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Farmers on the Front Lines
How U.S. Investments in Climate Adaptation for Smallholders Can Support Global Food Security

FARMJOURNAL FOUNDATION

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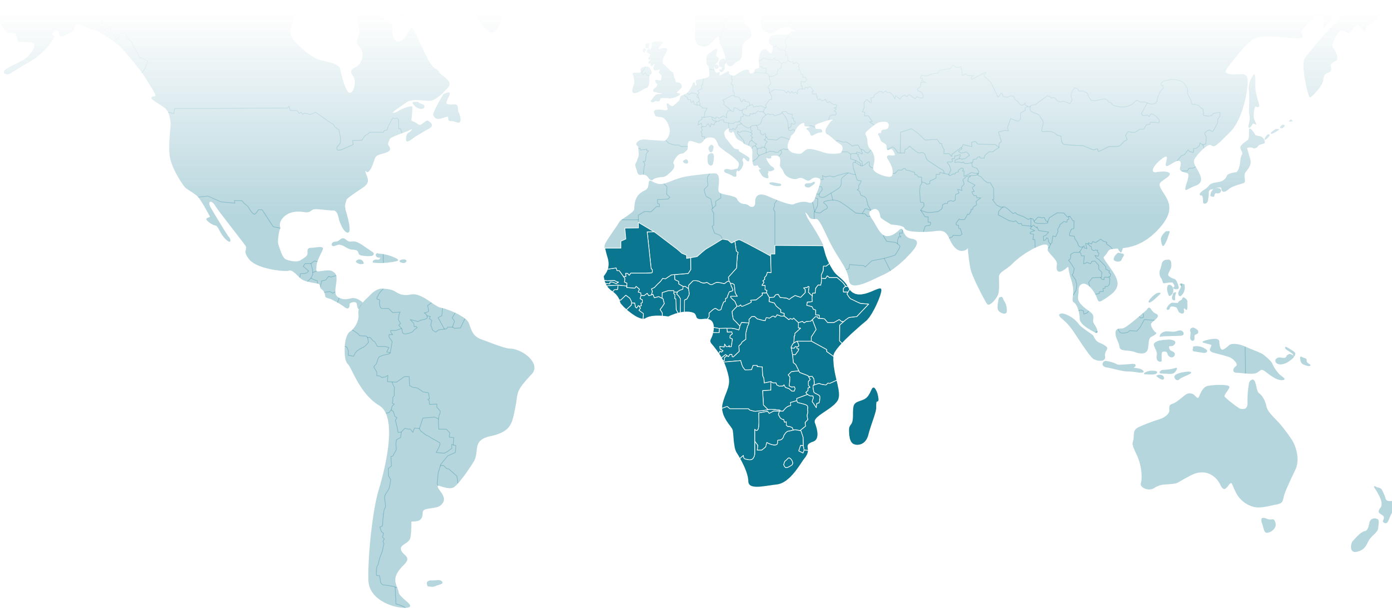
Farm Journal Foundation is a nonprofit, nonpartisan organization dedicated to achieving global food security by sustaining modern agriculture's leadership role and ability to meet the vital needs of a growing population.

EXECUTIVE SUMMARY

Today, our global food system is under extreme pressure. Demand for food is rising rapidly in response to population growth, urbanization, and higher incomes, while at the same time, farmers are tasked with producing more food with a dwindling supply of untapped natural resources, including arable land, fresh water, and healthy soils. Climate change is making farming even more difficult, with more frequent extreme weather events, migrating pests, and new diseases wreaking havoc on crops around the globe. According to one study by researchers at Cornell University, farm productivity over the past 60 years has been 21 percent lower than it would have been without climate change – an unspeakable loss during this era of increasing global hunger. The effects of climate change are only expected to intensify in the future, unless humanity takes significant steps to change course.

Climate-related shocks to our food system pose risks for everyone. But they are especially grave for the developing world – and in particular, for the 600 million smallholder households around the globe that depend on agriculture for their livelihoods. Smallholder farmers, especially those in Africa, disproportionately rely on rain-fed agriculture, and they often don't have access to resources and technologies that can help them adapt to increasingly common extreme weather events.

The world will need to produce 40 to 70% more food by 2050 to meet rising global demand. At current crop yield levels, this would require at least 20 million square kilometers of new farmland to be created, an area almost as large as the entire land mass of Sub-Saharan Africa. While some parts of the developing world have successfully raised agricultural yields as the main source of agricultural production growth, over 70% of production growth in sub-Saharan Africa since 2000 has resulted from the expansion of cropland under cultivation, with major damage to the region's forests, grasslands, water supply, and the ecosystems services that they provide. Without major and sustainable increases in the value of farm output on existing farmland, our food system is becoming unsustainable. Simply put, relying on area expansion as the main source of agricultural growth is not a sustainable option. Fortunately, however, there is still time to meet the world's rising food needs while also protecting the environment, biodiversity, and associated ecosystem services. But to do so, the world's leaders, and the U.S. in particular, must coordinate and invest in one critically important area: technical innovation and the agricultural organizations that generate it.



Public investment in agricultural science, research, innovation, and policy is the key to building climate-smart food systems and for ensuring that sustainable technologies reach the hands of farmers in both the developed and the developing world. **In this paper, we identify six areas where investment and coordination would be especially impactful and where the U.S. can have a specific role:**

1. **Investing in and prioritizing agricultural research, development, and extension (R&D&E) programs, and policy analysis systems in developing countries that promote climate adaptation and resilience, and that raise productivity on existing farmland rather than encouraging the conversion of forests and grasslands into new cropland. These outcomes can be promoted by:**
    - Providing incentives for CGIAR, Feed the Future initiatives, and other U.S. programs to elevate capacity development of national agricultural science, research and development, and policy analysis organizations as a key performance priority; and
    - Encouraging developing country governments to make greater investments in their own agricultural research, development, extension, and policy analysis programs
2. **Investing in educational institutions and initiatives that strengthen agricultural education systems, train agricultural scientists, and support farm extension services in developing countries**
3. **Investing in weather and early warning information services to help predict and rapidly respond to potential shocks**
4. **Coordinating international capital mobilization efforts around climate-resilient food systems, knowledge sharing, and infrastructure, including encouraging public-private partnerships like the Foundation for Food & Agriculture Research to stimulate outside investments in agricultural R&D**
5. **Coordinating government policies to improve the enabling environment for the private sector to make climate-smart investments in agrifood systems**
6. **Coordinating holistic, intergovernmental and inter-agency responses to address complex challenges and prevent work from taking place in silos**

This paper outlines a number of U.S. initiatives that are already in existence that could be effectively scaled up to increase the impact of the government's response to climate change – these include Feed the Future's Innovation Labs program, investments in the CGIAR system, food security projects under the Millennium Challenge Corporation, and new initiatives introduced by the current administration such as the President's Emergency Plan for Adaptation and Resilience (PREPARE) and the Agriculture Innovation Mission for Climate (AIM4C). The report also identifies additional areas where U.S. investments could be more effective.

The U.S., as a global leader in agricultural production and innovation, has a particularly important role to play in developing more sustainable, resilient, and equitable global food systems. Importantly, investing in long-term agricultural sustainability in developing countries is in the U.S. national interest, as it would (i) prevent future food crises that would hit farmers, consumers, and firms in the U.S. as well as those in developing countries, (ii) reduce the need for emergency food aid, (iii) support food security and political stability in developing countries, and (iv) reduce or avoid potential mass migration and civil unrest.

Climate change and population pressures in many areas of the world are exposing the highly vulnerable nature of agrifood systems in developing countries and the associated risks of acute hunger and loss of livelihoods. Smallholder farming communities in developing countries are particularly at risk. To reverse this dangerous course, farmers must be able to produce more with less – increasing yields on their existing crop land and adapting their farming practices to stabilize yields and farm incomes in the face of more frequent and extreme climate-related shocks. As we look toward the future, science and technology will be key to protecting our food supplies and the environment and preventing ever-worsening global hunger. Importantly, agricultural research and innovations take time to develop, so investments must be made now to enable our food system to produce and deliver safe, affordable food supplies, and ensure sustainable rural livelihoods for generations to come.

INTRODUCTION

A global consensus is emerging that the health of the planet and our livelihoods are fundamentally dependent on developing resilient and sustainable economies (World Bank, 2020). Achieving this outcome will require major restructuring of global food systems, in particular adapting them to become more sustainable and resilient to the effects of climate change (IPCC, 2021; AGRA, 2021). Mounting evidence indicates that climate change is already damaging agricultural systems around the world, and these effects will become more extreme over time unless greater resources are devoted to make food systems more productive and resilient.

