THE NEW GREEN REVOLUTION: HOW 21st CENTURY SCIENCE CAN FEED THE WORLD

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In Brief

The combined effects of climate change, energy scarcity, and water paucity require that we radically rethink our agricultural systems. Countries can and must reorient their agricultural systems toward modes of production that are not only highly productive, but also highly sustainable. Following the 2008 global food price crisis, many developing countries have adopted new food security policies and have made significant investments in their agricultural systems. Global hunger is also back on top of the international agenda. However, the question is not only how much is done, but also how it is done—and what kinds of food systems are now being rebuilt.

Agroecology, the application of ecological science to the study, design, and management of sustainable agriculture, offers a model of agricultural development to meet this challenge. Recent research demonstrates that it holds great promise for the roughly 500 million food-insecure households around the world. By scaling up its practice, we can sustainably improve the livelihoods of the most vulnerable, and thus contribute to feeding a hungry planet.

Some crises appear and disappear in global media while remaining acute in the lives of real people. Global food insecurity is this type of crisis. In January 2011 the Food and Agriculture Organization of the United Nations (FAO) warned that global food prices in December 2010 exceeded the 2008 peak during the so-called food price crisis that sparked food riots across Africa, Asia, and Latin America.[1] The UN also warned that the price increase would not stop overnight and that we were entering danger territory.[2] Although prices stabilized in the spring, global food prices in May 2011 remained higher than they were in June 2008. We will see more price spikes in the future, due to a growing discrepancy between supply and demand, the impacts of climate disruption on agricultural production, and the merger of the energy and food markets. The food crisis is here to stay.

Governments have pledged to reinvest massively in agriculture. After three decades of neglect, this is welcome news. However, as countries announce impressive figures on the scope of their reinvestment, we tend to forget that the most pressing issues today regarding agricultural reinvestment involve not only *how much,* but *how.*

The choice between agricultural development models has immediate and long-term consequences. Since 2008 some major reinvestment efforts have been

UN Photo/Eric Kanalstein

A farmer gathers wheat in Bamiyan, Afghanistan

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Key Concepts

- There are roughly 925 million hungry people on the planet. Many of them are smallholder farmers or farm laborers.
- With many governments poised for a large-scale reinvestment in agriculture, the question is not only how much, but how.
- Agroecology the effort to mimic ecological processes in agriculture could provide a framework for this reinvestment. Already, agroecological practices are being used around the world, increasing productivity and improving efficiency in the use of water, soil, and sunlight.
- But before agroecological practices can be scaled up globally, we must assess the market and political obstacles that stand in their way. Here, we present six principles that could help us overcome these obstacles.
- Our farmers-in-chief heads of states can make the new paradigm on agriculture, food, and hunger a reality.

channeled into a slightly modified version of the Green Revolution without fully considering our other great contemporary challenge of climate change. In contrast, scant attention has been paid to the most cutting-edge ecological farming methods methods that improve food production and farmers incomes, while also protecting the soil, water, and climate.

Yet, with an estimated 925 million hungry people on the planet,[3] we must think outside the box. Major shifts in food security policies are being discussed in most countries. Yet the best options are simply not being promoted sufficiently.

The first Green Revolution as developed in Mexico and then in South Asia in the 1960s succeeded in improving yields in the breadbasket regions where it was implemented.[4] But it sometimes came at a high social and environmental cost, including the depletion of soils, pollution of groundwater, and increased inequalities among farmers.[5] And the productivity gains were not always sustainable in the long term.

Our strategy today must recognize the connection between climate change and food security. It must leverage the potential of the new sustainable agriculture paradigm with policies designed to scale up and mainstream the systems that have proven records of success. It must not only preserve land and other agricultural resources for future generations; it must actively restore lands and resources that have been degraded. It must monitor progress using multiple indicators, ones that go beyond the amount of money invested and the amount of crops harvested. It must also create the enabling macroeconomic environment needed to link sustainable agricultural systems to markets.

Because hunger can be attributed to a wide range of causes, a comprehensive strategy to combat food insecurity would have to address issues such as an international trade regime that penalizes developing countries through subsidies that stifle local markets, the infliction of an unsustainable burden of foreign debt, and the impact of speculation on commodities markets. We do not focus on these themes, which are well known. Our interest is in the paradigm of agricultural development under which most policymakers work, and whether it meets the challenge of today and tomorrow. We believe it does not, and we seek to outline an alternative path.

