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FOOD SECURITY IN A WORLD OF GROWING NATURAL RESOURCE SCARCITY

The Role of Agricultural Technologies

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The world's population reached 7 billion in 2011 and is expected to reach 9 billion by 2050. Much of this growth will be concentrated in low-income countries, which already face serious challenges in satisfying basic needs, including food, water, and energy. Population and income growth will drive food demand in the coming decades; nearly 80 percent more meat, 52 percent more cereals, and 40 percent more roots and tubers will need to be produced between 2005 and 2050 (based on the MIROC A1B climate change scenario), at likely higher food prices and with adverse consequences for the world's poor and vulnerable populations. Under the same baseline scenario, food prices for maize, rice, and wheat would increase by 104 percent, 79 percent, and 88 percent, respectively, between 2005 and 2050, and the number of people at risk of hunger in the developing world would grow from 881 million in 2005 to 1,031 million people by 2050 (see "Methodology," below, for a description of the modeling used in this analysis).

Climate change is a significant contributor to the projected higher prices. Climate change could decrease maize yields by 9 to 18 percent by 2050 compared with a no-climate-change scenario, depending on the climate change scenario used, the cropping system (rainfed or irrigated), and whether the carbon fertilization effect is included; rice yields could drop by 7 to 27 percent; and wheat yields could decline by 18 to 36 percent by 2050, compared with a no-climate-change scenario (Nelson et al. 2009).

Addressing the challenges of climate change, rising long-term food prices, and poor progress in improving food security will require increased food production without further damage to the environment. Accelerated investments in agricultural research and development will be crucial to supporting food production growth. The specific set of agricultural technologies that should be brought to bear remains unknown, however. At the same time, the future technology mix will have major impacts on agricultural production, food consumption, food security, trade, and environmental quality in developing countries. The type and effectiveness of agricultural technologies is highly debated, and the debate is often polarized. Advocates of intensive agriculture believe that investments in upstream agricultural science, including biotechnology and genetic modification, are needed for rapid agricultural growth, together with high levels of inputs such as fertilizer, pesticides, and water. At the other end of the spectrum, advocates of low-input agriculture emphasize the role of reduced inputs and crop management improvement through water harvesting, no-till, and soil fertility management in boosting future yield growth.

Technology options are many, but transparent evidence-based information to support decisions on the potential of alternative technologies is relatively scarce. This is no longer a question of low- versus high-income countries but one of the planet: how do we achieve food security in a world of growing scarcity? Thus, a key challenge for our common future will be how we can grow food sustainably—meeting the demands of a growing population without degrading our natural resource base. This is the question that this study sets out to address.

This study compares the effects that different technologies have on crop yields and resource use, particularly arable area, water, and nutrients. By modeling technology-induced changes in crop yields, the analysis also helps to explain how the mix of technology may influence the global food market in terms of changes in food prices and trade flows, as well as calorie availability, in particular for developing countries.

METHODOLOGY

The study used a combination of spatially disaggregated crop models linked to economic models to explore the impacts on agricultural productivity and global food markets of 11 alternative agricultural technologies as well as selected technology combinations for maize, rice, and wheat, the world's key staple crops. The technologies cover a broad range of traditional, conventional, and advanced practices with some proven potential for yield improvement as well as the potential for wide geographic application. The chosen technologies are the following:

1. No-till (minimum or no soil disturbance, often in combination with retention of residues, crop rotation, and use of cover crops)
2. Integrated soil fertility management, or ISFM (combination of chemical fertilizers, crop residues, and manure/compost)
3. Precision agriculture (GPS-assisted delivery of agricultural inputs, as well as low-tech management practices that aim to control all field parameters, from input delivery to plant spacing to water level)
4. Organic agriculture (cultivation with exclusion of or strict limits on the use of manufactured fertilizers, pesticides, growth regulators, and genetically modified organisms)
5. Water harvesting (water channeled toward crop fields from macro- or microcatchment systems, or through the use of earth dams, ridges, or graded contours)
6. Drip irrigation (water applied as a small discharge directly around each plant or to the root zone, often using microtubing)
7. Sprinkler irrigation (water distributed under pressure through a pipe network and delivered to the crop via overhead sprinkler nozzles)
8. Heat tolerance (improved varieties showing characteristics that allow the plant to maintain yields at higher temperatures)
9. Drought tolerance (improved varieties showing characteristics that allow the plant to have better yields compared with regular varieties due to enhanced soil moisture uptake capabilities and reduced vulnerability to water deficiency)
10. Nitrogen-use efficiency (plants that respond better to fertilizers)
11. Crop protection (the practice of managing pests, plant diseases, weeds, and other pest organisms that damage agricultural crops)

