ECOLOGY

Agriculture at a Crossroads

The present path of agricultural development will not achieve development goals according to a recent assessment, but a solid foundation for improvements exists.

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Recent scientific assessments (*1–4*) have alerted the world to the increasing size of agriculture's footprint, including its contribution to climate change and degradation of natural resources (*5*). By some analyses, agriculture is the single largest threat to biodiversity (*6*). Agriculture requires more land, water, and human labor than any other industry (*7*). An estimated 75% of the world's poor and hungry live in rural areas and depend directly or indirectly on agriculture for their livelihoods (*8*). As grain commodity prices rise and per capita grain production stagnates (*9*), policy-makers are torn between allocating land to food or fuel needs. The governance of agriculture requires new thinking if it is to meet the needs of humanity now and in the future. The International Assessment of Agricultural Science and Technology for Development (IAASTD) brought together governments, international organizations, and private sector and civil society organizations to address these challenges (*10*). The task was to assess the current state and future potential of formal and informal knowledge, as well as science and technology (S&T), (i) to reduce hunger and poverty, (ii) to improve rural livelihoods, and (iii) to facilitate equitable, sustainable development.

The IAASTD recently released its assessment (*11*). The assessment acknowledges the enormous historical contributions of S&T to increased yields, nutrition, and aggregate wealth but also recognizes that gains have been uneven and that successes have been accompanied by environmental and social consequences. Production increases have not consistently improved food access for the world's poor. Where production has been intensified, it has generally been accompanied by costs such as extensive eutrophication from fertilizer runoff, pesticide contamination, and loss of local crop landraces (*12*). The assessment found that structural changes in governance, development, and delivery of S&T are required so that benefits are shared more equitably and environmental impacts are lessened.

Controversy arising from the assessment's findings (*13–15*) has focused on a single element of the study, namely, the role of transgenics, particularly genetically modified (GM) crops. The assessment, however, was tasked with appraising the contribution of a diversity of S&T approaches to the combined social, environmental, and production goals. GM technology was not rejected in principle; the assessment found GM crops appropriate in some contexts, unpromising in others, and unproven in many more. The potential of GM crops to serve the needs of the subsistence farmer is recognized, but this potential remains unfulfilled. No conclusive evidence was found that GM crops have so far offered solutions to the broader socioeconomic dilemmas faced by developing countries. Here, we, as IAASTD authors, summarize the wider key actions identified in the assessment and the solutions they offer.

Redirection of agricultural S&T. Inadequate attention has been devoted to the generation, dissemination, and uptake of S&T that addresses the needs of the rural poor and to developing technologies that lessen the environmental impacts of agriculture. A meager one-third (about U.S. $10 billion) of all global research expenditure on agriculture is spent on solving the problems of agriculture in developing countries (*16*), home to ~80% of the global population. This amount is less than 3% of the total value of agricultural subsidies that countries of the Organization for Economic Cooperation and Development (OECD) pay to maintain their agricultural output (*16*). Consequently, regions with severe biophysical constraints and marginalized communities have historically benefited least from S&T development (*17*).

In the next two decades, climate change is predicted to cause major crop losses in the world's poorest regions (*18*). The driest areas of the world are already home to more than 2 billion people. Agricultural S&T has yet to offer effective rural management options for crop and livestock systems appropriate for water-constrained dry lands and stress conditions. Except for the Consultative Group on International Agricultural Research (CGIAR) (*19*), few others have sought crop improvements in the small-grain cereals, tubers, and legumes cultivated by hundreds of millions of farmers.

Will private sector companies lead this redirection? There is plenty of scope for them to play a vital role, as they already dominate the research landscape. Private sector investments in agricultural research and development (R&D) reached more than $12 billion in 2000, 30 times the budget of the entire CGIAR international agricultural research system (*20*). A redirection of S&T is needed to move away from processes that have profited primarily large-scale enterprises to processes that address the most basic needs of the world's 900 million small farmers. The availability and cost of good-quality seed, especially in sub-Saharan Africa, pose real constraints for poor farmers (*21*), as does severe soil degradation and post-harvest losses.