Climate Change and Energy Scarcity: Key Elements of the New Food Security Context

Climate change is already having dramatic consequences for agriculture and international food security. Rain patterns are shifting, leaving farmers unable to harvest mature crops. More prevalent droughts and floods place unprecedented stress on agricultural systems. Water sources are more variable and are rapidly exhausted. Peasants are already struggling with these disruptions in Central America and East Africa. And, by 2080, 600 million additional people could be at risk of hunger as a direct result of climate change.[6] In Sub-Saharan Africa, arid and semiarid areas are projected to increase by 60 million to 90 million hectares, while, in Southern Africa, it is estimated that yields from rain-fed agriculture could be reduced by up to 50 percent between 2000 and 2020.[7] Losses in agricultural production in a number of developing countries could be partially compensated by gains in other regions. But the overall result would be a decrease of at least 3 percent in productive capacity by the 2080s, and up to 16 percent if the anticipated carbon fertilization effects (incorporation of carbon dioxide in the process of photosynthesis) fail to materialize.[8] Without closer international cooperation, the FAO and the Organisation for Economic Co-operation and Development (OECD) warn that the direct impacts of climate disruptions on food production patterns will also lead to more extreme volatility events on international food commodities markets the economists way of describing the 2008 global food price crisis.

Additionally, our current systems of agriculture are utterly dependent on fossil fuels. FatihBirol, the chief economist at the International Energy Agency, warned in August 2009 that oil is running out far more quickly than previously predicted, and that global production is likely to peak in about ten years. A study of the 800 biggest oil fields reveals that the rate of decline in the output of the world s oil fields is 6.7 percent a year.[9] The impacts of energy scarcity have been obscured by the economic crisis over the past two years. However, the price of the crude oil barrel has constantly increased in 2009 and 2010 thanks to economic growth in China and other emerging countries. Its level in May 2011 exceeds the level preceding the 2008 food price crisis.[10] Although the geopolitical situation in the Arab world and speculations about its consequences are currently driving oil prices up, economic recovery in developed nations and growth in the rest of the world will keep prices high.

Modern agriculture is highly sensitive to oil prices. Our food relies on oil or gas at many stages: nitrogen fertilizers are made of natural gas, pesticides are made out of oil, agricultural machinery runs on oil, irrigation and modern food processing are highly energy-dependent, and food is transported over thousands of miles by road or air. While the exact impacts of peak oil on the availability and cost of both oil and natural gas are unknown, it will undoubtedly affect food security. Energy scarcity is thus a key element of any policy for reinvestment in agriculture. But it is one that many current efforts lack.

Our current methods of food production are thus deeply unsustainable. Water scarcity and land degradation two of the anticipated results of climate change in many regions will add to the challenge of feeding the world. Already, 37 percent of China s total territory suffers from land degradation. And, while China has 21 percent of the world s population, it has only 6.5 percent of the freshwater available globally.[11]

This can be changed. Some agricultural systems can mitigate greenhouse gas emissions and increase resilience to climate extremes. According to a United Nations Environment Programme (UNEP) report, the agricultural sector could be largely carbon neutral by 2030 and could produce enough food for a population estimated to increase to 9 billion by 2050 if systems proven to reduce emissions from agriculture were widely adopted today.

Roots of the Future: The New Agricultural Paradigm

A few decades ago, agronomists were faced with a sharp increase in pest outbreaks in modern monocultures, while ecologists were starting to model the complex interactions between insects and plants. At the same time, scientists were observing the effectiveness of traditional farming systems. The two scientific disciplines of agronomy and ecology converged, shaping the field of agroecology. Agroecology is the application of ecological science to the study, design, and management of sustainable agriculture.[12,13] It seeks to mimic natural ecological

Christian Dupraz

An agroforestry system (interplanting poplar trees and wheat) in southern France. The system produces more grain and wood by hectare than if the two crops were cultivated separately

processes, and it emphasizes the importance of improving the entire agricultural system, not just the plant.