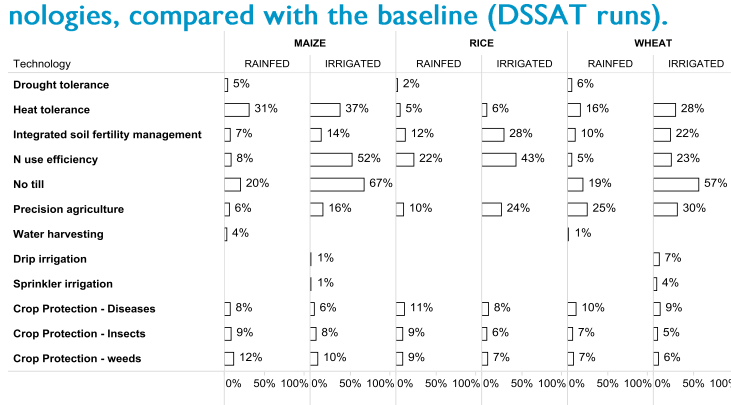
The study utilizes a groundbreaking modeling approach that combines comprehensive process-based modeling of agricultural technologies globally across a 60 kilometer by 60 kilometer grid of global arable land with sophisticated global food demand, supply and trade modeling. Specifically, the biophysical, process-based crop model (Decision Support System for Agrotechnology Transfer, or DSSAT) is used to assess the impact of a single technology or technology mix on productivity (yields) and use of resources (such as water and nitrogen). The IMPACT model (International Model for Policy Analysis of Agricultural Commodities and Trade) is a global partial equilibrium agricultural-sector model developed by the International Food Policy Research Institute (IFPRI) and simulates changes in productivity due to technology adoption that affect food production, consumption, and trade; international food prices; calorie availability; and food security.

Site-specific yields are simulated on one-half-degree (or about 60 km) grids for irrigated and rainfed maize, rice, and wheat, with and without access to the potential technologies, under current and future (2050s) climate conditions predicted by the MIROC (Model for Interdisciplinary Research on Climate) A1B and CSIRO (Commonwealth Scientific and Industrial Research Organisation) A1B climate scenarios. DSSAT-simulated yields for conventional farming practices, which constitute the baseline, reflect the current best understanding of farmers' management practices, based on a compilation of global datasets, literature, and IFPRI's synthesis of crop model input parameters. Agricultural technologies are implemented in the crop models by adjusting model input parameters and coding the management practice in detail to reflect how farmers would implement the technology in the field. The DSSAT results are then input into IFPRI's IMPACT model, using synthesized adoption pathways that consider profitability, initial costs and capital, risk reduction, and the complexity of the technology, to simulate global food supply and demand, food trade, and international food prices for these three crops, as well as the resulting population at risk of food insecurity.

RESULTS

Based on the biophysical (DSSAT) model results, under the hotter, wetter MIROC A1B climate scenario, the largest ex ante yield impacts are achieved with heat tolerance for maize, followed by no-till. Nitrogen-use efficiency has the highest yield impact for rice, followed by ISFM. For wheat, no-till has the highest yield impact, followed by precision agriculture (Figure 1). Under the drier, cooler CSIRO A1B climate scenario (not shown here), on the other hand, the benefits of heat tolerance are lower, moving this technology globally into third place for maize. The combined impact across three types of crop protection (from insects, pests, and weeds) ranks second or third, depending on the crop.

Figure 1. Global yield changes in 2050, alternative technologies, compared with the baseline (DSSAT runs).



Source: Biophysical model runs, MIROC A1B climate change scenario.

