to respond were Risbey, Mark Handel, and Peter Stone of MIT, writing in the 31 December 1991 issue of *EOS*, the weekly newspaper of the American Geophysical Union. The MIT group argued that Schlesinger and Jiang's supercomputer effort wouldn't narrow the uncertainties enough. And a decade, they say, will see only the beginning of crucial observations of the behavior of oceans and clouds—two key sources of uncertainty. Risbey and company's doubts echo those in a 1990 IPCC report, which foresaw the cloud and ocean uncertainties narrowing only in the 10- to 20-year range, by which point the globe might be committed to major climate change.

Nasty surprises. The other reason for not waiting is uncertainty itself, say Risbey and others. The possibility that greenhouse-induced change could turn out to be much more dramatic than any model predicts is spooking a generation of earth scientists who remember the nasty surprise sprung by stratospheric ozone. By the late 1970s, scientists knew of the potential for damage by manmade chlorine compounds, but their scenarios suffered from uncertainties and lacked a smoking gun. As a result, public interest in the problem declined. Then, out of the blue, atmospheric chlorine burned a hole in the ozone layer over the Antarctic and began eating away at the ozone over mid-latitudes. Scientists had simply overlooked ways that natural atmospheric particles could boost chlorine's destructiveness by a factor of 10.

Greenhouse specialists, too, are wondering what they might have overlooked. Perhaps an abrupt change in ocean circulation, Wallace Broecker of Columbia University's Lamont-Doherty Geological Observatory has suggested—although some studies have now discounted that idea. Or perhaps unanticipated feedback from polar ice caps or green plants, other workers venture. "It's a matter for concern," concedes Schlesinger. "How you deal with that depends on your philosophy."

The philosophy that many scientists contacted by *Science* are now espousing amounts to buying some insurance—in the form of no-cost or low-cost reductions in greenhouse gas emissions—against the possibility that the higher predictions of global warming turn out to be right or some nasty surprise is lurking in the greenhouse. And that notion of prudence seems to be catching on at last in the White House.

–Richard A. Kerr

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AGRICULTURE

Does Global Change Threaten The World Food Supply?

A.E. JOHNSTON

Land on the run. A river in Paraná state, Brazil, runs red with soil eroded from deforested land.

When most people think of global change, they think of its impact on the natural world: the loss of animal and plant species, the warming of the climate, the destruction of ozone. But global change is also taking its toll on one of humankind's most important activities—agriculture. Indeed, a distressing turn of events has already taken place in Asia's rice paddies and Mexico's potato fields, unnoticed by most of the developed world. After 3 decades of continuous increase, crop yields have leveled out or, worse, dropped, over the past few years.

And that's contributing to an alarming trend. In almost 70% of developing countries, population growth is outstripping gains in food production, reports the Washington, D.C.-based secretariat of the Consultative Group on International Agricultural Research (CGIAR), an informal association that supports 16 international agricultural research centers. "For the first time in modern history," says Paul Ehrlich of Stanford University, "absolute global food deficits may soon compound inequities in food production and distribution in causing famine."

Ehrlich, a population biologist, is known for pessimistic scenarios. But many agricultural researchers agree with him on this one. Uma Lele, an agricultural economist who until recently was with the World Bank and is now at the University of Florida, says, "A general impression remains that the Green Revolution has permanently solved the food problem. But the harvests of recent years suggest otherwise." Underlying this sputtering productivity, she and other researchers say, are broad global trends that include the loss and degradation of arable land and the increased genetic uniformity of world food crops, which opens the way for pests and diseases to have a devastating impact.

So far the list of causes doesn't include global climate change. Some researchers fear that in the future, though, the added stress of a climate that may become warmer or drier in key production areas could take a further toll on global agriculture, with catastrophic results. Others are more sanguine, pointing to agriculture's history of adapting to a range of climates. But whether they see the flattening yields of the present as a warning for the future or an anomaly, researchers are joining in a call—likely to be echoed at next month's United Nations Conference on Environment and Development in Rio de Janeiro—for the development of "sustainable" agricultural strategies that would stem the loss of land and increase crop diversity.

To some extent, researchers say, agriculture is a victim of its own success. For the past 30 or 40 years, gains in global food production have exceeded population growth throughout the world, parts of Africa excepted. In Latin America and much of Asia, for example, yields more than doubled over that period. But those boom harvests were sparked by the agricultural programs of the Green Revolution, which had built-in limits. Already, says Michael Collinson of CGIAR, "the second generation problems [of the Green Revolution] are coming home to roost."

Is the revolution over? The limits of the Green Revolution stem from its reliance on a few high-yield crop strains and intensive use of pesticides, fertilizers, and irrigation. Not only are insects becoming resistant to the pesticides, but high costs and concern about health risks are starting to restrict pesticide and fertilizer use. And crop strains that were widely planted because they promised high yields—and for a time delivered them—are now falling victim to new diseases: Witness the potato fields of Mexico where, according to Luis Herrera-Estrella of the Centro de Investigacion y Estudios Avanzados (CINVESTAV) in Irapuato, Mexico, "yields have decreased in recent years despite increased acreage planted to the crop. Typically,

30% to 50% is lost to viral disease."

Irrigation, too, is showing its dark side. When water evaporates from irrigated fields, it leaves a salt residue that is poisoning once-productive farmland in northern India, the Middle East, California's Imperial Valley, and parts of Australia. In some regions, water itself is running low, as irrigation drains lakes or ground water. As a result, governments and international funding agencies are backing away from major irrigation schemes.