Low-income countries are disproportionately affected by climate change, despite having contributed the least to the emissions of greenhouse gasses that have created global warming over the last few decades. In 2019, the United Nations Conference on Trade and Development (UNCTAD) estimated that the world's least developed countries contributed only 1.1 percent of total carbon dioxide emissions from fossil fuel use and industrial processes (UNCTAD, 2021). Unless sufficient resources are devoted to adapting agricultural systems in developing countries to climate change, between three and five billion people in developing countries who rely on agriculture for their livelihoods could be hit hard, slowing or even reversing progress made in the past several decades in alleviating global poverty and hunger. Other outcomes include destabilized global food markets, increased stress-related local and inter-regional migration, the commitment of greater resources for emergencies and humanitarian assistance, and greater stress on political, economic, and social systems around the world.

A failure to make developing country food systems more resilient and sustainable will exacerbate economic, social, and political stress in developed countries too. Therefore, promoting climate resilient food systems in developing countries is clearly in the U.S. national interest.

Improving agricultural productivity is not sufficient to reduce hunger and poverty, but it is necessary (Fuglie et al., 2020; BIFAD, 2021; von Braun et al., 2021). The agricultural sector is the largest employer in the developing world, but many developing regions, particularly Sub-Saharan Africa, are plagued with low productivity. For reasons explained below, raising the value of output on existing farmland is crucial for achieving sustainable and resilient food systems that deliver safe, nutritious quality diets to growing populations on a consistent basis. And raising agricultural productivity will increasingly require making agrifood systems more resilient to the ravages caused by climate change. Without adaptation strategies and technical innovation, climate change will make it even more difficult for the world's three billion people who live in rural agrarian communities to escape from poverty and hunger (BIFAD, 2021).

As stated by the Global Panel on Agriculture and Food Systems for Nutrition:

They (global food systems) are the largest single cause of anthropomorphic greenhouse gas (GHG) emissions (28% between 2007 and 2016), while agriculture alone accounts for 70% of freshwater use. Even without projected global population growth, food systems are operating well beyond planetary boundaries. The pressures placed on natural resources by food production have left 25% of the globe's cultivated land area degraded, while deforestation for agriculture is recognized as a major and irreversible cause of biodiversity loss. This situation is simply unsustainable. There is a very substantial risk that the world will irreversibly cross multiple planetary boundaries as a direct outcome of current agricultural and food system practices, which are underpinned by often perverse incentive structures." (GLOPAN, 2020, p. 17).

While the burden of changing food systems to reduce emissions – i.e. mitigation – is expected to largely fall on industrialized countries that are by far the greatest emitters of GHGs, achieving sustainable and resilient food systems in developing countries requires technical innovation and adaptation in those countries.

This report explores how developing countries can make their agrifood systems more resilient and sustainable in the face of climate change and describes how the U.S. government is already supporting climate adaptation to achieve that goal. This report also recommends actions to amplify the reach and impact of these efforts. In addition, this report synthesizes available research evidence to guide future U.S. efforts, including U.S. Agency for International Development (USAID) internal and inter-agency strategy discussions, Global Food Security Act (GFSA) reauthorization, farm bill discussions, and U.S. engagement at upcoming UN Climate Change Conferences.

This report is organized as follows: Section 2 defines key terms and concepts. Section 3 identifies the major challenges posed by climate change and related population-induced pressures on the natural resource base. Section 4 identifies a number of U.S. government-funded initiatives that support climate-smart agriculture in developing countries. Section 5 focuses on particular policy areas where actions are required to achieve more resilient and sustainable food systems in developing countries, and provides specific recommendations on how to make food systems more resilient to climate change. Section 6 summarizes the report's main findings and conclusions.

KEY TERMS

Agrifood systems are the totality of activities, people, institutions, and natural resources (e.g., land, water, and air) involved in supplying a population with food and agricultural products. Agrifood systems include (i) farming: those involved directly in producing crops, raising animals, and managing fisheries; (ii) upstream agrifood stages involving pre-farm value addition activities, e.g., farm input distribution, irrigation equipment, crop and animal science and technology generation, and farmer extension services; and (iii) downstream agrifood stages involving post-farm value addition, such as aggregation of crops, transportation, wholesaling, storage, processing, retailing, restaurants, beverage manufacturing, etc. At every stage in the system, food systems utilize natural resources, many of which are non-renewable. There is growing recognition that we need food systems that use resources sustainably and do not destabilize the environment.

Sustainability refers to the capacity to preserve and improve the welfare of current and future generations of humans and the planet. Investments and policies to create more sustainable food systems impose costs on society, but evidence is growing that the costs of maintaining unsustainable food systems are much greater (World Bank, 2020). Nowhere is this more evident than for agriculture, where lack of attention to sustainability can result in catastrophic losses in terms of income, human health, common-pool resources such as water and animal habitats, and social cohesion. Food systems using technologies that degrade the natural environment (e.g., through excessive greenhouse gas emissions, water pollution, soil erosion, soil nutrient depletion, deforestation, habitat loss, fossil-fuel-dependent processing and transportation, etc.) are, in general, not sustainable.

Resilience refers to the ability to dampen the impact of, and quickly recover from, shocks, and to adapt flexibly in response to stressors (e.g., Cutter et al, 2008). Resilient food systems minimize the effects of major shocks and stressors emanating from climate/weather, conflict, disease, global economic shocks emanating from outside the region, and other sources, which, if not prevented or mitigated, would delay or limit economic progress, transformation, prosperity, and self-reliance. Resilient food systems also evolve flexibly to adapt to “new normal” conditions.

Shocks are “external short-term deviations from long-term trends that destabilize people’s current state of well-being, level of assets, livelihoods and safety” (Choularton et al., 2015). Floods, droughts, pests and diseases, military conflicts, and rapid changes in economic conditions such as high fuel prices, volatile exchange rates, or inflation, are recent examples of shocks. **Stressors** are “long-term trends or pressures that undermine the stability of a system and increase vulnerability within it (Zseleczky and Yosef, 2014). Climate change, population pressures, and protracted political instability are examples of stressors.

Climate-smart agriculture (CSA) has emerged as an approach that enhances the resilience of farm systems to the effects of climate change. CSA is defined by three principle objectives: 1) sustainably increasing agricultural productivity and incomes; 2) adapting and building resilience to climate change; and 3) reducing greenhouse gas emissions (FAO, 2013). Notably, a resilient food system minimizes the effect of a negative shock and recovers more quickly than a less resilient system. A lack of resilience impedes progress in any domain, as losses slow down or impede system progress.

Ecosystem services are benefits that natural systems provide to people, such as clean air, pollination, marine life and seafood, genetic resources used in medicine and the development of new crops, recreation, and cultural heritage.

DEFINING THE CHALLENGE:
CLIMATE CHANGE POSES HUGE RISKS TO FOOD SYSTEMS IN DEVELOPING COUNTRIES

The status quo is not sustainable; decisive action is required now.

Food systems in developing areas are typically fragile; climate change is making them even more so. Climate change has been estimated to reduce global agricultural total factor productivity (TFP) by about 21% since 1961, a slowdown that is equivalent to losing the last 7 years of productivity growth. The effect is substantially more severe (a reduction of about 26-34%) in warmer regions such as Africa, Latin America, and the Caribbean (Ortiz-Bobea et al., 2021). Lachaud et al (2021) estimate that climate change, if not addressed, will reduce agricultural productivity in the Latin American and Caribbean regions by between 9.03% and 12.7%, amounting to USD$14.7 to $31.4 billion dollars in foregone agricultural income (cumulatively) over the 2015–2050 period, depending on the scenario. According to the Global Panel on Agriculture and Food Systems for Nutrition, the number of people living in fragile settings by 2030 will reach 2.3 billion, including 80% of the world's poor people. Some projections forecast a doubling in the number of people requiring targeted assistance from around 110 million in 2018 to over 200 million per year by 2050; humanitarian funding requirements after climate-related disasters could increase from between US$3.5-12 billion to US$20 billion annually by 2030. These trends and other evidence indicate that agrifood systems worldwide must be transformed in many respects if they are to become more resilient and sustainable.

Climate change is projected to make extreme weather events more frequent, with accompanying cascading impacts, feedbacks, and tipping points in the biophysical and social systems. Coastal areas are particularly vulnerable, such as river deltas in Bangladesh, Vietnam, and Nigeria, which may induce major livelihood stress and increased migration (e.g., Douglas et al., 2008; Steimanis et al., 2021; Angel et al, 2021).

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Even though agricultural production in many regions has grown impressively in recent years in spite of climate change, there are growing indications that this production growth reflects an unsustainable consumption of the earth's natural capital stocks. Since 1970, 14 of the 18 categories of natural capital stocks, such as soil organic carbon and pollinator diversity, have declined globally, indicating that gains in resource-based production may not be sustainable. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019), land degradation has reduced productivity in 23% of the world's agricultural land area, and between $235 billion and $577 billion in annual global crop output is at risk because of pollinator loss. Moreover, loss of coastal habitats and coral reefs reduces coastal protection, which increases the risk from floods and hurricanes to life and property for the 100 million to 300 million people living within coastal 100-year flood zones worldwide (IPBES, 2019).