The pioneers of agroecology proposed that agroecological systems be based on five ecological principles: (1) recycling biomass and balancing nutrient flow and availability; (2) securing favorable soil conditions for plant growth through enhanced organic matter; (3) minimizing losses of solar radiation, water, and nutrients by way of microclimate management, water harvesting, and soil cover; (4) enhancing biological and genetic diversification on cropland; and (5) enhancing beneficial biological interactions and minimizing the use of pesticides.[14] Now, agroecologists are looking to integrate food systems, as well as agricultural systems, into the scope of agroecology.[15]

A growing number of scientists work and publish on this field,[16,17] and, recently, the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), a four-year study involving 400 experts from all regions as well as international organizations such as the World Bank, the FAO, and UNEP, called for a fundamental paradigm shift in agricultural development and strongly advocated the increase of agroecological science and practice.[18] Agroecology is also at the core of the latest reports published by the FAO and UNEP.[19,20] Meanwhile, the farmers united through La Via Campesina, the largest transnational peasant movement, have rapidly integrated agroecological principles in recent years.[21]

Today, agroecology has concrete applications on all continents. Its results speak for themselves. The widest study ever conducted on these approaches, led by Jules Pretty of the University of Essex, identified 286 recent interventions of resource-conserving technologies in 57 developing countries covering a total area of 37 million hectares in 2006.[22] The average crop yield increase was 79 percent, and a full quarter of projects reported relative yields greater than 2.0 (i.e., 100 percent increase). Malawi, which ramped up its fertilizer subsidy program in 2002 following the dramatic drought-induced food crisis the year before, is now also implementing agroforestry systems using nitrogen-fixing trees.[23] (Agroforestry involves planting trees with crops to more efficiently use land, nutrients, and water.) By mid-2009, over 120,000 Malawian farmers had received training and tree materials from the program, and support from Ireland has enabled extension of the program to 40 percent of Malawi s districts, benefiting 1.3 million of its poorest people. Research shows that the program has increased yields from one ton per hectare to two to three tons per hectare, even if farmers cannot afford commercial nitrogen fertilizers.[23] With an application of a quarter-dose of mineral fertilizer, maize yields may surpass four tons per hectare. The Malawi example shows that while investment in organic fertilizing techniques should be a priority, it should not exclude the use of other fertilizers. An optimal solution could be a subsidy to sustainability approach: an exit strategy from fertilizer subsidy schemes that would link fertilizer subsidies directly to agroforestry investments on the farm in order to provide for long-term sustainability in nutrient supply, and to build soil health for sustained yields and improved efficiency in fertilizer use.[23] In Tanzania, 350,000 hectares of land have been rehabilitated in the Western provinces of Shinyanga and Tabora using agroforestry.[24] In Zambia, agroforestry practices outperform fertilizers in rural areas where road infrastructure is poor and transport costs for fertilizer are high (which is the case in much of the African continent). The benefit to cost ratio for agroforestry practices ranges between 2.77 to 3.13 in contrast to 2.65 with subsidized fertilizer applications, 1.77 in fields with nonsubsidized fertilizer, and 2.01 in nonfertilized fields.[25] Dennis Garrity, the director of the World Agroforestry Centre in Nairobi, estimates that a global implementation of agroforestry methods could result in 50 billion tons of carbon dioxide being removed from the atmosphere about a third of the world s total carbon reduction target.[26] Such agricultural developments are examples of what many experts and scientists are calling the evergreen revolution. Among them is M.S. Swaminathan, the architect of the first Green Revolution in India, who now advocates organic farming.

In West Africa, stone barriers built alongside fields help retain water during the rainy season, improving soil moisture, replenishing water tables, and reducing soil erosion. Significant gains result: the water retention capacity of the soil is increased five to ten-fold, the biomass production ten to twenty-fold, and livestock can feed on the grass that grows along the stone barriers after the rains. Such water harvesting techniques are highly efficient in fighting desertification. They match the efficiency of mechanized irrigation, and are vital for food-insecure communities who live in dry environments. Indeed, it is impossible to build a truly *Green* Revolution without what Alan Savory calls a *Brown* Revolution: one that enhances soil organic matter, leading to sustainable productivity gains.[27]

In Kenya, researchers and farmers developed the push-pull strategy to control parasitic weeds and insects that damage crops. The strategy consists of pushing away pests from corn by interplanting corn crops with insect-repellent crops like Desmodium, while pulling them toward small plots of Napier grass, a plant that excretes a sticky gum that attracts the pest and traps it. The system controls pests without using costly and harmful insecticides. It also has other benefits, as Desmodium can be used as fodder for livestock. The push-pull strategy doubles maize yields and milk production while improving soils. The system has already spread to more than 10,000 households in East Africa through town meetings, national radio broadcasts, and farmer field schools.

