Report

Catalyzing Innovation: Scaling Solutions *for* Resilient Agriculture

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1

Executive Summary

The global food system faces significant challenges stemming from its increasing vulnerability to extreme weather events, threatening agricultural productivity and food security. The agriculture sector is also a major source of emissions, exacerbating the situation.

As a response, the public and private sectors are innovating and developing new technologies to address these challenges. Moving along the innovation cycle — from research and development to scale-up to ensure adoption of new technologies at the farmer level — is a critical step in these efforts.

The topics of this report were discussed with various stakeholders at an event organized by the International Finance Corporation (IFC) of the World Bank Group in conjunction with the Innovation Commission for Climate Change, Food Security, and Agriculture (IC), and the Market Shaping Accelerator (MSA), both of the University of Chicago, in February 2025. The event highlighted how policymakers, development finance institutions (DFIs), and the private sector can collaborate to develop and scale innovations to address the challenges of resilience, food security, and agriculture.

While ongoing research and development (R&D) on technologies in this field is extensive, the event discussed three technological innovations to showcase how the IC, MSA, and IFC can collaborate with partners to operationalize areas of alignment and identify new opportunities:

- **Reducing Livestock Methane Emissions:** Greenhouse gas (GHG) emissions in the agrifood system are significantly driven by the livestock (ruminant) sector. A large share of these emissions can be attributed to middle-income countries (Sutton et al., 2024). Innovations that reduce methane emissions in ruminants can be an important component of the global response to climate change. Monogastric animals have one stomach and produce minimal amounts of methane in their production systems. Promising solutions in this field include feed additives and nutritional supplements already available, or methods like selective breeding and innovative vaccines at an earlier research stage. Livestock producers often lack sufficient incentives to invest in technologies to reduce emissions partly because livestock and other agriculture systems do not price greenhouse gas emissions in final products. Commercial incentives for R&D on methane-reducing technologies fall far short of the social value of these innovations. Some of the emerging technologies to reduce livestock methane emissions would have to be adapted to the extensive production systems typical in low- and middle-income economies. As environmental and sustainability issues become more acute and consumers more aware, livestock investments have come under closer scrutiny from civil society organizations (CSOs) with direct implications for investment decisions.
- **Climate-Resilient Crops:** The increasing prevalence of extreme weather events is hurting crop yields, which are already declining in Sub-Saharan Africa. Developing and scaling climate-resilient crops would help maintain yields and extend the area of staple or strategic crops where conventional varieties either fail to grow or generate poor yields. The potential economic benefits of these crops are significant, potentially saving billions of dollars. The improved varieties include those with shorter gestation periods that maximize production cycles and reduce production costs, pest-resistant varieties that reduce the need for pesticides, and heat-resistant and drought-tolerant varieties that increase resilience against climatic shocks. Despite the benefits, seed systems development in low- and middle-income countries (LMICs) face challenges, and adoption of improved varieties remains low. This is, in part, due to farmers' limited access to quality seeds, which stifles public and private investment in seed enterprises and seed systems' R&D. Farmers also may not sufficiently value such traits before experiencing their benefits, and firms may not be able to charge enough to make R&D investment attractive, especially for seeds that farmers' reuse and share.
- **Microbial Fertilizers:** These use bacteria to facilitate the absorption of nutrients necessary for plant and soil health. These fertilizers can regulate soil-nutrient dynamics and promote soil-nutrient cycling by improving microbial community changes. This process helps restore the soil ecosystem, which in turn promotes nutrient uptake, regulates crop growth, and enhances crop resistance to biotic and abiotic stresses. Microbial fertilizers could reduce emissions from synthetic fertilizers, generating billions of dollars in social benefits (Bomfim et al., 2021). New and emerging technologies aim to expand their application to other staple crops, further decreasing the need for synthetic inputs. These fertilizers have also proven highly effective in boosting productivity in legumes, enhancing biological nitrogen fixation (a process in which nitrogen gas from the atmosphere is incorporated into the tissue of certain plants), and increasing yields by 10% to 30% in crops like soybeans, chickpeas, and common beans (see diagnostic on microbial fertilizers below). However, their effectiveness varies across soil types and settings, leaving issues that need to be addressed before scale-up can accelerate. Concurrently, the use of animal manure (e.g., global animal manure production amounted to 131 million metric tons of nitrogen in 2022, according to FAO estimates (2024)) should be (and often is) used to fertilize arable lands by improving soil structure, diversity (e.g., soil microbiota), and fertility.

The Catalyzing Innovation event identified how advance market commitments (AMCs) could promote climate-resilient agricultural innovation. AMCs involve funders committing to subsidize the use of a yet-to-be-developed innovation. This approach allows funders to attract investment and expertise from different private sector actors. In the case of agricultural innovations such as climate-resilient crop varieties, the subsidies could be linked to adoption of improved varieties measured in farmer surveys and by using DNA fingerprinting. This would provide a market test — incentivizing firms to develop technically sound and adoptable innovations.