African food systems are particularly vulnerable to weather-related shocks due to the continent's reliance on rain-fed production systems and the continent's growing reliance on global markets for a substantial portion of its staple food requirements, combined with poorly functioning transport systems to inland cities and smallholder farmers' limited access to resources and technologies to adapt and cope with extreme weather events (AGRA, 2022).

Climate change is posing a wide range of challenges that go beyond extreme weather.

Climate change adaptation is not only about adjusting to more extreme weather events. Civil instability, the spread of human, plant, and animal diseases, and other stressors on natural resources driven by population growth are often related to and exacerbated by climate change. For example, changes in rainfall and humidity are exacerbating the spread of plant diseases and pests (Ristaino et al., 2021). Climate change has contributed to the movement of flora and fauna, creating expanded zones for invasive pests and diseases that depress crop yields, kill farmers' animals, and erode communities' assets and livelihoods. For example, the parasitic weed Striga, which is widespread throughout Africa and can cause cereal yield losses as high as 60%, thrives in drought-prone, low-fertility soils and has become more widespread in semi-arid and dry sub-humid systems that are water- and nutrient-limited and have short growing seasons (Dugje et al., 2006).

Climate change is also altering the length and predictability of growing seasons, creating water stress and calling into question the sustainability of irrigation schemes. A 2022 report by the World Meteorological Organization (WMO) found that increased temperatures contributed to a 34% reduction in agricultural productivity growth in Africa since 1961 – more than any other region in the world. Water is becoming scarce in semi-arid and densely populated areas, such as in parts of India, Mexico, Australia, much of the western United States, and large portions of the African continent. Agriculture accounts for roughly 70% of national water withdrawals in many countries reliant on irrigation. Policies and institutions governing water allocation have been slow to adapt to rising water scarcity in many rapidly growing developing areas. Climate change and population growth are challenging nations to resolve how to allocate water more efficiently – developing resilient and sustainable food systems will depend on doing so.

Raising productivity of existing farmland is crucial for achieving sustainable and climate-resilient food systems.

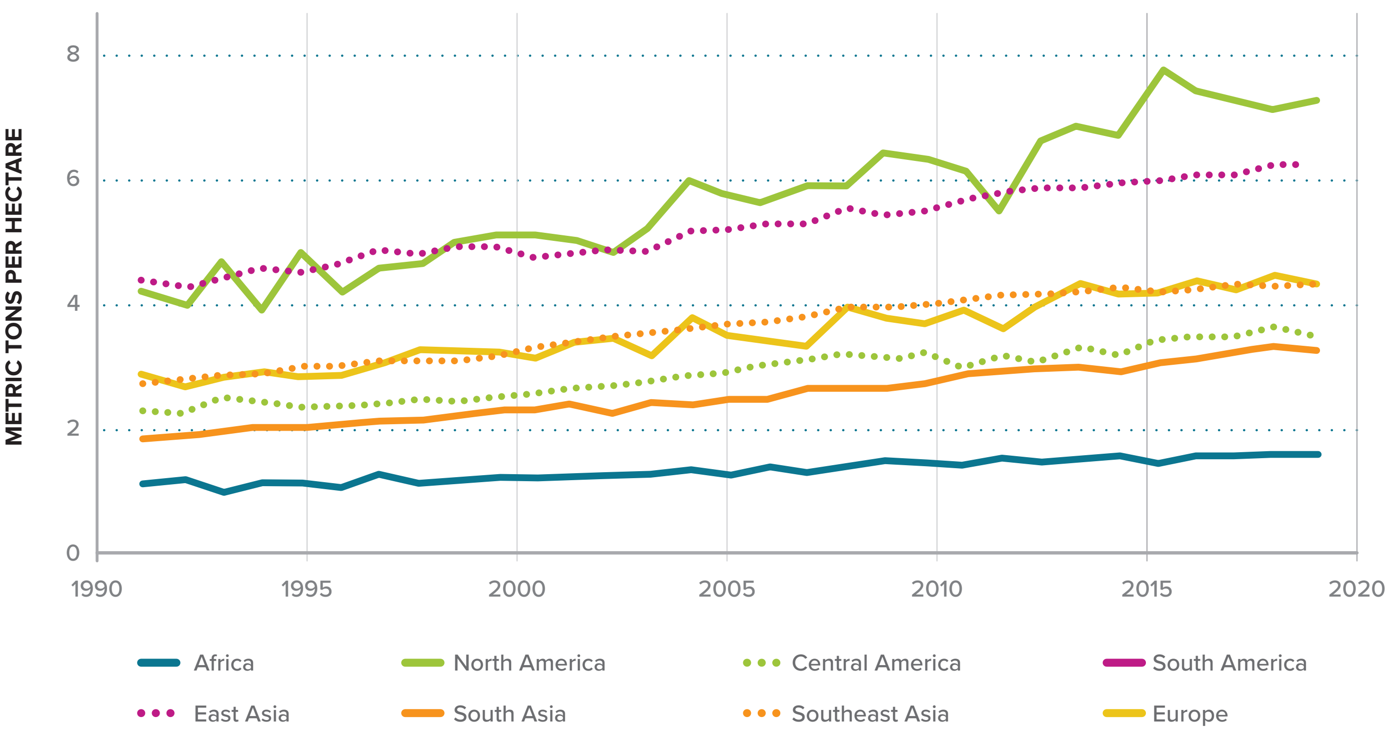
Given current population and income growth assumptions, the world is estimated to require a 40-70% increase in food availability by 2050 (Fisher, 2014; van Dijk et al., 2021). At existing crop yield levels, this 40-70% increase in food supply would require 23-34 million km2 of new farmland and ranches to be created, an area at least as large as all of sub-Saharan Africa (Fisher, 2014). Sub-Saharan Africa in particular has depended primarily on expansion of area under crops as the main source of the region's food production growth in recent decades. But continued reliance on area expansion as the main source of agricultural growth is not a viable option on environmental grounds, as it destroys forests, grasslands, and biodiversity and releases greenhouse gasses into the earth's atmosphere (Sanchez, 2019). The goals of feeding the world's growing population and conserving the planet's natural resources, diverse ecosystems, and the services they provide will require producing more from existing farmland instead of area expansion (van Ittersum et al., 2016).

Fortunately, yields are rising in some regions to reduce the pressure on continued area expansion to feed the world's population. But particularly in Sub-Saharan Africa (SSA), yields are rising very slowly (Figure 1). According to the International Food Policy Research Institute (IFPRI), if we do not increase and stabilize food availability to keep up with population growth and climate change, an additional 78 million people will face hunger by 2050 (Sulser et al, 2021).

Technical innovation – for example through adopting new higher-yielding crop varieties and practices that improve soil health – is a precondition for sustainably promoting productivity growth on existing farmland. Technical innovation is also required to reduce the vulnerability of crop and animal production systems to increasingly volatile weather. Technical innovation requires the coordination of favorable policies, investments in physical infrastructure, and strong agricultural science and extension systems that generate and disseminate improved technologies and practices.

Of all types of agricultural expenditures, spending on research and development is among the most crucial to growth (Alston et al., 2021; Fuglie et al., 2020).

Figure 1. Cereal yield growth by region (metric tons per hectare), 1990 to 2020



Source: FAOSTAT (last accessed May 2022)

Table 1.

	Agricultural R&D		Agricultural Research Intensity, 2011 Expenditure			
	1981	2011	R&D/Ag GDP		R&D/ Cropland	R&D/ Ag Labor
Region	(2011 PPP$, millions)		(%)	Trend	($/hectare)	($/worker)
Public Agricultural R&D						
Latin America & Caribbean	2,820	4,689	1.06	↑	24.98	106.71
West Asia & North Africa	978	2,253	0.49	↑	26.45	79.55
East Asia & South Asia	2,709	13,572	0.46	↑	27.11	22.28
Sub-Saharan Africa	1,179	1,893	0.38	↓	9.25	10.11
Developing-Country Total Public Agricultural R&D	7,686	22,406	0.52	↑	22.91	25.79

Unfortunately, Sub-Saharan African governments invest relatively little in agricultural R&D compared to other regions of the world. According to the Agricultural Science and Technology Indicators (ASTI) database, Asian governments spent 8 times more on agricultural research and development per hectare between 2010 and 2016 than Sub-Saharan African governments; see also (Table 1). Over the last four decades, most African governments have allocated only a small fraction of their agricultural expenditures to crop and livestock research and extension services and even less to climate adaptation. Indeed, the weaknesses of agricultural research and development and extension organizations (R&D&E), particularly in Sub-Saharan Africa, have constrained the pace of technical innovation and agricultural productivity growth (Fuglie et al., 2020). IFPRI (Sulser et al 2021) concludes that increased investment in agricultural R&D would be one of the most cost-effective ways of promoting food security and livelihood objectives in the face of increasing climate variability.

