CHAPTER 4

Research for the Future
Investments for Efficiency, Sustainability, and Equity

GERT-JAN STADS, KEITH WIEBE, ALEJANDRO NIN-PRATT, TIMOTHY B. SULSER, RUI BENFICA, FASIL REDA, AND RAVI KHETARPAL

Gert-Jan Stads is a senior program manager, **Keith Wiebe** is a senior research fellow, **Alejandro Nin-Pratt** is a senior research fellow, **Timothy B. Sulser** is a senior scientist, and **Rui Benfica** is a senior research fellow, all in the Environment and Production Technology Division, International Food Policy Research Institute, Washington, DC. **Fasil Reda** is coordinator of the UNIDO Program for Country Partnerships, Ethiopia. **Ravi Khetarpal** is executive secretary of the Asia-Pacific Association of Agricultural Research Institutions (APAARI), Bangkok.

KEY MESSAGES

- Research and innovation are critical not only to increase agricultural productivity in the face of climate change, but also to transform global agrifood systems through improved efficiency and resilience in achieving social, economic, nutritional, and environmental goals.
- Investment in agricultural research and innovation by larger middle-income counties has expanded substantially in recent decades, but investments, especially in smaller low- and middle-income countries, are too small to address future impacts of climate change across food systems.

Steps can be taken to ensure that R&D contributes to greater productivity, sustainability, and equity:

- Increase research investments for food systems in the context of climate change, both on and beyond the farm in low- and middle-income countries. Sustained growth in public and private investment in food innovation will depend on large middle-income countries, such as China, Brazil, and India, and accelerated growth in other countries with large research systems.
- Build cooperation for sharing innovations. Greater integration of food research at the regional and global levels will allow countries with limited domestic research capacity to benefit from the gains achieved by countries with more developed systems.
- Promote both public and private sector investment. Governments should provide an enabling environment for private sector investment in agrifood innovations, but a clear and critical role also remains for increased public investment to achieve broad food system goals.

Food systems everywhere are facing major new challenges. Shocks caused by COVID-19 have currently seized our attention, but the pandemic has also accentuated persistent problems of poverty, hunger and malnutrition, population growth, and pressure on natural resources, notably land, water, and biodiversity. Adding to these challenges, climate change poses a serious threat to food security and livelihoods as greenhouse gas (GHG) emissions continue to rise. Changing temperatures, highly variable precipitation, shifting growing seasons, and extreme weather events are already making agricultural yields and prices more volatile, with rural areas across the world feeling the effects most profoundly. Yet, as the world's population moves toward 9 or 10 billion by 2050, unprecedented increases in global food production — of at least 60 percent over 2005–2007 levels — will be needed to meet growing demand.[1]

Innovation is essential to address these challenges and to ensure more inclusive access to food and decent livelihoods for future generations. Innovation will be needed in agricultural technologies to increase and diversify production in ways that make more efficient use of resources. It will also be needed in the infrastructure, institutions, and services that support food systems in order to make them more inclusive, resilient, and sustainable.[2] Some innovation will happen autonomously (for example, as producers, consumers, and other private sector actors respond to changing market conditions), but much more research and investment is needed if long-lasting, broad-based sustainability is to be achieved.

Investing in the agriculture sector — and particularly in agricultural research — can be a highly effective pathway for both reducing poverty and hunger and addressing climate change impacts on food systems.[3] A recent modeling exercise found that raising agricultural productivity enough to reduce global hunger to 5 percent would require additional investments of $52 billion annually until 2030 in agricultural research, resource management, and infrastructure.[4] Investment in agricultural research is particularly effective: past R&D investments by CGIAR and by national agricultural research systems in low- and middle-income countries (LMICs) have shown a 10 to 1 benefit-cost ratio.[5] This suggests that $1 invested in research today will yield, on average, a stream of benefits equivalent to $10 over future decades (in present value terms). Moreover, studies consistently show that spending on agricultural research has a greater impact on agricultural productivity than other types of public expenditures, regardless of the mode of investments, timeframe, and specific targets chosen. Agricultural research spending has also performed best or second-best in reducing poverty, whether the comparison is with other agriculture spending, such as irrigation, soil conservation, and farm subsidies, or with investments in other rural areas, such as health, education, and roads.[6]