Agroecological practices enhance on-farm fertility production. Malawian farmers call it a fertilizer factory in the fields. These practices reduce farmers reliance on external inputs and state subsidies. This, in turn, makes vulnerable smallholders less dependent on local retailers and moneylenders.

Similar examples exist around the world. In Japan, farmers found that ducks and fish were as effective as pesticide for controlling insects in rice paddies, while providing additional protein for their families. The ducks eat weeds and insects, thus reducing the need for labor-intensive weeding, otherwise done by hand by women, and duck droppings provide plant nutrients. The system has been adopted in China, India, and the Philippines. In Bangladesh, the International Rice Research Institute reports 20 percent higher crop yields, with net incomes increasing by 80 percent.[28] In 1998, after Hurricane Mitch, agroecological plots on sustainable farms from southern Nicaragua to eastern Guatemala had on average 40 percent more topsoil, 69 percent less gully erosion, higher field moisture, and fewer economic losses than control plots on conventional farms.[29] This greater resistance to climatic disruptions will be vital in the coming decades.

This is only the tip of the iceberg. Cutting edge innovation in agroecology is taking place in research centers in Santa Cruz, Nairobi, and Beijing. Scientists are discovering Iroko trees that build a carbonate-layer in the soil from CO_2 captured in the atmosphere, offering new opportunities for long-term carbon sinks.[30] They are designing future perennial cereal systems for sustainable grain production.[31] And they are developing mycorrhizal products that could be applied in small doses to mimic in modern farming the mycorrhizal systems that exist between fungus and trees, a source of extraordinary productivity.[32]

It would be unwise, however, to wait for a silver-bullet solution to emerge from years of research and development. The most urgently needed effort for increasing food security is the scaling up of existing systems. Understanding what keeps agroecology

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Women work on a small farm in Orissa, India

underdeveloped is a necessary first step.

The Obstacles to the Necessary Change

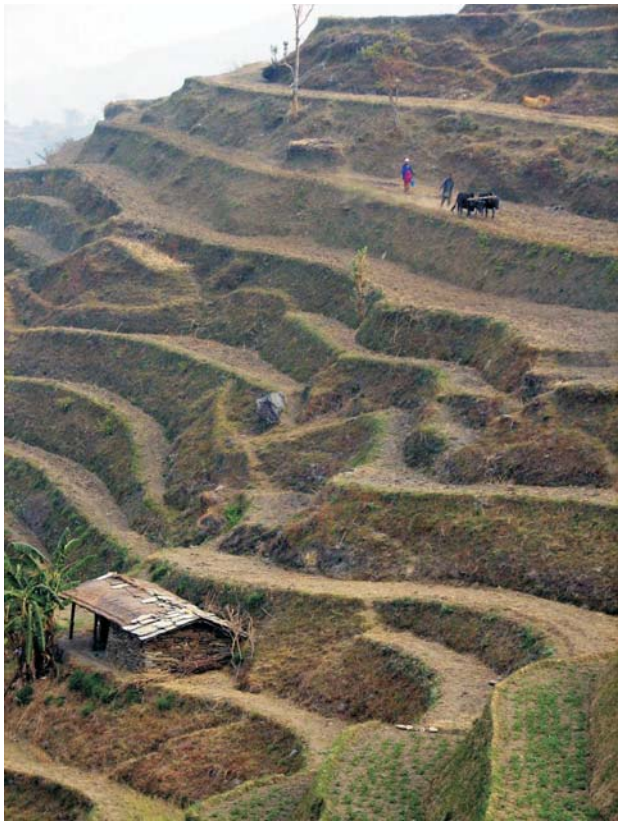
We identify at least seven, largely self-reinforcing obstacles to the expansion of agroecological practices.

First, small-scale farmers, the primary practitioners of agroecology and the main beneficiaries of its expanded use, are marginalized in policy decisions. Small-scale farms use land and water more efficiently, and economists have long demonstrated the inverse relation between farm size and land productivity.[33-40]

However, a number of factors in the real world favor large farms: Large-scale operations are more competitive in the agribusiness sector because of facilitated access to credit (including from state-owned development banks). Large farms have a greater ability to integrate globalized food chains and to comply with the standards of the retail industry, including quality and sanitary standards but also social and environmental certification schemes. They also benefit from recent technological innovations that are designed to meet their needs, such as genetically modified crops, information technology, and zero-tillage machinery.[40,41] In addition, decentralized small farmers experience agency problems and transaction costs that cannot be underestimated.[35]