Chronically low funding for agricultural R&D&E has contributed to the situation in which Sub-Saharan Africa has recorded the slowest rate of yield improvement and productivity growth of any region of the world over the past few decades (Figure 1). Cereal yields in South America and South Asia rose from 2.17 and 1.90 tons per hectare in 1990 to 4.97 and 3.31 tons per hectare in 2020, respectively. This represents a 129% increase in South America and a 70% increase in South Asia. By contrast, cereal yields in Sub-Saharan Africa rose by only 41% over the same period, from 1.15 to 1.63 tons per hectare. Raising and stabilizing crop yields is particularly challenging in Sub-Saharan Africa, where more truncated growing seasons, more variable weather patterns, and the region's reliance on rainfed agriculture has required smallholder farmers to modify cropping practices and technologies without strong R&D support.

Yet, spending on R&D alone is likely insufficient to have a meaningful impact on productivity outcomes. Extension systems also need to be reformed. To cope with the socio-economic and agro-ecological diversity of farming systems in developing areas, R&D must be integrated with a participatory extension model that enables a bi-directional flow of information out to farmers and information into agricultural research stations (Bezner Kerr et al., 2016). As additional large agri-business firms invest in African agrifood systems, opportunities for private extension services will expand. However, given the scope and scale of the challenges facing African agrifood systems, and the geographic clustering of most private agri-business investments in high-potential and market accessible areas, revitalizing public extension will be critical for promoting technical innovation in less favored regions on the scale required to enable millions of farmers to adapt effectively to climate change.

Forests and grasslands play a vital role in storing carbon, which in the form of carbon dioxide is the main greenhouse gas linked to climate change. Grasslands contain as much as 30% of the carbon stored in the Earth's soil. Plowing them to plant crops releases great amounts of carbon into the atmosphere (New York Times, 2021). By relieving pressure on expanding the area to feed the world's growing population, achieving yield/productivity growth on existing farmland is an essential condition for creating resilient and sustainable food systems (van Ittersum et al., 2016).

Climate change is heightening the need for international water management.

Management of water supplies across borders is becoming increasingly problematic with climate change and population growth. Downstream users of river water are affected by decisions made by upstream users. For example, China has rivers that flow into other south and east Asian countries; hence China's actions that affect the volume of water flowing into neighboring countries can hurt their ability to ensure national food security in response to climate change. Similarly, the resilience and sustainability of Egypt's agricultural system is affected by Ethiopia's actions in damming up the Blue Nile, which could potentially lead to conflict and humanitarian crises if not amicably resolved. Regional institutions and agreements are needed to efficiently allocate water, especially in extreme years or periods of low rainfall or extreme rainfall (Postel, 2017). International coordination has always been important in this regard, but the need for coordination has become ever more acute as climate change and growing competition for natural resources create new political and social frictions, often ending in conflict.

Smallholder farmers in developing countries are particularly vulnerable to climate change.

Africa has unique challenges due to rapid population growth, which will put mounting stress on the continent's natural resources to grow more food and provide more water and energy. Sub-Saharan Africa's population is projected to double from 1.1 to 2.2 billion people over the next 30 years (United Nations, 2018). Moreover, since much of Africa is prone to increasing weather variability, outbreaks of animal and plant diseases and pests, hotter temperatures, and more erratic rainfall, its dependence on rainfed agriculture creates major challenges in absorbing the rapidly growing youth population into gainful employment – thus potentially making countries more prone to conflict. This situation makes large parts of Africa especially vulnerable to climate change impacts. On top of these challenges, developing countries need to avoid the massive costs that more developed nations are incurring from only recently realizing the importance of sustainability. For example, many countries are experiencing (i) dead zones in their marine estuaries from agricultural nutrient runoff, impairing the earning opportunities for people in those areas relying on fishing; (ii) toxic water effects that destroy aquaculture potential; and (iii) insufficient freshwater reserves to continue agricultural production because of overuse of water, threatening local economies and community livelihoods. As mentioned earlier, coastal countries where agricultural production greatly depends on river deltas such as in Bangladesh and Vietnam may also be considered priority hot-spots for climate-change mitigation programs (Douglas et al., 2008; Steimanis et al., 2021; Angel et al, 2021).

Summary

Developing countries need more sustainable food systems that efficiently and reliably deliver needed affordable food to rapidly growing populations while conserving water and energy, minimizing pollution, and preserving forests, grasslands, and the ecosystem services that they provide. Achieving these goals will require faster progress on three fronts simultaneously: (1) improving the stability of crop yields and animal production in response to extreme weather events and the increased prevalence of invasive pests and disease resulting from climate change; (2) growing more on existing farmland (through productivity growth) to feed rapidly growing populations while at the same time conserving scarce natural resources (especially land, water, and energy), preserving the environment (forests, grasslands, and biodiversity), and the ecosystem services that they provide; and (3) improving the efficiency of water use in agriculture.

Achieving these three objectives will require progress on many fronts: strengthening the systems that generate new technologies and practices appropriate to the wide range of farming conditions in developing regions; enabling environments that provide the incentives for private companies to make climate-smart investments at the various stages of agrifood systems; international coordination and agreement on how shared resources are to be allocated; programs that anticipate and respond to emerging new diseases and pests affecting crops and animals; and special focuses on vulnerable regions increasingly affected by extreme weather and where the ability of local and national governments to meet these challenges with their own resources is severely limited.

U.S. GOVERNMENT-FUNDED INITIATIVES TO SUPPORT CLIMATE-SMART AGRICULTURE IN DEVELOPING COUNTRIES

The U.S., as a global leader in agricultural production and innovation, has a particularly important role to play in developing more sustainable and equitable global food systems. Importantly, investing in long-term agricultural sustainability is in the U.S. national interest, as it can prevent future food crises, reducing the need for emergency food aid, and support food security and political stability in developing countries, preventing potential mass migration and civil unrest.

As such, the U.S. government actively supports developing countries in building climate-resilient food systems. This section highlights several U.S. government-funded initiatives, including PREPARE and AIM for Climate, launched by the current administration to address some of the challenges mentioned previously in this report. Importantly, this section does not intend to be an exhaustive list or to critically review the strengths and weaknesses of certain programs – it is only meant to highlight some examples of important work being done and to provide context for policy recommendations found later in this report.

PREPARE

On November 1, 2021, the U.S. government launched the President's Emergency Plan for Adaptation and Resilience (PREPARE) as the cornerstone of the U.S. foreign policy response to address the impacts of global climate change. PREPARE is a whole-of-government effort involving 19 U.S. federal agencies to help more than half a billion people in developing countries to adapt to and manage the impacts of climate change by 2030. PREPARE aims to provide $3 billion in U.S. adaptation finance annually by FY2024 and coordinate the United States' diplomatic, development, and technical expertise with a goal of helping more than half a billion people in developing countries adapt to and manage the impacts of climate change through locally led development by 2030. PREPARE will focus on addressing long-standing gaps in adaptation that disproportionately affect women, youth, indigenous peoples, and low income and marginalized groups that have historically been excluded from adaptation planning and action, yet often face the greatest risks.

The PREPARE Action Plan outlines key areas where the United States will work with partners to catalyze adaptation action. First, the U.S. government will work with partners to strengthen climate information services and early warning systems to equip people and institutions with the information they need to make sound decisions and take effective actions. The program recognizes that the next generation of decision makers and professionals need to have the skills, knowledge, and solutions to adapt to today's climate impacts and build a climate resilient future. Second, the program will build capacity to mainstream adaptation into policies, programs, and budgets and to support locally led adaptation, focusing on the impacts of climate change on food security, water, health, and infrastructure. Third, PREPARE will help unlock finance to support national, sub-national, and local climate adaptation action.

Agriculture Innovation Mission for Climate (AIM for Climate)

In March 2021, President Biden announced the AIM for Climate initiative to significantly increase and accelerate investments in climate-smart innovations over the next five years, along with the government of the United Arab Emirates (UAE). AIM for Climate was formally launched at COP26 in 2021, with an initial U.S. commitment of $1 billion. As part of U.S. AIM for Climate commitments, USAID committed at least $215 million in funding over five years (2021-25) for the CGIAR to help 200 million people raise agricultural productivity in South Asia and Sub-Saharan Africa by 25 percent by 2030. This goal is being pursued primarily by encouraging pursuit of "innovation sprints," which involve climate financing from non-governmental partners as a vehicle to seek specific technical solutions in the areas of innovative and climate-smart agriculture. AIM for Climate announced additional innovation sprints at COP27 in late 2022 with a focus on four areas: smallholder farmers in low- and middle-income countries, methane reduction, emerging technologies, and agroecological research.