Nevertheless, many LMICs consistently underinvest in agrifood systems research. This neglect can be attributed in part to long lags between investments and reaping benefits at the farm level,[7] widely diffused benefits, and the "abstract" nature of research and innovation compared with more tangible investments in physical infrastructure. Concerted action to increase LMIC investment will be crucial to accelerating innovation and addressing challenges that are beyond the ability of individuals (and even individual countries) to manage on their own. Moreover, addressing today's nexus of threats will require a holistic research agenda for food systems (beyond agricultural production) to better understand the biological, economic, social, environmental, and health aspects of interlinked areas — from crop and animal production and their inputs, yields, and emissions to storage, transport, food processing, packaging, and marketing, as well as food consumption and waste.

In this chapter, we review how patterns of research investment for food systems have evolved over the past half century and how research and innovation will need to evolve to address climate change and the host of challenges facing food systems in the decades ahead.

THE CHANGING AGRICULTURAL RESEARCH ENVIRONMENT

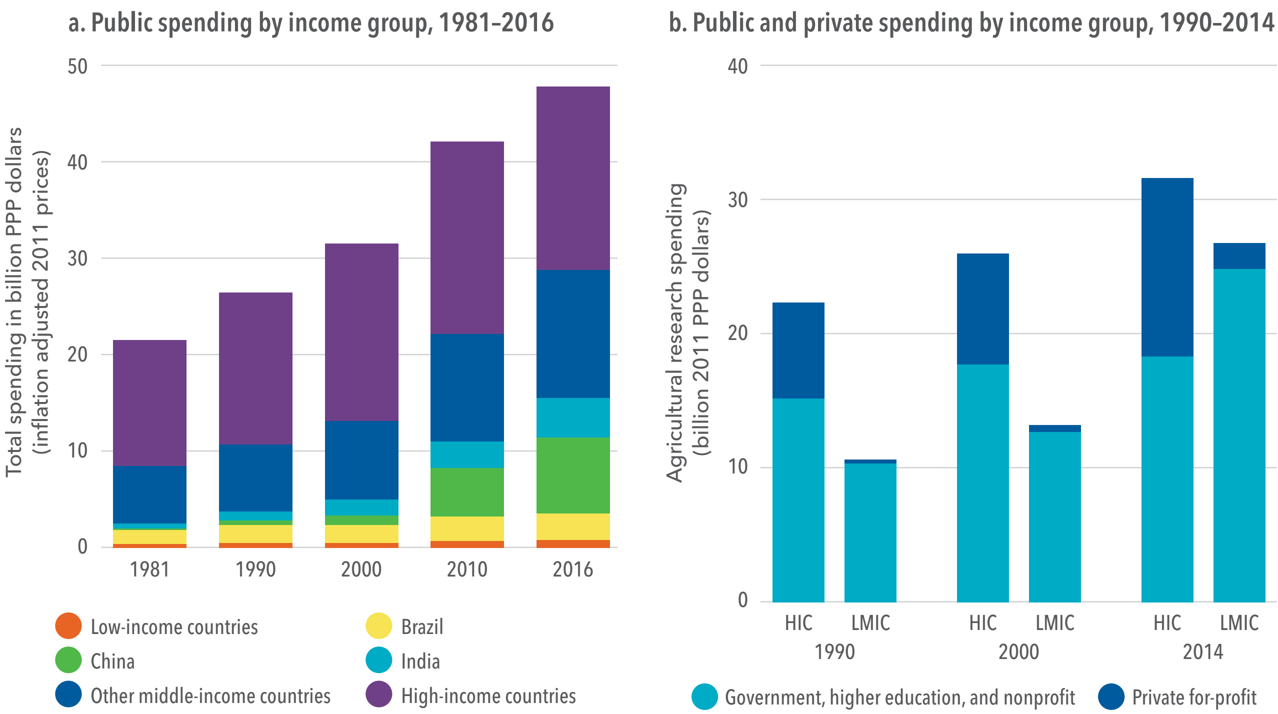
Over the past five decades, LMICs have benefited from considerable improvements in agricultural productivity, with positive impacts on poverty reduction and nutrition.[8] During the Green Revolution of the 1960s and 1970s, large public investments in crop genetic improvements and yield-enhancing inputs — built on scientific advances made in high-income countries and adaptation to LMIC conditions — prompted significant productivity increases, especially for rice, wheat, and maize.[9] Since then, global public agricultural research investment has continued to grow, doubling between 1981 and 2016 (Figure 1).