At the same time, the belief that larger farms are more productive continues to be disseminated by influential authors.[42] This is a mistake. Large, mechanized, monocropping operations are more competitive than small farms for the reasons explained above, but competitiveness and productivity are different things. Big farms outperform small farms according to only one measure of economic efficiency: productivity per unit of labor. Indeed, one agricultural worker on a modern, mechanized farm in the most fertile regions of the world can manage as much as 100 hectares of land, with a total output of 1,000 tons of cereal a year. A small-scale farmer with only a hoe can manage just one hectare, with a productivity per hectare as low as one ton a year in many African regions.[43,44] But the global expansion of highly mechanized farming is something the planet simply cannot afford. The agroecological approaches highlighted above not only are more resource efficient that is, they produce more from less they also, with appropriate kinds of support, have a higher productivity per hectare, a different measure of productivity. The fact that some agroecological approaches require more labor can actually be positive, if the harvest provides sufficient incomes, since it can slow rural flight to cities and encourage rural development by attracting off-farm labor in rural areas. This is not a minor advantage as many countries face double-digit rates in urban unemployment.

Second, agroecology has rarely been supported by mainstream trade and agricultural policies. While agroecology supports diversified production systems, short food chains, and a balance of power among all actors, the structural adjustment programs of the 1980s and 1990s and the schedules of commitments under the Agreement on Agriculture of the World Trade Organization (WTO) led to a rapid (albeit still partial) liberalization of agricultural trade. This liberalization, in turn, encouraged the building of an export-led sector based on monocultures and the globalization of food chains, making transnational agribusiness companies



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Villagers sow crops like wheat, barley, and mustard on the mountain slopes of the Himalayas in Nepal using traditional farming techniques, such as terracing and labor intensive agriculture

increasingly influential.[45] Similarly, while the development of agroecology would have required a strong state to empower small-scale farmers, disseminate best practices, and invest in agriculture, the Washington consensus was imposed on most developing countries through the International Monetary Fund (IMF) and the World Bank. This orientation toward economic deregulation and privatization resulted in a 25-year downsizing of public services and disinvestment in agricultural systems.[46-50]

The dominance of neoliberal thinking during the last three decades has had lasting impacts on agricultural policies. Although some questioned this dominant model after the 2007 2008 food price crisis, it continues to influence current debates and many elites in developing countries continue to believe that they must mimic the modernization-liberalization path pursued by developed countries.

The combination of the first two obstacles explains why small farmers are unable to compete with large-scale enterprises. Although the World Bank has put more emphasis on their importance in its 2008 World Development Report,[51] small-scale agriculture is still seen as nonviable in many mainstream policy discourses.

Third, the development of agroecology is impeded by the absence of security of land tenure for a large fraction of small-scale farmers. Improved security of tenure plays a vital role in agroecology: it encourages the planting of trees, the more responsible use of soils, and other practices with long-term payoffs (planting fruit trees, for example, also contributes to improved nutrition and health). However, some recent developments are increasing the threats to security of tenure: large-scale land acquisitions and leases (widely known as land grabs) are putting an enormous pressure on land access for vulnerable land users. Yet the policy debate on their regulation continues to be largely influenced by the belief that any private investment, whatever form it takes, will contribute to food security.[52]

Fourth, the common belief that a Green Revolution complemented by a gene revolution could solve global hunger puts scientific and technological progress at the core of efforts to alleviate hunger, diverting attention from a broader exploration of agricultural development. Agroecological research struggles with inconsistent research investments as well as a lock-in situation (an accumulation of obstacles) in agricultural research systems, which both hinder its development.[53]

Fifth, agroecology has been mischaracterized as a return to the past and as incompatible with the mechanization of agriculture. Agroecology is not about a return to a model of agriculture that relies solely on human power for tilling and harvesting. Agroecological approaches are perfectly compatible with a gradual