CGIAR

CGIAR is the world's largest publicly funded agricultural research network committed to agriculture innovation for farmers and food systems in the developing world. The organization has a unique role in the global agricultural development landscape, providing evidence to policymakers, innovations to partners, and new tools to harness the economic, environmental, and nutritional power of agriculture.

The U.S. government is the single largest contributor to CGIAR. In 2021, CGIAR launched a new research and innovation prospectus and a 2030 Research and Innovation Strategy to provide the science, knowledge, and tools needed to carry out a radical realignment of food systems and reach global targets for transforming food, land, and water systems by 2030. It includes three action areas to drive progress on climate adaptation and mitigation: (i) food systems transformation; (ii) resilient agrifood systems; and (iii) genetic innovation.

With a presence in 90 countries, CGIAR scientists are on the ground, giving CGIAR a unique ability to work with local communities to adapt innovation to local conditions. CGIAR also has one of the largest collections of genetic diversity, holding roughly 10 percent of the world's germplasm. These genebanks have already provided critical traits to improve flooding and drought tolerance for rice varieties in South Asia and improved wheat traits that are being used all over the world.

CGIAR is currently undertaking what is arguably the most significant reform in its history, transforming itself from a decentralized model to One CGIAR to better integrate research programs and maximize organizational efficiencies. In some developing countries, particularly those in Africa, CGIAR is the main or only non-private sector organization prioritizing agricultural research objectives and carrying out research in areas such as improved seed varieties, agronomic practices, animal husbandry advances, artificial insemination (AI), agroforestry, and conservation farming practices to support adaptation to climate change. The private sector is also actively carrying out agricultural research for commercial crops and agro ecologies, but the fact that CGIAR and the private sector have accounted for the majority of agricultural research in many developing countries can be interpreted as a reflection of historical weaknesses of national agricultural research programs and hence a long-term failure of international partners to adequately strengthen their national partners in developing countries.

An important initial mandate of CGIAR was to build the capacity of the national and regional agricultural research organizations in developing countries so that they would eventually be in a position to prioritize and lead strong national programs. However, many if not most national agricultural research organizations remain poorly funded, unable to attract and/or retain well-trained national scientists or invest in the laboratories, equipment, and programmatic budgets to carry out effective adaptive agricultural research programs, especially in Sub-Saharan Africa. Well-trained agricultural scientists and policy analysts in national research systems often migrate to the CGIAR or other international research units because of better working conditions. This tends to strengthen the CGIAR but weakens the capacity of national systems.

The effectiveness of resources devoted to CGIAR and resources committed by private firms requires having strong national partners on the ground, which are needed to adapt international germplasm, management practices, and policies to the highly varied agroecological conditions and resource constraints faced by farmers in developing countries. More effective performance of national agricultural research and extension organizations will also require greater and more sustained support from national governments themselves. Demonstrating to developing country governments that achieving their own development policy objectives is strongly dependent on improving the performance of their own national agricultural research systems is in many cases the first priority. CGIAR itself can also contribute to more rapid uptake of sustainable climate-smart technical innovation and productivity growth in developing countries by renewing and intensifying its efforts to strengthen the capacities of its regional and national partners, including the National Agricultural Research System (NARS), regional centers of excellence, African agricultural universities, and public extension systems.

Feed the Future Innovation Labs

The U.S. whole-of-government Feed the Future initiative focuses on supporting agriculture and local food systems in developing countries to address the root causes of hunger, malnutrition, and poverty. There are currently 21 Feed the Future Innovation Labs headquartered at leading universities across the U.S., conducting research ranging from genetic improvement to agronomic management and soil health.

All Feed the Future Innovation Labs are doing important, groundbreaking work. However, below we highlight two illustrative examples of the work being done at individual laboratories that are particularly relevant to improving food system sustainability in developing countries in the context of climate change.

- **Feed the Future Innovation Lab for Sustainable Intensification:** Healthy soils are a key driver of improving crop yields, enabling farmers to increase their production on existing farmland without clearing additional forests, grasslands, or savannah to grow crops. The Feed the Future Innovation Lab for Collaborative Research on Sustainable Intensification (SIIL) at Kansas State University, partnering with the Appropriate Scale Mechanization Consortium (ASMC) at University of Illinois at Urbana Champaign, trains local farmers in sustainable intensification farm management practices in 12 countries in Africa, Asia, and Central America. Conservation agriculture is a set of practices that promotes no-tillage, continuous soil cover, and crop rotation to improve soil health and biodiversity. The lab's work has been so successful that an external evaluation in 2018 recommended that SIIL develop additional strategies to scale up other existing innovations with national and international development partners to improve adoption and impact. The evaluation also recommended new agricultural extension investments to help scale knowledge-intensive innovations, such as integrated pest management (IPM) to control potentially damaging insects, weeds, and other pests, and conservation agriculture-based sustainable intensification and/or multicomponent innovations, such as the conservation agriculture-based, dry-season, irrigated horticulture production.

- **The Feed the Future Innovation Lab for Food Security Policy Research, Capacity, and Influence (PRCI):** PRCI is a collaborative effort to strengthen human and institutional capacity across the developing world to do applied policy research that influences policy and programmatic thinking and decision making related to transforming food systems. Developing enabling environments that support resilient and sustainable food systems is a key aim of PRCI. Led by Michigan State University, together with the International Food Policy Research Institute (IFPRI), Cornell University, and the Regional Network of Agricultural Policy Research Centers (ReNAPRI) in Africa, PRCI has partnered with national and regional policy research organizations across Africa, Southeast Asia, and South Asia in pursuit of this goal. By working with and through these local and regional organizations, PRCI taps into and strengthens existing policy processes, making it more likely that real impacts will be achieved.

  PRCI has brought this approach to bear on the challenge of climate change through the Comprehensive Action for Climate Change Initiative (CACCI). Launched first in Africa by USAID Administrator Samantha Power and African Union Commissioner Josefa Sacko at COP26, CACCI in Africa is partnering with two premier African policy research organizations – ReNAPRI and AKADEMIYA2063 – to strengthen national, regional and continental capacity to implement National Determined Contributions (NDCs) and develop National Adaptation Plans (NAPs). They are conducting joint stock-taking exercises, mapping of local policy priorities against Paris Agreement mandates, and conducting ex-ante assessment of likely tradeoffs and outcomes of alternative courses of action. Together with national counterparts, they are developing metrics to monitor NDC benchmarks and are incorporating these into an online platform to track Paris Agreement implementation at country, regional, and continental level. They are also building metrics of household and community vulnerability and resilience into this platform, to inform the design of NAPs. In these ways, CACCI works to incorporate best evidence into officially approved policy and investment programs for NDCs and NAPs and to monitor and evaluate their implementation. Based on initial experience in these four countries, PRCI with ReNAPRI and AKADEMIYA2063 will adapt and roll out this approach in up to 25 additional countries over the next four years of the five-year effort. The result will be a critical mass of countries able to implement their commitments under the Paris Agreement in a manner that improves household and community level resilience and food security together with robust inclusive growth. Similar efforts have started in Tajikistan and are in the planning phase in Latin America.

Millennium Challenge Corporation (MCC)

The Millennium Challenge Corporation (MCC) was established under the Presidency of George W. Bush in January 2004 as an independent foreign assistance agency with a mission to deliver aid more effectively by seeking to reduce poverty through economic growth. Resources under MCC are targeted to projects in countries with commitments to good governance, with projects deemed to be cost-effective that have obtained local government buy-in.

Through 2021, it is estimated that MCC has invested about $5 billion in projects focused on food security. About 43 percent of that amount has been invested in rural transportation improvements, 28 percent in bolstering agricultural supply chains, 11 percent in irrigation infrastructure, and 10 percent in water, sanitation, and hygiene infrastructure. For example, in 2010, MCC launched an Integrated Water Resource Management (IWRM) project in Senegal, one of two projects commissioned as part of a five-year compact with that country's government. The project sought to rehabilitate existing irrigation infrastructure and build new infrastructure in two regions in northern Senegal, and help to create a transparent and fair process to allocate rights to newly irrigated cropland.

The International Development Finance Corporation (DFC)

The DFC was established in 2018 by an Act of Congress, consolidating the Overseas Private Investment Corporation (OPIC) with the Development Credit Authority operated by USAID into a single independent agency. In September 2022, the DFC board of directors approved a total of $1.6 billion in investments focused on key development challenges such as energy, food security, and climate solutions.