Just 20 years ago, high-income countries still accounted for the bulk of this research spending, but rapid increases in spending by large middle-income countries, coupled with stagnating spending growth in high-income countries, has shifted the global balance. By 2016, LMICs accounted for nearly 60 percent of global agricultural research spending. However, China, India, and Brazil alone accounted for more than half of LMIC spending, while sub-Saharan Africa's share in global public agricultural R&D spending has stagnated at about 5 percent. Private sector involvement in agricultural research also shifted the balance in investment. Private spending tripled from $5.1 billion to $15.6 billion globally between 1990 and 2014, outpacing growth in public spending. Though most private R&D expenditures originate in high-income countries, more than a quarter of these expenditures (including those by seed and fertilizer multinationals and tropical fruit companies) directly target commodities or research areas relevant to LMIC farmers.[10] However, overall, private research has focused on just a few commodities, notably cereals, soybeans, horticulture, meat, cotton, aquaculture, and oil and sugar crops,[11] and has neglected many commodities that are economically and nutritionally important in LMICs, including roots, tubers, legumes, and indigenous crops (such as teff in Ethiopia). Given that 800 million people around the world still faced hunger in 2020[12] and many more consume low-quality diets that cause micronutrient deficiencies and diet-related obesity and noncommunicable diseases[13] (see Chapter 8), a critical role for public agricultural research remains.

PRODUCTIVITY GROWTH REMAINS A PRIORITY

Agricultural productivity growth will remain a priority not only to meet food needs, reduce poverty, and improve nutrition[14] but also to address climate change. To meet projected food demand by 2050, global

FIGURE 1 Long-term trends in agricultural research spending



Source: Public sector data compiled from ASTI (https://www.asti.cgiar.org/data) ; private sector data from K. Fuglie, The Growing Role of the Private Sector in Agricultural Research and Development World-Wide," *Global Food Security* 10 (2016): 29–38.