When adoption profiles, trade in agricultural commodities, and international food prices are taken into account, the realized global yield impacts in 2050 for maize are about 16 percent for heat tolerant varieties and no-till; for rice, 20 percent for nitrogen-use efficiency and 9 percent for precision agriculture; and for wheat, 13 percent for no-till and 8 percent for heat tolerant varieties (Table 1). Combining the three types of crop protection provides a yield impact of 7 percent for maize and rice and 8 percent for wheat.

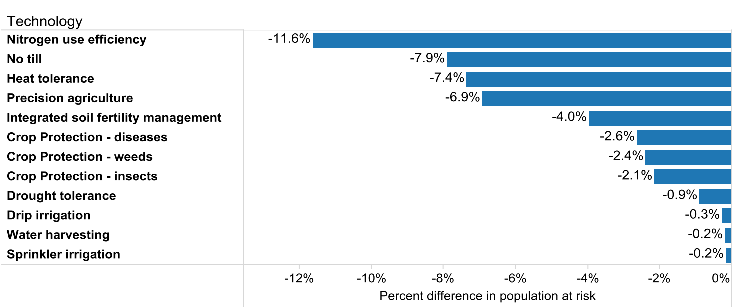
Table 1. Global yield changes in 2050, alternative technologies, compared with the baseline (IMPACT runs).

Technology	Maize	Rice	Wheat
Nitrogen-use efficiency	11.34	20.20	4.97
No-till	15.82		13.42
Heat tolerance	16.16	3.05	7.84
Precision agriculture	3.73	8.56	7.86
Integrated soil fertility management	1.77	6.69	2.63
Crop protection - diseases	1.77	2.53	3.44
Crop protection - weeds	2.67	2.23	2.51
Crop protection - insects	2.12	2.14	2.29
Drought tolerance	1.07	0.15	1.54
Drip irrigation	0.10		0.63
Water harvesting	0.48		0.20
Sprinkler irrigation	0.11		0.38

Source: IMPACT simulations with adoption profiles, MIROC A1B climate scenario.
Note: Empty fields indicate that the technology is not applicable.

Impacts on food security (again using the MIROC A1B scenario) could be substantial. The number of food-insecure people in developing countries in 2050 could be reduced by 12 percent if nitrogen use–efficiency technologies were rolled out, by 8 percent if no-till is adopted more widely, by 7 percent if heat tolerant varieties, precision agriculture, and the combined crop protection technologies are adopted, and by 4 percent for ISFM (Figure 2).

Figure 2. Change in the number of people at risk of hunger in 2050, alternative technologies, compared with the baseline.



Sources: IMPACT simulations, MIROC A1B climate scenario.
Note: ISFM = integrated soil fertility management.

Worth noting are five additional key results based on the biophysical and economic modeling. First, agricultural technology impacts differ substantially by region and within regions, by country. Across the three crops, the largest yield gains, in percentage terms, are in in Africa, South Asia, and parts of Latin America and the Caribbean. Given the heterogeneity in yield response, it is important to target specific technologies to specific regions and countries. This includes targeting heat tolerant varieties to North America and South Asia; drought tolerance to Latin America and the Caribbean, the Middle East and North Africa, and Africa south of the Sahara; and crop protection to Africa south of the Sahara, South Asia, and eastern Europe. Precision agriculture shows the highest total gains in major production areas in South Asia, the Middle East and North Africa, and parts of Western Europe. Nitrogen-efficient varieties are also critical to reducing resource use and moving toward sustainable development, and these show gains in most developing regions, particularly in Africa south of the Sahara and Latin America and the Caribbean. The largest potential for ISFM is in low-input regions within Africa and also in parts of East Asia and the Pacific region.

Second, agricultural technology impacts are amplified with irrigation (Figure 1). While direct yield impacts from substituting furrow irrigation with drip and sprinkler irrigation are small for maize and wheat, water savings are substantial. Moreover, because the yield impacts of other technologies tend to be larger with irrigation, continued investment in advanced irrigation should go hand in hand with technology rollout.

Third, technologies are important to addressing abiotic stresses that are expected to increase as a result of climate change. Drought-tolerant varieties perform as well as susceptible varieties under no drought stress and have significant yield benefits under drought conditions. Heat-tolerant varieties can help reduce the projected negative impacts of climate change. In addition to biotic stresses, further rollout and continued development of crop protection for weeds, insects, and diseases achieves large benefits in developing countries.