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An agroforestry system in Morocco that combines a staple food crop (cereals) with a cash crop (the oil from argan trees is used in expensive cosmetics). The argan trees provide an extra source of income, especially for women, who have established cooperatives in Morocco to process and sell the oil

and adequate mechanization of farming. However, for the farmers who have only hoes for tools and who live in areas where oil is scarce, the first step toward development may well be use of animal traction rather than tractors. A forced path toward mechanization one that focuses on rapid mechanization of farming or use of technology that is not affordable for small-scale farmers could aggravate rural depopulation. One tractor replacing the daily work of twenty landless laborers is only progress if nineteen jobs are created in the secondary and tertiary sectors.[43]Yet most developing countries currently cannot offer urban job opportunities to those who leave the farming sector. Instead, the production of simple mechanical equipment adapted to smallholders and fit for agricultural techniques that conserve soil and water will actually result in more jobs in the manufacturing sector in developing countries.[54]

Sixth, the absence of full inclusion of externalities in agrifood price systems has enabled the development of industrial farming despite important social and environmental costs, and has hindered a comprehensive valuation of the benefits of agroecology.[55] The success of large plantations is, in part, attributable to the fact that the price of food does not reflect the real costs to society resulting from their operations, particularly from the impacts of their modes of production on the soil and climate and on public health.[56]

And, finally, organizations with vested interests in the status quo have ignored or resisted the benefits of agroecology.

Scaling Up Sustainable Agriculture: Policies for Change

Despite these obstacles, the scaling up of existing agroecological practices is achievable if we can develop a policy framework to move from successful pilot projects to nationwide policies.[57] Six key principles could help us do this.

First, we need better targeting. Focusing our efforts on the needs of smallholders may seem obvious, yet only a few existing programs effectively target this group. Today, 50 percent of the hungry live in small-scale farming households, living off less than two hectares of land, and 20 percent are landless.[58] This is unacceptable. Nor is it adequate to fixate on productivity improvements in breadbasket regions while ignoring the people who live in more inhospitable environments such as semiarid lands or hills. Trickle-down economics failed the test in Africa and South Asia the two regions with the highest incidence of hunger. In the 1960s, investing in the Punjab (as the Green Revolution did) did little to improve the situation of farmers in the eroded hills of Karnataka.

Second, the redistribution of public goods must be prioritized in food security policies. Agroecological practices require public goods such as extension services; storage facilities; rural infrastructure (roads, electricity, and information and communication technologies) for access to regional and local markets; credit and insurance against weather-related risks; agricultural research and development; education; and support to farmers organizations and cooperatives. The investment can be significantly more sustainable than the provision of private goods, such as fertilizers or pesticides that farmers can only afford so long as they are subsidized. World Bank economists have rightly noted that underinvestment in agriculture is [ ] compounded by extensive misinvestment [59] with a bias toward the provision of private goods, sometimes motivated by political considerations.[60] A 1985 2001 study of 15 Latin American countries in which government subsidies for private goods were distinguished from expenditures on public goods indicated that, within a fixed national agriculture budget, a reallocation of 10 percent of spending to supplying public goods increases agricultural per capita income by 5 percent, while a 10 percent increase in public spending on agriculture, keeping the spending composition constant, increases per capita agricultural income by only 2 percent.[61] In other words, even without changing overall expenditures, governments can improve the economic performance of their agricultural sectors by devoting a greater share of those expenditures to social services and public goods instead of non-social subsidies. [62] Thus, while the provision or subsidization of private goods may be necessary to a point, the opportunity costs should be carefully considered. Extension services that can teach farmers often women about agroecological practices are particularly vital. In today s knowledge-based economies, increasing skills and disseminating information are as important as building roads or distributing improved seeds. Agroecological practices are knowledge-intensive and require the development of both ecological literacy and decision-making skills in farm communities.

Market failures affect the provision of these services. There is just too little incentive for the private sector to invest in these domains, and transaction costs are too high for local communities to create these goods

themselves. States must step in. Seeds and fertilizers at subsidized prices are not a substitute for these public goods, although they may be competing for the provision of private assets in public budgets. Increasing the share of public goods in the government s budget would have a significant positive impact on rural per capita income.

Third, if we want the best food security policies, we need a richer understanding of innovation that includes indigenous, local, and traditional knowledge. Simply put, not all innovations come from experts in white coats in laboratories. In large areas of Asia, farmers now join farmer field schools, a group-based learning process that enables farmer-to-farmer instruction. In India, farmers pool their seeds in community seed banks, which are administered through institutional arrangements to ensure the availability of planting material and the preservation and improvement of agrobiodiversity. And in Ghana, scientists launched radio broadcasts in local languages to popularize the best techniques to grow rice without additional inputs, rather than breeding new rice varieties. These techniques were identified through consultations with peasant groups, and they resulted in an average yield increase of 56 percent.[63]

Farmer field schools and community seed banks are not new technologies: they are social or institutional innovations. Such innovations are important to future food security because they can channel farmers experiences into knowledge-sharing processes with a considerable multiplier effect and at minimal cost.