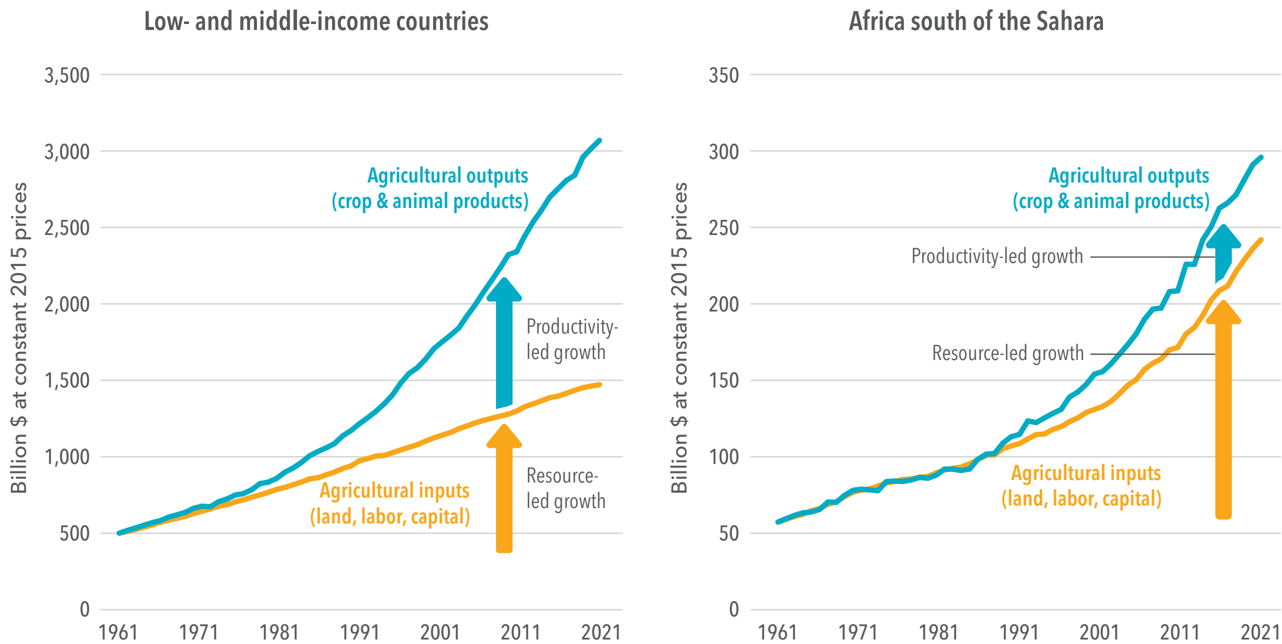
Note: Income group classifications are based on the situation in 2019. HIC = high-income countries; LMIC = low- and middle-income countries.

agricultural productivity must grow at an average rate of at least 1.28 percent annually.[15] Since 2010, global agricultural productivity has grown at 1.51 percent per year, but growth in low-income countries has averaged only 0.96 percent. With such sluggish growth rates, LMICs will only meet a fraction of their increased food demand through productivity improvements.[16] Moreover, climate change is already eroding earlier productivity gains, necessitating urgent shifts in research goals and priorities toward adaptation, especially in the most vulnerable countries.[17] The world can no longer rely on the main drivers of past agricultural growth – namely, expansion of cultivated land area and exploitation of natural resources (Figure 2) – which have contributed to GHG emissions and resource depletion. Agricultural productivity must be boosted through yield increases, more efficient use of scarce resources, and a reduction in crop losses, rather than greater use of natural resources. Increasing investment in R&D to support innovation in agricultural technology and other segments of food value chains, as well as a strong enabling environment to achieve rapid and wide-scale adoption of sustainable technologies, is therefore a top priority.

GREATER AGRICULTURAL R&D INVESTMENT IS NEEDED IN LMICS

Agricultural productivity growth will continue to be crucial to LMICs and is inextricably linked to investments in R&D that generate improved technology for more precise breeding and input use efficiency,[18] as well as other investments *in* agriculture, such as extension, irrigation, and input distribution policies, and *for* agriculture, such as rural roads and electricity.[19] Yet, a recent global estimate of underinvestment in agricultural R&D suggests that LMICs achieved just 50 percent of attainable investment levels in 2016,[20] with underinvestment most prevalent among countries with small and medium-size research systems.[21] Given that private R&D investment – while significant – cannot fully close the investment gap, agrifood

FIGURE 2 Drivers of past agricultural growth



Source: USDA-ERS, accessed 2021.

innovations will continue to rely heavily on public agricultural research. The findings suggest that closing the LMIC investment gap will depend on sustained investment growth in large countries, such as Brazil, China, and India, and accelerated growth in other countries with large research systems. This will allow countries with lagging research systems to benefit from the gains made by countries with more advanced systems and similar agroecologies. National and international public research institutions must play a large role, particularly in areas where economic incentives for private research are weak.