Approaches		Redirection		Arrangements, laws, regulations
Farmer participation Funding for affordable technology development	←	Generation of S&T	→	IPR to support farmer innovation
Governance to allow public deliberation of S&T	←	Policy and planning of S&T	→	Regional and international forums to drive S&T planning Governmental regulation of private sector
Access to trade and market analysis Funding for higher education	←	Access and exchange of S&T	→	New information and communication tools for rural communities
Access to natural resources Building local expertise	←	Capacity development	→	Decentralized R&D facilities Rural to urban supply chains Research networks

Translating redirection of agricultural S&T into concrete approaches, arrangements, laws, and regulations.

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All of these problems can be tackled with relatively simple technologies and investments. Evolving intellectual property rights (IPR) regimes to encourage farmers' entrepreneurship and initiatives to develop small seed companies can improve delivery of locally appropriate seeds to poor farmers, not currently offered by the few companies dominating the global seed market (*22*). Reversing soil infertility through use of locally available resources (e.g., nitrogen-fixing trees, indigenous rock phosphate) has increased food security for tens of thousands of African farmers (*23*). Recent research from the Food and Agriculture Organization of the United Nations (FAO) suggests that total milk spoilage, spillage, etc., in East Africa and the Near East costs small farmers $90 million/year. Dairy imports to the developing world, which increased 43% between 1998 and 2001, could have been significantly reduced with simple on-farm post-harvest technologies (*24*). Similar investments in affordable technologies (e.g., small metallic silos) could prevent rice post-harvest losses ranging between 8 and 26% in China (*25*).

There is a need to capitalize on human ingenuity, deployed for centuries to solve agricultural challenges. Scientists at the African Rice Center are adapting the use of golden weaver ants (a centuries-old technology developed by farmers in Asia) as a pest control method, so West African mango producers can access profitable European markets (*26*). In some cases, existing small-scale farming systems have high water-, nutrient-, and energy-use efficiencies and conserve resources and biodiversity without sacrificing yield. The extrapolation of these principles to larger-scale farming is another critical research direction (*2*).

Developing S&T to increase agricultural market access for rural communities is needed, including optimizing rural supply chains, increasing local addition of value, and simple, but effective, measures like enhancing market feeder roads. S&T has largely ignored using "wild" species as resource production systems, even though their positive impacts are clear (*27*). Such initiatives engage communities in decision-making processes while building production capacities.

Innovation. Initiatives in which local communities effectively set the agenda, alongside S&T developers, have emerged in the last decade. Farmers and formal plant breeders in West Africa are creating rice varieties that compete effectively with weeds to relieve labor shortages, alongside dual-purpose cowpea varieties with good yields followed by a green foliage harvest for livestock (*28*), and farmer-led seed multiplication strategies for stressful climate and economic conditions (*19*). Examples from fisheries, rural energy, and agro-processing all abound. It is not the technologies that are innovative here, but the pathway to their development, which involves continuous on-site cycles of learning and change (*27*).

The assessment's message is clear: Innovation is more than invention. Success is not based on technological performance in isolation, but rather how technology builds knowledge, networks, and capacity. Simply put, plant breeding and natural resource management practices are very "blunt tools for social change" (*29*); innovation demands sophisticated integration with local partners.

Investment. The growth rate for investments in agricultural R&D declined during the 1990s, particularly for publicly funded agricultural R&D (*30*), despite research showing that investments in agricultural R&D are one of the most successful ways to alleviate hunger and poverty (*31*). Developed countries spend, on average, $5.16 on S&T for every $100 of agricultural output, whereas developing countries invest only $0.57 (*20*).

Continued S&T advancements need to be accompanied by investments in rural infrastructure (physical, market, and finance) and local governance (see table on page 320). Countries lagging behind in these investments simply cannot compete in domestic or international markets. Investments that improve farmers' access to land and water resources are equally vital.

Basic education investments are needed as well. A study of farmers in developing countries showed that those who completed 4 years of elementary education had, on average, 8.7% higher productivity (*32*).

Agricultural S&T, in and of itself, cannot solve structural inequities and may worsen them by reinforcing existing advantage; nevertheless, S&T can help advance sustainability and development goals with policies and investments that support small-scale sectors. Small farmers in Zimbabwe grew over 90% of the commercial maize crop when markets and services were well organized (*33*), and Ghanaian cocoa farmers more than doubled their market sales in response to marketing reforms that left them a higher profit share (*34*). In contrast, an overreliance on free market forces has led to suboptimal investment patterns. For instance, trade arrangements that open national agricultural markets to international competition before basic national institutions and infrastructure are in place can undermine local agricultural sectors (*35*). The most successful investments will increase the resilience of local and global food systems to environmental and economic shocks.

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