Fourth, programs and policies must involve meaningful participation of smallholders. While some of the largest efforts to reinvest in agriculture shy away from a genuine engagement with representative farmer organizations, participation, if done properly, has several advantages for food security. First, it enables us to benefit from the experience and insights of the farmers. Second, participation can ensure that policies and programs are truly responsive to the needs of vulnerable groups. Third, participation empowers the poor, a vital step toward poverty alleviation because the lack of power exacerbates poverty: marginal communities often receive less support and are less able to advocate for their rights than the groups that are better connected to government. And finally, collaborations between farmers, scientists, and other stakeholders will facilitate innovation and create new knowledge.[64]

Existing projects demonstrate that participation works. Farmer field schools have been shown to significantly reduce pesticide use: large-scale studies from Indonesia, Vietnam, and Bangladesh recorded 35 to 92 percent reduction in insecticide use for rice.[65] At the same time, the schools have contributed to a 4 to 14 percent improvement in cotton yields in China, India, and Pakistan.[65] In Syria, Nepal, Nicaragua, and many other countries, participatory plant breeding schemes have been introduced in which researchers work directly with farmers, often combining traditional seeds with modern varieties.[66] This practice empowers poor rural women who are key actors in seed management.[67] In Latin America, the Campesino a Campesino movement has demonstrated that, when given the chance to generate and share agroecological knowledge among themselves, smallholders are very capable of improving their methods.[68] In Cuba, a country that met its own peak oil when cheap oil imports from the USSR stopped, the adoption of agroecological practices was supported by the National Association of Small Farmers: between 2001 and 2009, the number of promotores (technical advisers and coordinators) increased from 114 to 11,935 and a total of 121,000 workshops on agroecologicalpractices were organized.[69] Participation, a key principle in the activities of the grassroots organizations and NGOs that currently promote agroecology,[68,70] should be an element in all food security policies, from policy design to management of extension services. Experts, technical advisers, and farmers should be encouraged to collaborate in identifying innovative solutions.[71]

Fifth, states could use public procurement to speed a transition toward sustainable agriculture. In several European countries, schools have already started sourcing food from local producers with sustainability criteria. In June 2009 Brazil decided that 30 percent of the food served in its national school-feeding program should come from family farms.[72]

Sixth, performance criteria used to monitor agricultural projects must go beyond classical agronomical measures, such as yield, and economic measures, such as productivity per unit of labor. In a world of finite resources and in a time of widespread rural unemployment, productivity per unit of land or water is a vital indicator of success. Overall, measuring efficiency in the new agricultural paradigm of agroecology requires a comprehensive set of indicators that assesses the impacts of agricultural projects or new technologies on incomes, resource efficiency, hunger and malnutrition, empowerment of beneficiaries, ecosystem health, public health, and nutritional adequacy. The assessment of progress

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Women in Myanmar work in a rice field using organic farming methods

should be appropriately disaggregated by population, so that improvements in the status of vulnerable populations can be monitored.

Promoting agroecological approaches does not mean that breeding new plant varieties is unimportant. Indeed, it is vital. Already, new varieties with shorter growing cycles enable farmers to continue farming in regions where the crop season has already shrunk and where classical varieties did not have time to mature before the arrival of the dry season. Breeding can also improve the level of drought resistance in plant varieties, an asset for countries where lack of water is a limiting factor. Reinvesting in agricultural research must involve continued efforts in breeding, though caution is needed due to the drawbacks of current seed policies and of intellectual property regimes on seeds.[73] Just as breeding should not be discontinued, but rather done with the participation of the farmers most in need, fertilizers should not be forbidden. Agroecology provides the larger framework for their use, and it emphasizes that fertilization can be pursued through natural means, such as nitrogen-fixing trees.

Linking Sustainable Farming to Markets: The Political Economy of Food Chains

The above principles are not sufficient in themselves. Efforts by agronomists will be pointless if the right institutions, macroeconomic regulations, and accountability mechanisms are not established and implemented. In other words, farmers need enabling economic and institutional environments, allowing the 500 million households that depend on small-scale farming today not only to put food on the table, but also to market their surpluses. Public action is needed, not in order to feed the world, as stated in the food security policies of the past century, but rather in order to help the world feed itself.