R&D MUST ALSO TARGET SUSTAINABILITY AND RESILIENCE

Higher productivity alone will not be sufficient to achieve sustainable and inclusive agrifood systems. Food systems are major drivers of changes in land use, depletion of freshwater resources, and pollution of aquatic and terrestrial ecosystems,[22] and the production of food (especially animal-source foods) generates more than a third of the anthropogenic GHG emissions that cause climate change.[23] In turn, climate change will have major impacts on the future quality, quantity, and distribution of food. At present, only about 7 percent of LMIC spending on agricultural innovation targets sustainable agricultural intensification.[24] Going forward, increased investment will need to be directed to research and innovation focused on healthier and more sustainable diets, improvements in technologies and management, reductions in food waste and loss, mitigation of GHG emissions, and increased smallholder resilience and adaptation to climate change, to name but a few areas.[25]

INNOVATION IN AGRICULTURAL TECHNOLOGIES IS CRUCIAL

ADAPTATION. Innovations in breeding and in production and management systems will play a crucial role at the farm level in adaptation to climate change impacts. Promising agricultural technologies such as precision agriculture, biofertilizers, and genome editing are already accelerating productivity growth without adding to pressures on natural resources (see Chapter 12). These technologies offer novel uses and applications that address environmental conditions and climate change effects.[26] In addition, new breeding techniques can help crops and animals become more tolerant of heat stress and pests.[27] Innovative farming systems can counter soil erosion and improve moisture and nutrient retention. These include crop and animal diversification; integration of livestock systems, forestry, and crop production; changes in feeding practices; and shifting livestock and crop production locations.[28]

The impact of technological advances will vary with the diverse contexts in which the technologies are applied.[29] For example, drought-tolerant, early maturing varieties will provide greater benefits to farmers and consumers if climate change brings sharp decreases in growing season rainfall. Likewise, nitrogen-use efficiency is only useful in cropping systems where nitrogen availability is a constraining factor. Investments and innovations therefore need to be tailored to the specific context in which they are being applied.[30]

MITIGATION. To achieve mitigation goals, R&D must be stepped up to develop new agricultural technologies that can reduce GHG emissions. The technologies and practices currently available are insufficient to mitigate global warming. For example, practices like alternate wetting and drying in paddy rice and expansion of agroforestry systems can only provide a portion of the mitigation required in agriculture to reduce the pace of global warming.[31] Land-based mitigation technologies play an important role, but are in turn dependent on negative emissions through afforestation/reforestation, intercropping, agricultural productivity improvements, and shifts in food demand. To complement land-based mitigation, potent non-CO_2 gas emissions like methane must be reduced, given the potential for rapid reduction of these shorter-lived GHGs in the atmosphere. For example, feed additives and supplements can reduce methane emissions from livestock production, while alternative approaches to water, soil carbon, nitrogen, and land management provide options to reduce emissions from rice production. Furthermore, food waste and loss, which generate 8 to 10 percent of global GHG emissions,[32] must be addressed. On a per capita basis, postharvest losses are highest in low-income regions due to poor infrastructure, storage, and handling. Innovations that enhance operational management of harvest, transport, and storage of agricultural commodities could therefore have a significant impact on food security and GHG emissions (see Chapter 11).