International Agricultural Education Fellowship Program (formerly AgriCorps)

AgriCorps was established in 2013 as a 501(c)(3) nonprofit organization, with a mission of "connecting American agriculture volunteers to the demand for experiential, school-based, agricultural education in developing countries." The organization first dispatched a group of about 11 recent U.S. agriculture education graduates as "fellows" to small African communities to serve as both agriculture teachers and de facto extension agents for those communities for an 11-month term of service.

As of 2018, AgriCorps fellows taught over 800 African secondary students, 70 post-secondary students, and advised over 700 4-H and FFA members, with many of them participating in contests and workshops. In communities where AgriCorps fellows serve, their work contributed to a 40% increase in the number of students choosing to study agriculture in high school. In addition, 125 farmers completed training through extension programs facilitated by AgriCorps fellows and 1,137 African teachers attended professional development workshops led by fellows. In that year, a provision was included in the Agriculture Improvement Act of 2018 (2018 farm bill) which authorized federal funding of up to $5 million annually between fiscal years 2019 and 2023 to fund "fellowships to citizens of the United States to assist eligible countries in developing school-based agricultural education and youth extension programs" (Section 3307), which took the program under USDA management and renamed it the International Agricultural Education Fellowship Program (IAEFP).

PRIORITY POLICY AREAS AND RECOMMENDATIONS

The U.S. could scale up support for existing programs, including those discussed in the previous section, and/or develop new initiatives to increase the impact of the government's overall response to climate change. Based on the review of evidence above, several priority actions should be undertaken together to achieve resilient and climate-smart agrifood systems. These include: (1) investing in agricultural research, development, and extension (R&D&E) to accelerate the pace of technical and farm management innovation that can raise and stabilize yields under increasingly variable weather, pest, and disease conditions; (2) strengthening national tertiary education institutions to generate a continuous stream of well-trained agricultural scientists required to improve the performance of national agricultural R&D&E systems; (3) expanding weather and early warning information services; (4) mobilizing the investment capital required to create climate-resilient agrifood systems; (5) supporting locally led approaches and policy analysis to improve the enabling environment for climate-resilient investments; (6) facilitating inter-ministerial coordination to enable holistic policy and programmatic responses to climate change based on the recognition that progress in achieving climate resilience requires multi-sectoral actions and strong coordination across various branches of government. These priority actions, as well as concrete U.S. policy recommendations, are discussed below.

RECOMMENDED FOCUS AREA 1:

Investing in agricultural R&D&E to accelerate the pace of technical innovation for smallholder farms

Adaptation to climate change requires technical innovation on millions of smallholder farms operating under highly diverse conditions that cannot be reached without strong local agricultural R&D&E systems. As indicated in Section 3, achieving resilient and sustainable food systems will require developing countries to raise farm productivity growth rates on existing farmland as the means to feed rapidly growing populations, promote economic transformation, and raise incomes in developing countries, rather than relying on the conversion of forests and grasslands to farmland as the source of agricultural growth. Achieving this outcome also means strengthening the durability of upstream and downstream stages of agrifood systems to climate-related shocks, so that shocks hitting a particular stage of the food system do not cripple the entire system's capacity to produce and distribute food supplies when and where they are needed. An analysis commissioned by the Food and Land Use Coalition in 2019 estimated that at least $300 billion per year in climate finance investment is needed to transform the global food system to reduce its current greenhouse gas footprint, while only about $9 billion per year is currently being expended in this area. The AIM for Climate initiative has the potential to catalyze such efforts by focusing more attention and resources in this area at the international level.

In concrete terms, the type of technical innovation required will vary by country and within a given country, but will generally entail:

- Bi-directional extension systems that transfer information and feedback between farmers and scientists. By promoting bi-directional learning between farmers and scientists, adaptive R&D systems can support co-learning and co-creation of technical innovation that is so necessary given the highly diverse socio-economic and agro-ecological conditions of farming systems in developing areas. The R&D system is more effective when coupled with a participatory extension model that enables a bi-directional flow of information out to farmers and information into agricultural research stations (Bezner Kerr et al., 2016).
- Expanding the availability and use of soil fertility-enhancing organic inputs to improve soil health. Healthy soils are one of the most important tools to help farmers capture carbon, mitigate climate change, and sustainably increase crop yields on their land. Incentivizing farmers to make long-term investments in soil health requires innovative strategies to drive down the cost of these investments in the beginning stages. In areas where local markets for organic composts and manure do not exist, U.S. programs can consider working with governments to modify existing input subsidy programs to promote the use of organic fertilizers, manure markets, lime, biochar, and a range of other soil-augmenting or soil fertility inputs that can help restore soil productivity on degraded land.
- Other integrated soil fertility management practices and technologies can help rural communities adapt to

small or moderate changes in climate. For example, smallholders' adoption of certain minimum tillage and conservation farming practices is associated with less yield loss in drought years and in response to extreme heat (Steward et al., 2018; Thierfelder et al., 2015). However, there are limits to how far agricultural production systems and entire food systems in developing countries can effectively adapt to more extreme climate change or address the onslaught of inevitable new diseases and pests associated with climate change, unless improved resources for generating, adapting, and adopting effective new technologies and practices are put in place. Many technical challenges still need to be worked out to help smallholders reliant on rainfed agriculture to engage in more productive and resilient production systems (Lee and Thierfelder, 2017; Steward et al., 2018).

- Development and cultivation of new, farmer-preferred seed varieties that stabilize and improve productivity under increasingly volatile weather conditions is critical to helping farmers adapt to climate change. Investments could be made to expand the utilization of high value genetic diversity from CGIAR germplasm banks in the development of new climate-smart crop varieties and more productive and resilient livestock for millions of smallholder farmers worldwide.
- Small-scale farmer-led investments in irrigation have contributed greatly to national food security in China and South Asia and also hold great potential for Sub-Saharan Africa (Shah et al., 2020). However, You et al. (2010) estimate that Sub-Saharan Africa would be capable of small-scale irrigation on a maximum of only 20% of the region's agricultural area. Such an outcome would represent a near tripling of current irrigated area but would nonetheless fall well short of what is needed. Generating more drought, flood, and heat-tolerant crop varieties is therefore needed to contribute to climate resilience in the majority of Africa's farmland that will continue to depend on rainfed agriculture.

While effective agricultural R&D&E systems are not sufficient to make progress on all these fronts, they are a necessary component of the effort. Increasing support for agricultural R&D&E is perhaps the single-most important driver of needed technical innovation in response to climate change and associated weather, pest, and disease challenges. Agricultural R&D has consistently been identified as generating the highest impact on agricultural growth and rural poverty reduction of all types of public agricultural expenditures (Economist Intelligence Unit, 2008; Alene and Coulibaly, 2009; Alston et al., 2021). The rising importance of making food systems more resilient in order to achieve sustained agricultural productivity growth under increasingly volatile weather conditions puts even more emphasis on strengthening international, regional, and national agricultural R&D&E systems.

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Alene and Coulibaly, 2009; Alston et al., 2021).

Advances in digital information and communications technology are making it feasible to reach farmers even in the most remote areas (Carter, 2022). However, because of decades of neglect of adaptive agricultural crop and animal science in the region, the binding constraint in providing management support services to millions of smallholder farmers is less and less the ability to reach them and more and more providing proven effective guidance based on evidence of best practices suitable to farmers' specific soil, rainfall, elevation, and market conditions (Dalbert/CTA, 2019). International R&D cannot substitute for local R&D because agricultural technologies, especially seed varieties, must be locally adapted, tested, and refined to be appropriate for the highly varied conditions in which farmers operate even within a single country. Hence investments to the international agricultural research systems will provide greater payoffs if strong local partners were in place to adapt and scale-out technical innovation on the ground (Lynam et al., 2016; Fuglie et al., 2020).

Building R&D&E capacity in developing countries requires sustained investments in people, facilities, lab equipment, budgets for field trials, and other recurrent costs. And because the benefits of most agricultural R&D&E investments accrue broadly and cannot be captured by individual firms investing in them, there is a strong rationale for investing in public R&D, although certainly international and private sector partners can help as collaborators in this process. Building the capacity of strong national agricultural R&D and extension systems should be a priority area for international development assistance.

National-level agricultural R&D&E is needed to enable millions of smallholder farmers to (i) adopt practices that enhance soil health in the highly varied farming conditions of Africa, with particular attention to increasing the application of both mineral fertilizers and organic inputs (e.g., compost, manure, and crop residues) that improve crops' ability to survive mid-season drought periods; (ii) adopt proven soil and water conservation and nutrient management practices; (iii) utilize management practices and inputs that limit downside yield loss to plant and animal pests and diseases; (iv) support diversification of production and value chains in areas where new crops have great potential to improve resilience and sustainability; and (v) adopt improved seed varieties that are better suited to emerging local climate and management conditions. In addition to national governments, both the CGIAR system and broader international research system have an important role to play in strengthening national agricultural R&D&E and policy institutions in developing countries.

