it. That would let farmers experiment and adjust to local conditions. Agricultural subsidies that contain a soil conservation element could reward long-term planning instead of the short-term pursuit of maximum yields. Reforming wasteful procedures for storing and transporting grain would produce a "second harvest" that could take some pressure off the land. Finally, more equitable land distribution would ease the strain on the most marginal land, and perhaps on higher quality land as well, since owning a productive field from which one can feed one's own family is a strong incentive to conservation.

But fixing agriculture will take more than simple policy reform: it will require us to reconcile the diverging imperatives of conservation and production. The latter concern still dominates agricultural policy, which often treats the soil as just a "given," without considering the costs of losing it. But clearly, the way to a sustainable agriculture begins with the study of ecology. And where the economics allow, some farmers are trying to build agricultural ecosystems that resemble natural ones.

Such efforts are still fraught with problems, and no one knows for sure where they might lead. But there is little doubt where our current practices will take us if we persist in them. Our destination can be read, for instance, in the abandoned cities of North Africa—in places like El Jem, on the plain of Tunisia, and Timgad, in northeastern Algeria. These cities once supplied imperial Rome with grain, olive oil, wine, and wood. Now they lie abandoned and partly buried beneath the dust from eroded hillsides and barren fields. There were many reasons for the decline of Rome, but few have had an effect as lasting as the loss of the Empire's soil. If our own societies are to avoid this fate, we must learn to watch over our soils as carefully as we watch over our harvests. And ultimately, we will have to find ways to farm that create at least as much soil as is lost. If this sounds utopian, that's a measure of how far we have yet to go.

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