MORE FOCUS IS NEEDED ON DOWNSTREAM VALUE CHAINS

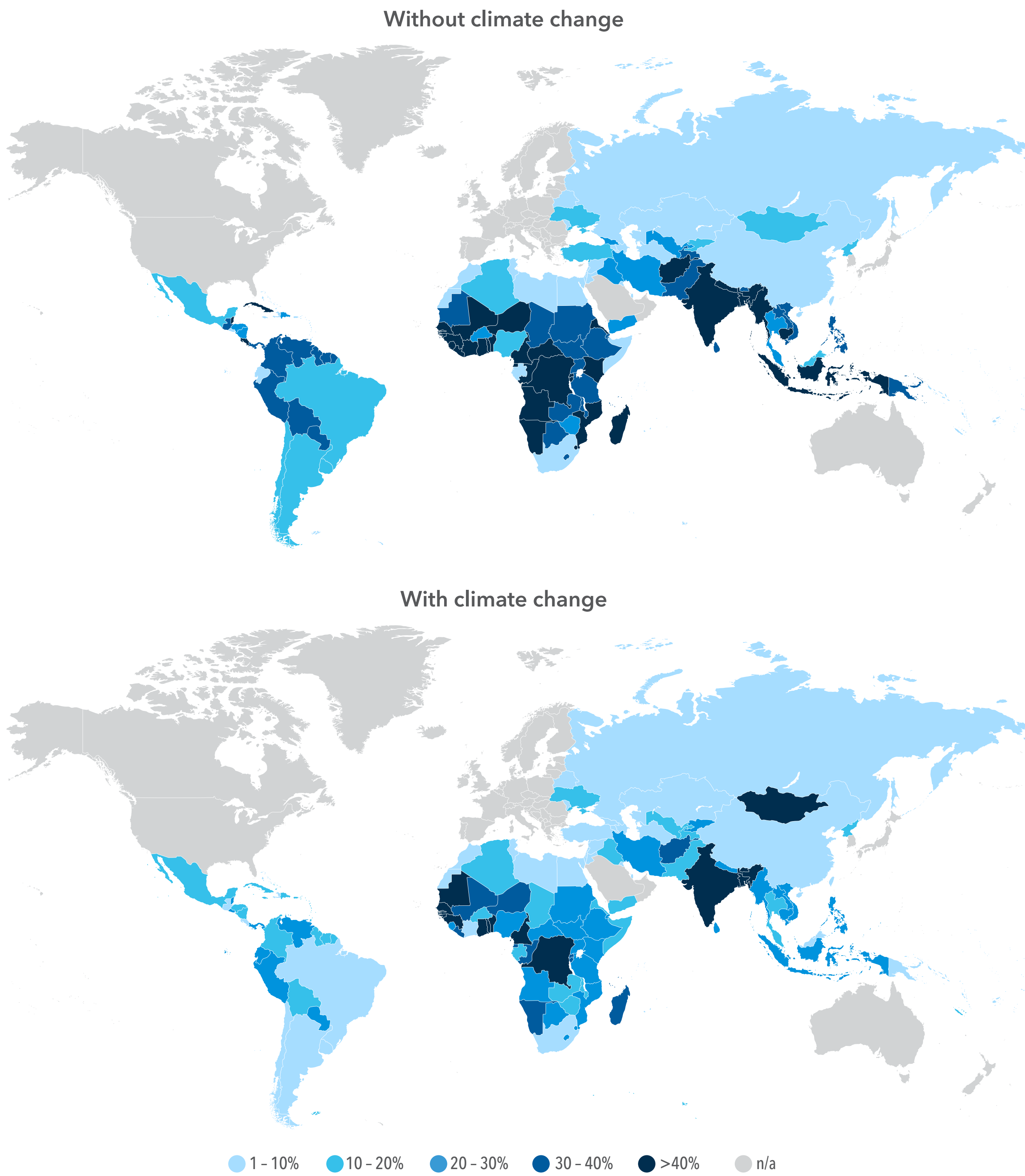
Most agrifood system research on climate change adaptation and mitigation has focused on agricultural production, leaving the implications of climate change for downstream components of food systems largely unexplored. These include the effects of extreme events and sea level rise on agriculture-related services, transportation, infrastructure, and storage facilities, as well as the effects of regulatory policies and energy and GHG mitigation policies on the adaptive capacity of domestic food systems.[33] Innovations in processing, packaging, logistics, and commercializing technologies are also important.[34] These supply chain innovations facilitate profitable marketing of output by farmers, creating returns to new technologies, and thus widespread adoption of the new technologies. R&D investment for downstream technologies in the food system will need a much higher profile in the context of climate change and development of food systems.