As the tools of the Green Revolution begin to lose their edge, arable land is vanishing. Cities were often founded near productive farmland and good water sources, with the result that explosive city growth in recent years has gobbled up some of the most fertile land. Such land loss, combined with population growth, says Lele, is pushing farming onto marginal lands—areas that are too nutrient-poor, dry, or steep to support it readily. Soils there are quickly exhausted, one factor in what Lele cites as a particularly alarming trend: "the stagnation in rice yields, the world's most important food crop." What's more, the clearing of natural vegetation from marginal lands can expose them to erosion. Even fertile lowlands suffer when exposed to rainwater rushing off denuded hillsides. All told, CGIAR and the Worldwatch Institute in Washington, D.C. have both suggested, about 25 billion tons of soil may be lost each year to erosion. Says A.E. Johnston, a soil fertility specialist at the Rothamsted Experimental Station in Harpenden, England: "The soils of the fertile valleys are now collecting on the ocean floor, where they are of no value for agriculture."

WALTER O. SCOTT

To some researchers, including Ehrlich and agriculture specialist David Pimentel of Cornell University, those trends spell the potential for widespread famine in coming decades. "Each year," says Ehrlich, "farmers have to feed 90 million more people with billions of tons less topsoil and trillions of gallons less ground water." If climate change enters the picture, say researchers, the prospects could get even darker.

Many climate models predict an increasing frequency of droughts in the American Midwest, according to climatologist Stephen Schneider of the National Center for Atmospheric Research in Boulder, Colorado. But areas already suffering famine may be hit hardest by climate change, says Lele. For example, rising oceans might submerge the low-lying, fertile Ganges delta. Such concerns make curbs on population growth and on the emission of climate-warming gases such as carbon dioxide an urgent priority, Ehrlich says.

But even among researchers who don't share Ehrlich's pessimism, a growing number agree that agriculture needs to get its own house in order, by departing from some Green Revolution practices and adopting those of so-called sustainable agriculture. Organizations that support agricultural research, including CGIAR, the Rockefeller Foundation, and the McKnight Foundation in Minneapolis, have now joined the sustainable agriculture bandwagon, looking for crops and farming practices that can increase productivity while sparing soil, water, and natural ecosystems.

Under the banner of sustainable agriculture come familiar erosion-control measures that were abandoned during recent decades: contour plowing, no-till agriculture (which avoids plowing altogether), and the preservation of natural vegetation for as much of the year as possible on cultivated hillsides. Advocates of sustainable agriculture are also urging the development of so-called neglected crops, such as cassava, sorghum, millet, plantains, and bananas. These traditional crops, now producing nowhere near their potential yields, were often overlooked in the rush to plant corn, rice, wheat, and potatoes throughout the developing world. But unlike many Green Revolution crops, some neglected crops do well without large inputs of chemical pesticides and fertilizers; others, such as millet, can grow in dry soil, reducing the need for irrigation. And the resulting increase in genetic diversity could help secure the world's food supply against new pests and disease.

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Neglected crops. Foxtail millet *(top)* and Fe'i bananas from the Pacific island of Vanuatu.

Even Green Revolution crops could become mainstays of sustainable agriculture with the help of biotechnology. For example, last month at a conference in Annapolis, Maryland, called "Feeding the World: Protecting the Environment," which was sponsored by the Rockefeller Foundation, Herrera-Estrella reported his laboratory's success in developing genetically engineered potatoes in collaboration with Monsanto. The new varieties, he says, are resistant to the viruses that have been devastating Mexico's potato harvest, reducing the need for chemical pesticides to control the insects that spread the diseases. Other work, at BioTechnica International and the Boyce Thompson Institute for Plant Research in Ithaca, New York, might make it possible to infect cereal crops with symbiotic nitrogen-fixing bacteria. Nitrogen-fixing corn or wheat could drastically reduce the world demand for nitrogen-containing fertilizer—now some 80 million metric tons each year.

On the bright side. Not every researcher agrees that entirely new agricultural strategies are needed to restore productivity growth. Paul Waggoner of the Connecticut Agricultural Experiment Station in New Haven thinks that more deft and sparing use of traditional Green Revolution tools—irrigation, fertilizer, and pesticides—can help return agricultural productivity to the fast track. Waggoner does advocate such "sustainable" innovations as greater use of biological pest controls, however.

Nor is Waggoner especially worried about global warming. At the February meeting of the American Association for the Advancement of Science in Chicago, he advised his colleagues to "overcome the predilection to think drought when climate change is mentioned, and remember that more rain might fall in the new climate." And even if global warming does bring drying to some agricultural regions, Waggoner is confident of agriculture's resilience.

But like his colleagues, Waggoner stresses that restoring and sustaining the growth in agricultural yields in the face of global change will take research—and he, Ehrlich, and everyone in between worry that not enough is being done. In the developing world, says Lele, local support for agricultural research has been a casualty of budget cuts, especially in Latin America and Africa. She adds that contributions to international organizations that support agricultural research have stayed flat; the CGIAR annual budget, for example, has hovered around $300 million for the past 3 years. "Enormous attention should be paid to agriculture," agrees Ehrlich, "and it's just not happening."

–Anne Simon Moffat

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