Fourth, improved land management has large yield impacts in many regions. Key land management practices with high impacts include no-till (particularly for maize), precision agriculture, and ISFM. On the other hand, organic agriculture is not a preferred strategy for maize, wheat, or rice, although it might have a role in niche high-value markets.

Fifth, given growing natural resource scarcity, technologies that reduce environmental impacts (such as water use and nitrogen runoff emissions) are particularly important. These include advanced irrigation, such as drip and sprinkler as compared with furrow irrigation, particularly if renewable energy sources are used for its application. Other important technologies that address growing resource scarcity include no-till, which conserves soil moisture and reduces erosion; ISFM, which can provide important nutrients for farms in Africa south of the Sahara; and nitrogen-use efficiency in new varieties, which both has strong yield impacts and reduces negative environmental impacts from fertilization. A final technology that is gaining wider acceptance and furthers resource conservation is precision agriculture, for which the model finds particularly strong yield gains in wheat.

In addition to the individual technologies assessed, the study also evaluated a series of joint technology applications that combine elements from more traditional agriculture, such as no-till, with modern forms of plant breeding, for example, for heat or drought tolerance. Findings show that the combination of no-till with heat tolerance works particularly well for maize and no-till with precision agriculture achieves high yield boosts for wheat. Finally, stacked technologies (applications of components of all technologies) can successfully boost yields for all three crops.

THE WAY FORWARD

This analysis shows that adoption of the set of technologies examined here would substantially increase food production, reduce food prices, and improve food security under climate change. Implementing these technologies on the ground will require institutional, policy, and investment advances in many areas. There is currently a clear divide between technologies in use in developed versus developing countries, with key adoption challenges in developing countries in the areas of finance (particularly length of payback of the investment), relative profitability, and farm size. For example, ISFM and rainwater harvesting are key technologies widely discussed in parts of Africa south of the Sahara and parts of South Asia. They are considered to have a relatively low cost, but they require substantial labor and are independent of scale. On the other hand, precision agriculture and drip and sprinkler irrigation currently remain concentrated primarily in the developed countries. No-till is one of few technologies assessed here that can be and has been increasingly adopted in parts of the North and the South because it is independent of scale, relatively inexpensive, and relatively easy to implement for maize and wheat. However, importantly, all technologies examined here show clear potential for future broader adoption of all technologies in both developed and developing countries, and growing convergence across appropriate technologies.

The crop breeding–related advancements examined here are also mostly found in developed countries but could find relatively faster adoption in developing countries, if favorable regulatory frameworks, extension, and other supports are in place. Continued investment by the private sector will be essential to reaping the benefits of the drought- and heat-tolerant as well as the nitrogen use–efficient varieties described in this study.

The yield improvements of advanced irrigation technologies over furrow irrigation are limited. Given the cost of these advanced irrigation options, these technologies are generally adopted in cases of water scarcity or labor shortage. However, the present findings confirm that irrigation technologies substantially boost the yield impact of direct yield-advancing technologies, and given growing water and labor shortages in parts of the developing world, one would also expect more convergence on these technologies.

Given that many of the technologies are knowledge intensive, it will be crucial that extension systems increase knowledge capacity and that innovative forms of extension—through information and communication technologies, for example—be implemented. Moreover, several technologies will take many years to reap final benefits. This often hinders adoption in places where land tenure systems are weak or where farmers do not have access to cheap financing. Such technologies include minimum tillage, ISFM, and water harvesting. To support further adoption of these technologies, improved governance and legal systems will be important as well as investments by the finance sector.

The results show that sustainably meeting the challenge of climate change while substantially improving food security requires a three-pronged effort: increasing crop productivity through enhanced investment in agricultural research; development and use of resource-conserving management; and increased investment in irrigation. Crop (and animal) breeding should be targeted to abiotic stresses such as heat and drought, and biotic stresses such as pest and disease, as well as continuing to invest in broad-based yield improvement. Resource-conserving management and technology should be expanded, including no-till, integrated soil fertility management, improved crop protection, and precision agriculture. Increased investment in cost-effective irrigation will serve to increase the returns to other technologies, while advanced irrigation technologies such as drip and sprinkler can save water in specific locations while maintaining yield levels.

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