COMPLEX INTERPLAY OF CLIMATE CHANGE AND INNOVATIONS

There are complex interconnections between climate change impacts and the effectiveness of increased investments in R&D and specific innovations. Climate change blunts the impact of agricultural R&D and complementary investments, making it that much more important to increase these investments, as Figure 3 illustrates. With climate change, progress in reducing hunger slows compared to a world without climate change. By 2030, the number of hungry in the developing world drops by 186 million (36 percent) with investments under no climate change while making the same investments under climate change reduces hunger by only 165 million (28 percent).[35]

Challenges that come with gradual changes in temperature and precipitation patterns can mostly be met, on average globally, through normal adaptation

FIGURE 3 Impact of investments in agricultural R&D, water management, and market access infrastructure on hunger reduction (% reduction in 2030 compared to no climate change scenario in 2030)



Source: Data mapped from T. Sulser, et al., *Climate Change and Hunger: Estimating Costs of Adaptation in the Agrifood System*, Food Policy Report (Washington, DC: IFPRI, 2021).

Note: Assumes middle-of-the-road changes in population and income (IPCC socioeconomic pathway SSP 2). Climate change is modeled based on IPCC emissions pathway RCP 8.5 with the HGEM general circulation model. See Sulser et al. 2021 for details.

processes in the food system with funding levels following historical trends.[36] In fact, the impacts on production and food security of expected changes in population and per capita incomes are projected to outweigh the impacts of average changes in climate out to mid-century.[37] However, extreme and sudden shocks[38] and the combination and interaction of these driving forces — that is, changes in longer-term climate trends and socioeconomic development, plus increasing frequency of shocks and extreme events — present major challenges. The impact of climate change depends on the resilience of communities, with wealthier societies and communities better able to withstand shocks and recover afterward. Likewise, the effectiveness of different interventions will depend on socioeconomic status, the severity of climate change, and other factors.[39] All these complex, simultaneous challenges call for more balanced research and innovation agendas concerned with environmental sustainability, climate change adaptation, and mitigation and with nutrition and inclusion, as well as the more traditional focus on productivity growth.

INSIGHTS AND PRIORITIES FOR ACTION

Agriculture and food systems need to provide sufficient and nutritious food for a growing global population, while at the same time minimizing environmental impacts, enabling producers to earn a decent living, and adapting and responding to climate change. The traditional focus of agricultural research and innovation systems has been on enhancing productivity. Looking ahead, this focus must broaden to include the larger set of social, economic, nutritional, and environmental goals that are becoming increasingly important to ensure the sustainability of global food systems.

RAISE LMIC INVESTMENT ACROSS FOOD SYSTEMS AND BUILD COOPERATION. Collectively, LMICs spend less than 0.5 percent of their agricultural GDP on agricultural R&D.[40] A recent recommendation suggests that countries allocate at least 1 percent of their food-system-related GDP to food systems research.[41] Although detailed information on global food research investment is unavailable, the data on LMIC agricultural R&D spending imply that this ambitious investment target will require considerable effort. Certainly, not every country will be in a position to invest 1 percent, while others can easily invest more. This highlights the need for closer integration of research activities at the regional (and global) level — in an increasingly globalized world, technologies and innovations can more easily spill across borders.

LMICs are a very diverse group, and not every LMIC is underinvesting. Many large LMICs (notably China, India, and Brazil) have well-developed systems producing world-class innovations. In contrast, most small low-income countries, challenged by low capacity and limited ability to take advantage of economies of scale and scope, have overall been less effective in driving food systems transformation. The scarce resources of smaller LMICs are spread thinly over a wide range of commodities and agroecological zones. As a result, they generally record much lower returns to R&D investment compared with their larger counterparts.