Many, including respected food security pundits, think smallholder farmers are incapable of producing sufficient food for rapidly growing urban markets. This is simply false. The reality is that small food producers face a number of obstacles when trying to market their surpluses. We met with smallholders in Benin who insisted that improving market conditions is a greater priority than and a condition for improving crop productivity.[74] An enabling market environment does not mean greater trade liberalization and a favorable environment for investment, as proponents of the new conventional wisdom, a slightly adapted version of the Washington consensus, contend.[75] Rather, it means supporting the diversification of trade and distribution channels in order to create the conditions for genuine choice by small farmers between rural and urban markets and, in some cases, the high-value markets of industrialized countries.[76] It also means preventing gains from being wrested from smallholders by better-resourced farmers.
Today, the limited number of buyers, the paucity of

information on prices, and the absence of storage facilities all contrive to deprive farmers of any choice but to sell during the harvest period, when prices are at their lowest. A rapid and significant expansion of storage facilities capable of preventing postharvest losses in rural areas is needed. Mechanisms such as warehouse receipt systems are spreading across Asia and Africa. Such systems enable farmers to sell crops to warehouses at harvest time, but obtain the additional revenue generated when the food is sold at higher prices during the dry season.[77]

States should also aim to improve equity in the food system, especially in global supply chains where inequity is most pronounced. In too many cases, global food chains primarily reward large producers who have access to inputs (land, water, and credit), technologies, and political influence, and who can meet the volume and standards required by global buyers and retailers. Where small food producers are willing to be integrated into global food chains, states should actively support them through technical assistance and cheap credit, if needed. The promotion of modern farmer cooperatives is one way to improve the market position of producers, especially women. Ultimately, what matters, from a social point of view, is that the incomes of the poorest increase, whether they choose to serve local, regional, or global markets. As Nobel laureate AmartyaSen has remarked, hunger is not necessarily a problem of food availability; it is primarily a problem of people lacking the purchasing power to procure the food they need.[78]

Because the power relationships that exist in food chains are so central to global hunger over two-thirds of those who are hungry today produce food centralized control over key agricultural functions must be dismantled.[79] In the Brazilian soybean market, 200,000 farmers attempt to sell to five main commodity traders. Three large transnational commodity buyers ADM, Cargill, and Barry Callebaut dominate the Ivorian cocoa industry. Four firms carry out 45 percent of all coffee roasting, and four international coffee traders control 40 percent of an industry on which 25 million producers depend. The result of this power distribution is that a significant portion of the reinvestment in agriculture will be captured by global players, instead of vulnerable food producers.

Stopping the Damage: The Role of Land

Farmers around the world face increasing pressures from large-scale development projects (including dams), extractive industries, logging, land conversion to agrofuels, and the creation of special economic zones. The result is that the poorest farmers are priced out of land markets and that evictions are rising everywhere, cutting farmers off from their livelihoods.[80-82]

States should strengthen customary land tenure systems, while at the same time weeding out their discriminatory components against women, and should reinforce tenancy laws in order to significantly improve the protection of land users. There is also ample empirical evidence of the positive impacts of land redistribution on the livelihoods of smallholders as well as on broader rural development.[37] Agrarian reform with a strong redistributive component has been an important element in economic growth in South Korea and China. The belief that land redistribution is communism has led many to reject it out of hand. But, if it is part of comprehensive rural development policies that support the beneficiaries of land redistribution, complemented by an implementation of the six principles we put forward in this paper, it can contribute to increased food security and nutrition, prevent environmental losses, and put people to work in rural areas, thus reducing the effects of ecological, financial, and economic crises. The current wave of large-scale land acquisitions and leases unfortunately moves us in the opposite direction: in many cases it amounts to nothing less than a counter-agrarian reform that poses threats to food security.[52]

Farmers-in-Chief

Our farmers-in-chief heads of states can make the new paradigm on agriculture, food, and hunger a reality.[83] The strategies highlighted in this essay can shape productive, sustainable, healthy food systems for the twenty-first century. Concrete recommendations to states and donors have been identified to scale up these promising agroecological farming systems and to shape an economic and institutional environment that will allow them to thrive. If significant progress is not achieved in the next three years, huge opportunities will be missed for feeding the world s poorest people, mitigating climate change, and avoiding worsening water scarcity. In that case, coming generations will judge us harshly.

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