Recommendations:

- Increase or sustain long-term core donor support for the CGIAR and Feed the Future Innovation Lab (IL) systems. Greater weight should be put on ensuring that funds to CGIAR and IL systems directly contribute to strengthening the capacity of national partner agricultural institutions in developing countries. Involving national partner institutions as grant co-awardees and co-directorships would be a concrete first step in this direction. Doing so will require that CGIAR and IL prime awardees are rewarded and held accountable for building the capacity of national partners in addition to the achievement of shorter-term outcomes such as introducing a given number of new articles, varieties, or improved management practices generated under the award.

- Scale up and target investments in agricultural R&D initiatives that promote smallholder climate adaptation, sustainable intensification, or have dual benefits for crop yields and the environment. This could include increasing investments to scale up the sequencing and trait mining of genetic material to improve crop and animal varieties to help farmers improve their productivity and livelihoods. CGIAR holds around 10 percent of the world's germplasm – including seeds and other genetic material – in banks across the globe. This rich supply of germplasm is key to developing new crop varieties adapted to climate change, including the development of more productive, nutritious disease resistant local crops that communities rely on for their food security.

  In addition, greater investment in research on improved fertilizer practices and viable alternatives to commercial fertilizers should also be considered. Additional R&D investments to improve animal agriculture (health, nutrition, efficiency) are also essential to improving the nutrition and livelihoods of smallholders. Healthy animals also possess a lower carbon footprint and can support sustainability.

- Encourage developing country governments to make greater investments in their own agricultural R&D&E systems and strengthen the capacities and accountabilities of international, regional, and national agricultural research, development, and extension systems in developing countries. The responses will differ according to country readiness; Kenya and Ethiopia, for example, can build on strengthening their existing national institutions to achieve required responses, while many fragile states may lack such institutions entirely and thus have little ability to respond, at least in the near future. The latter category of countries may therefore rely more on regional approaches to mobilize R&D&E services for national constituencies. Several options can be considered:

  - First, revive support for commitments already made by governments. While almost all African governments have formally committed themselves to allocating 10% of national public expenditures to agriculture under the Comprehensive African Agricultural Development Program (CAADP) launched in Maputo, Mozambique, in 2003, only seven countries (out of over 50) have achieved this outcome (Benin, 2020; Dorosh and Minten, 2020). Ethiopia is one of the few African countries to substantially increase its spending on public agricultural research, which has more than tripled in real terms since 2000 (Dorosh and Minten, 2020). Ethiopia also employs half of Sub-Saharan Africa's agricultural extension workers (Fuglie et al., 2020). Not surprisingly, Ethiopia has enjoyed the highest rate of agricultural growth of any country in SSA since 2000 at 6.0% per year (FAOSTAT, 2021; World Development Indicators, 2021).
  - Secondly, the U.S. government could more effectively leverage developing country government investments in climate-resilient food systems by offering matching funds for developing country governments to support their own national R&D and policy institutes responsible for achieving climate-resilient food systems. This effort could be spearheaded by the DFC.

- In addition, donors can jointly establish with national governments accountability systems to encourage good performance for the use of greater funding of national R&D&E systems in developing countries. While increased funding for national R&D&E is an important requirement for developing climate-resilient local agricultural systems, simply calling for greater spending on agricultural research is unlikely to move the needle on the critical need to build national capacity for agricultural innovation (Lynam et al., 2016; Fuglie et al., 2020). Performance contracts and accountability frameworks led by national governments can generate greater accountability for the funds allocated for national climate adaptation efforts.
- Finally, much can be learned from a detailed stocktaking of past efforts to promote technical innovation on smallholder farms to guide U.S. government efforts. A detailed examination of which policy or organizational management reforms are most needed to improve the coordination between and effectiveness of international and national agricultural research and extension systems is warranted (Lynam et al., 2016).

RECOMMENDED FOCUS AREA 2:

Strengthening national tertiary education systems in developing countries to increase the pipeline of well-trained agricultural scientists

Achieving sustainable and resilient food systems requires continuous technical and policy innovation in response to multiple ongoing shocks and stressors; adaptation is a continuous process. The level of human capacity in any country is primarily determined by the strength of its own national educational system. Resilient agrifood systems require sufficient capacity in government ministries and agencies to respond effectively to shocks and stressors. National capacity to undertake scientific crop and animal research in most developing countries is greatly affected by the capacity of nations' agricultural higher education systems. In most developing countries, national universities contribute by far the greatest number of scientists engaged in government ministries, national agricultural R&D organizations, and extension systems. Moreover, workers graduating from national universities also influence the quality of the rest of their countries' workforces through the training that they provide to others – in primary and secondary schools, agricultural training colleges, technical and vocational education training schools (TVETs), public sector jobs, civil society, the private sector, and households. So even though most people in developing countries do not personally attend their national universities, their skill sets are indirectly influenced by those who do.

A recent World Bank study found that a one-year increase in average tertiary education levels would raise annual GDP growth in Africa by an estimated 0.39 percentage points and eventually generate up to a 12% increase in GDP (Darvas et al., 2017). For these reasons, upgrading the performance of national universities will be fundamentally important to enable the local workforce to effectively contribute to climate-resilience and general development of agrifood systems.

Recommendations:

- Strengthen the capacities and accountabilities of international, regional, and national agricultural research, development and extension (R&D&E) systems in developing countries. Stronger coordination between CGIAR, international and local universities, including collaborations in research and capacity strengthening activities, could enable national agricultural research systems (NARS) and extension systems to more effectively promote climate-resilience.

- Support initiatives to strengthen agricultural universities, training colleges and TVETs in developing countries. The performance of national R&D&E systems is strongly dependent on having competent scientists and managers. Achieving resilient food systems requires generating a steady stream of well-trained local professionals to raise the performance of the public and private sector organizations in which they work. Because food systems function according to the capacities of the individuals engaging in these systems, human-capacity development will be required to generate more climate-resilient food systems in developing countries.

- U.S. programs can focus more on building individual and institutional capacity in developing country R&D&E systems. The U.S. government has much to contribute here. It can tap upon its world-class university land-grant system to support developing countries' national agricultural higher education systems to produce a steady stream of trained scientists and policy analysts to become more capable of meeting the evolving challenges related to development and climate resilience.

- Expand support to scale up the International Agricultural Education Fellowship Program (formerly AgriCorps), allowing for its introduction into additional countries to support local extension efforts.

RECOMMENDED FOCUS AREA 3:

Expanding weather and early warning information services

Investments in early warning systems help countries anticipate, mitigate, and cope with forecasted shocks. Weather shocks often affect many countries at the same time. Hence, regional systems may be a cost-effective approach for investing in climate data and knowledge systems to support national early warning systems.

Recommendations:

- Strengthen the performance of national and regional early warning systems and the coordination between them, leveraging the U.S. government's President's Emergency Plan for Adaptation and Resilience (PREPARE), which, among other priorities, aims to work with partners to strengthen climate information services and early warning systems. CGIAR should also be funded to support regional weather and early warning systems to enable millions of smallholder farmers to effectively anticipate and respond to impending climate-related shocks and stressors. USDA, USAID, and U.S. universities could lend their expertise to contribute through such initiatives. Pan-African development organizations such as the African Development Bank could co-invest in these efforts.

RECOMMENDED FOCUS AREA 4:

Mobilizing the investment capital required to create climate-resilient agrifood systems

Public financing is needed to encourage a faster rate of investment in public goods that support climate-resilient agrifood systems, including transport and communications infrastructure, irrigation, community wells and pumps, funding for agricultural R&D&E to develop and disseminate improved stress-tolerant seed varieties, farmer management practices to improve soil health conditions for the varied topographies in developing countries, etc. Public finance is also needed to strengthen local capacities for generating knowledge, such as national agricultural universities, training colleagues, and as well as technical vocational education and training (TVET), which provides knowledge and skills for employment. Faster progress in securing the needed financing for these national and regional investments will improve the enabling environment and thereby encourage a faster rate of private investment in agrifood systems.

USAID's Bureau for Resilience and Food Security is currently collaborating with national governments and policy analysis units to develop and implement the Comprehensive Africa Climate Change Initiative (CACCI) to address challenges to food systems caused by the growing demands for water, energy, and natural resources. CACCI is also designed to assist national governments to develop approaches for fulfilling their nationally determined contributions (NDCs)to greenhouse gas reduction as per the Paris Agreement mandates. U.S. government and research institutions could meaningfully inform and guide the CACCI process in its efforts to develop metrics of household and community vulnerability and resilience, inform the design of or operationalize existing national adaptation plans (NAPs) submitted under the Paris Climate Change agreement, support governments in their preparation of detailed investment plans associated with achieving economic growth targets while reducing GHG emissions to target levels, and assist national and regional organizations to monitor and evaluate their implementation.