To allow countries with lagging innovation systems to benefit from the gains made in countries with more advanced systems and similar agroecological conditions, a closer integration of agricultural R&D and innovation at the (sub)regional level is required. Smaller countries will need to collaborate with countries with large research systems that share mutual research needs and goals, as well as with regional and global R&D institutions, in order to acquire the knowledge and technologies that will support agricultural development and growth in the coming decades. In Africa, for example, the larger systems of South Africa, Kenya, Nigeria, and a few other countries can become the regional drivers of innovation, while smaller African systems should focus on coordinating their innovation activities with these leading players and investing to maximize "spill-ins." In addition, better coordination and a clear articulation of mandates and responsibilities among national, (sub)regional, and global R&D and innovation players (including the establishment of regional centers of excellence and/or specialization) are essential to ensuring that scarce financial, human, and infrastructure resources are optimized, duplications minimized, and synergies and complementarities enhanced. Continued support to and growth of regional bodies, networks, and mechanisms will further aid in supporting agendas that target issues of

BOX 1 SETTING R&D PRIORITIES IN EGYPT

A recent analysis in Egypt shows how investment in a range of innovations can be the most effective way to tackle the complex problem of climate change. Egypt is expected to see particularly strong climate change impacts, with a 10 percent decline in food crop yields by mid-century. Our modeling work shows that adverse climate effects on some crops (such as fruits and vegetables, potatoes, rice, and wheat) can be fully offset with increased investments in drought- and heat-tolerant crop varieties plus combinations of investments in soil fertility improvement, water management, and crop protection. Other crops prominent in Egypt's agricultural portfolio (maize, oil crops, pulses, and sugar) are projected to experience more severe impacts from climate change. For these, combinations of technologies will be crucial for minimizing the negative climate impacts.

Source: N. Perez, Y. Kassim, C. Ringler, T. Thomas, H. ElDidi, and C. Breisinger, *Climate-Resilience Policies and Investments for Egypt's Agriculture Sector: Sustaining Productivity and Food Security*, IFPRI Food Policy Report (Washington, DC: IFPRI, 2021).

(sub)regional interest. The restructured One CGIAR can play a constructive role in this regard.

SET CLEAR R&D INVESTMENT PRIORITIES. Countries and regions will need to identify priority innovation areas that are sustainable, equitable, inclusive, and scalable, and consider where additional spending has the largest impact in terms of both productivity and climate change adaptation and mitigation. Investments must target innovations not only in primary production, but also in the postharvest handling, storage, processing, distribution, and consumption of food and agricultural commodities.[42] Even at the farm level, a combination of technologies may be the most effective way to boost productivity and meet climate change goals (Box 1). Moreover, national and regional investments in food systems innovations need to be aligned with broader public and private investments — such as those in infrastructure, financial services, information technology, and digital services — for synergistic adoption and inclusion in agrifood systems.

PROMOTE BOTH PUBLIC AND PRIVATE INVESTMENT IN RESEARCH AND INNOVATION. Although private sector investment in agrifood innovations is increasing, greater private involvement is needed to tackle key emerging challenges, particularly in the postharvest stages of value chains (see Chapter 11). Cultivating private R&D funding requires that national governments provide a more enabling policy environment through tax incentives, protection of intellectual property rights, and regulatory reforms to encourage the international spill-in of technology (see Chapter 10). In addition to stimulating agribusiness research funding (see Chapter 5), countries also need to forge and leverage new mechanisms and partnerships that bring together different investors, including small-scale farmers.

Even with an improved enabling environment and increased private investment, a clear role remains for increased public investment to achieve broader food system goals for which private incentives are insufficient. The current low levels of investment in many LMICs are striking, considering the high potential returns on these investments, particularly compared with payoffs to other types of investment (see Chapter 2). Looking ahead, the challenge of mobilizing public support for shared investment to achieve shared food system goals may well be greater than the challenge of innovation itself. But it is not a challenge we can afford to ignore.

> Investing in agricultural research can be a highly effective pathway to both reducing poverty and hunger and addressing climate change impacts on food systems.