Recommendations:

- USAID should continue to collaborate and support the CACCI process and strategy launched under the auspices of the African Union (AU) to mobilize investment capital and a strategic response to address the challenges posed by climate change.
- In addition, the U.S. government should utilize PREPARE to fund agriculture-related infrastructure that supports climate-resilient agrifood systems, including transport and communications infrastructure, irrigation, community wells and pumps, and agricultural R&D&E.
- Encourage public-private partnerships through the Foundation for Food & Agriculture Research (FFAR) to increase outside investments in agricultural research and development. The private sector has an important role to play, and U.S. agencies, including USAID, USDA, the National Science Foundation (NSF), Department of Defense (DoD), and the U.S. International Development Finance Corporation (DFC), can utilize FFAR as their foundation to leverage non-U.S. government funding for climate-smart agriculture research, similar to the way the CDC and NIH-related foundations enable strategic partnerships with the private sector in health. FFAR has been successful in building research consortia, bringing $1.40 in non-government matching funds for every government dollar spent, and has more than 500 partners in the agriculture space funding solutions for commercialization. FFAR could bring matching funds to national governments, providing an incentive for more local investment in NARS research.

RECOMMENDED FOCUS AREA 5:

Supporting locally led approaches and policy analysis to improve the enabling environment for climate-resilient investments

Governments need to make it attractive for private businesses – small, medium, and large – to invest in their countries' food systems because it is these firms that provide crucial services to farmers that make it possible for them to move to more resilient and sustainable food systems. A key role of the government is to enact and implement policies that encourage private investment, innovation, and competition in developing country agrifood systems – recognizing that both informal small firms and large agribusiness firms are all needed. Smallholder farmers and consumers still rely greatly on the informal parts of food systems in Africa, Latin America, and Asia. Regulatory barriers that hinder the private sector's access to land, finance, inputs, and other relevant requirements for establishing, building, and nurturing agri-businesses need to be identified, revised and/or eliminated. Governments are encouraged to create incentives for private sector participation and remove relevant tariff and non-tariff barriers. Land ownership and land-use policies, fiscal, monetary, trade and competitiveness policies, as well as private sector regulation are some specific areas of reforms required to promote access to financing and agricultural inputs.

Building strong national policy research institutions is an important priority for enabling national governments to develop home-grown, nationally embraced climate-resilient food systems policies and plans. Such institutions is can be effective with national governments in ways that international research teams cannot. Working closely with governments, they can improve the enabling environment and thereby provide the incentives for the science and associated financing and investment to follow.

The African Continental Free Trade Area (AfCFTA) is a prime example. This initiative has been led by the African Union to encourage greater intra regional trade of agricultural products. Many national governments have sought technical assistance from locally led policy units (including at national universities) to guide governments on how to respond. AfCFTA has great potential to promote climate-resilient food systems in a number of ways. First, it will expand the market for local producers, encourage competition and efficiency in food production and marketing and promote investments in resilient and productive new technologies and practices on existing farmland. Second, it will encourage new private investment by small, medium, and large-scale agribusiness firms, expanding employment and diversifying the labor force into off-farm stages of the food system and non-farm economy; this growth and diversification is itself a powerful contributor to resilience in food systems. Third, the expansion of intra regional trade will reduce food price volatility associated with local weather shocks by encouraging shortfalls in some areas to be relieved by trading surplus production from other areas. Drought affected areas can mobilize food supplies from neighboring countries instead of the world market, and countries experiencing surpluses can sell into a larger more stable regional market. This effort should be accompanied by government investments in transportation and communications infrastructure to lower the costs of food trade between African countries. AfCFTA is an important policy mechanism that is now available to facilitate more effective responses to climate change.

Recommendations:

- Strengthen the capacities of national policy analysis organizations to guide and inform local agricultural policy processes. To guide this process, draw from the growing literature on best practices for strengthening the capacities of national agricultural policy analysis units (e.g., Jayne et al., 2019).

RECOMMENDED FOCUS AREA 6:

Facilitating inter-ministerial coordination to enable holistic policy and programmatic responses to climate change

The challenges facing developing country food systems are complex and multi-dimensional – most of them cut across government ministries and agencies. Implementing holistic responses to climate change in developing countries hence requires a platform for inter-ministerial coordination, which is currently absent in many countries. An inter-ministerial platform for responding to climate change can integrate multiple stakeholders' views into policymaking to build broad ownership and support for national climate adaptation policies and programs. Regional and continental development organizations can also support knowledge development and consensus building to advance solutions to address chronic food systems resilience and sustainability problems, especially if they are also supported by external donors to do so.

Recommendations:

- Support the development of platforms for intergovernmental coordination in responding to climate change and supporting climate resilience.

CONCLUSION

Developing countries need more sustainable and resilient food systems that efficiently and reliably deliver needed food to their rapidly growing populations while conserving water and energy, minimizing pollution, and preserving forests, grasslands, and the ecosystem services that they provide.

Technical change, employing both indigenous knowledge and modern science, is required to help developing countries mitigate the impacts of climate change by reducing emissions and promoting more environmentally sustainable food systems. Traditional systems that served local communities well in the past may become ineffective under stress from the combination of rapid population growth, acute land scarcity, and climate change.

The relative importance of mitigation and adaptation varies by region. In some developing regions that already contribute a sizable share of the world's GHG emissions, actions to mitigate climate change are crucial. In other developing regions, adaptation is the clear priority. For example, Sub-Saharan Africa accounts for only 1% of the world's GHG emissions; hence efforts to reduce SSA's GHG emissions may be costly while contributing little to reducing the world's GHG emissions. This report has focused on adaptation measures to make developing country agricultural systems more sustainable and resilient in the face of climate change.

While technical change throughout developing countries' agrifood systems are needed, technical innovation is particularly important on smallholder farms. In Sub-Saharan Africa, for example, population growth and urbanization has led to rapidly rising food imports, which currently stand at $53 billion per year. Most of the other stages of African food systems (e.g., input supply chains, aggregation, farm storage, wholesaling, transport) cannot grow unless the production base also expands; there is a symbiotic relationship between expanded production of domestically produced food and new investments in agri-input supply, agricultural advisory services, local crop assembly and wholesale trading, rural processing, agricultural finance and insurance, etc. Fortunately, there is great potential to expand investment, innovation, and employment throughout developing countries' agrifood systems if farm production and marketed output can be obtained from existing farmland (i.e., productivity growth), which will catalyze private investment throughout global agrifood systems and contribute to the economic transformation.

Achieving these outcomes will require rapid progress on three fronts simultaneously: **(1) improving the stability of crop yields and animal production in response to extreme weather events; (2) raising farm productivity growth on existing farmland; and (3) conserving scarce natural resources (especially land, water, and energy), preserving the environment (forests, grasslands, biodiversity), and protecting the ecosystem services that they provide.**

Achieving all three of these outcomes require continuous technical innovation throughout developing countries' agrifood systems, with a particular focus on the millions of smallholder farms that employ the majority of these countries' populations. The foundations of a sustainable and climate-resilient food system will require progress on many fronts:

- Strengthening institutions – both internationally and in developing countries – responsible for developing and adapting new technologies and practices for the wide range of farming conditions in the developing world, to enable global food demand to be met via productivity growth on existing farmland rather than area expansion onto the world's remaining forests and grasslands;
- Improving policy and enabling environments that incentivize the private sector (which includes millions of smallholder farmers and traders) to make climate-smart investments in the various stages of agrifood systems;
- Inter-ministerial coordination, recognizing the multifaceted decisions required across many national ministries and departments to make sustained progress;
- Creating and mobilizing sufficient funds for land set-asides and conservation areas to protect biodiversity that contributes to planetary resilience and sustainability;
- Supporting international coordination and agreement on how natural resources (e.g., water and air) are to be allocated and shared;
- Bolstering programs that anticipate and respond to emerging new diseases and pests affecting crops and animals, with a special focus on vulnerable regions increasingly affected by extreme weather.

U.S. government programs are already supporting many of these activities; however the U.S. government could further enhance its contributions by supporting sustainable approaches that build local capacities to carry out activities by national governments, universities, R&D organizations, and policy institutes. In some cases, this may entail (a) putting host-country institutions in the lead, supported by international expertise; (b) substantive activities being defined by communities and local governments to build local ownership; and (c) taking a systems approach to climate-resilient agriculture, which may entail support for strengthening national university systems to raise the quality of the local labor force engaged in public and private sector activities and thereby increase the payoffs to most other kinds of investments in building sustainable food systems that are resilient to the effects of climate change.

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