Scaling these technologies will require partnerships across public and private sectors to bring appropriate financing instruments, as well as creating an enabling environment to facilitate adoption. This paper is intended as a discussion starter on the state of innovation and financing required to achieve scale-up and adoption. Diagnostics on the state of play in the three areas of innovation are presented, together with a chapter on the role of governments, development finance institutions, and the private sector in financing the technologies along the innovation cycle. Financing the development and scaling of agricultural innovations that promote food security and sustainability requires tailored solutions. Innovations differ regarding their evidence base and maturity, potential social and environmental consequences, as well as financing needs, and need to be adapted to country-specific contexts. The roles of DFIs, donors, and the public and private sectors remain topics for further discussion.

2

Introduction

The global food system faces pressing challenges that threaten food security, sustainability, and equitable access. This is compounded by the interlocking challenges of rising temperatures, unpredictable weather patterns, and extreme events disrupting agricultural production such as droughts and floods.

Economic and social inequalities also hinder progress, as millions of people, particularly in low-income countries, continue to face food insecurity. Inefficiencies in food supply chains, food waste, and infrastructure constraints exacerbate the problem. Food insecurity is most acute in parts of Sub-Saharan Africa, Asia, and the Middle East, where poverty, extreme weather events, political instability, and inadequate infrastructure exacerbate limited food production capacity.

How can policymakers, development finance institutions, and the private sector best address these challenges? What are the constraints and challenges to the development, scaling, and adoption of agricultural innovations aimed at promoting the resilience of the agri-food system to extreme weather, while enhancing sustainable agriculture and food security in developing countries?

Among various solutions addressing challenges linked to resilience and food security, IFC, IC, and MSA are examining the current state and opportunities of climate-smart agricultural technologies in three areas of innovation. In particular, solutions discussed are those that (i) contribute to reducing methane emissions from the livestock sector, which are a significant source of GHG emissions, (ii) support food security by introducing climate-resilient crop varieties, and (iii) utilize microbial fertilizers to reduce the usage of synthetic fertilizers, which are a source of GHG emissions and environmental degradation.

Clearly, access to finance is critical for both agricultural technology developers and adopters. Funding for innovation aimed at promoting resilience continues to rely on partnerships to support a conducive enabling environment. DFIs such as the IFC can leverage their convening power to support the development and sustenance of an enabling (policy) environment that promotes growth of agricultural innovations and private sector investment through policy advocacy and public-private partnerships (PPPs).

As DFIs partner with traditional and nontraditional sources of blended finance, such as family foundations and others, the scope and number of facilities supporting innovative approaches to food security will continue to grow.

The private sector plays a pivotal role in scaling out (transferring innovations across geographies) and scaling up (increasing the number of users, speed, etc.) in emerging markets. DFIs can be a catalyst for these investments. As the technologies move along the innovation cycle, the roles of the public and private sectors are subject to further discussion.

The paper is organized as follows: Section 3 introduces the unique challenges and solutions that emerge in financing climate-smart agricultural innovations, highlighting the roles and interrelations of DFIs, the public, and the private sector. Sections 4-6 present specific diagnostic notes for innovations on microbial fertilizer, livestock methane emissions reduction, and climate-resilient crops. Each diagnostic note describes the opportunities to scale these innovations, the current landscape for each, and specific constraints, and how policymakers, DFIs, and the private sector can help overcome these constraints. The final section features discussions on forward-looking solutions and prompts to stimulate conversation.

3

Financing Resilient Agricultural Innovations to Scale: Synergy Between Policymakers, DFIs, and the Private Sector

1. Background

The global agri-food systems face many challenges to scaling agricultural innovations that address resilience as well as food and nutrition security, which require a balance between extensification and intensification of production to enhance sustainable agriculture. Changes to weather patterns pose significant threats and opportunities to agricultural productivity (Sutton et al., 2024; Yang et al., 2024). This is compounded by the fact that agriculture is the third-largest source of anthropogenic GHG emissions after the energy and industrial sectors (IPCC, 2023). The challenges can be better addressed through adaptive and/or mitigative innovations such as climate-resilient crop varieties, microbial fertilizers and biostimulants, and livestock methane emissions reduction practices and technologies. However, there are binding constraints to development, adoption, and scale-up of these innovations in emerging markets. These constraints include lack of finance, market failures such as dysfunctional markets, misaligned incentives for innovation, weak policy and regulatory environment, lack of awareness and misinformation, and socio-cultural barriers, among others. This brief focuses on how policymakers, DFIs, and the private sector can address the challenges to the development, scaling, and adoption of agricultural innovations aimed at mitigating and/or adapting to climate change, while enhancing sustainable agriculture and food security in developing countries. Later sections discuss the current landscapes of the three highlighted innovations, as well as related constraints and challenges.

Access to finance is critical for both agricultural technology developers and adopters (Llewellyn and Brown, 2020; Mwangi and Kariuki, 2015; Feder et al., 1985) at different stages of the innovation lifecycle (Figure 1). For developers, there are three major types of players, namely, (1) the leading multinational players, typically with access to capital; (2) local (national) or regional players, including established firms and startups, typically needing access to venture, risk, or patient capital and early-stage equity, and (3) public sector research institutions. The financing instruments needed by each type of player can differ remarkably. For instance, while the local or regional developers may require grants, concessional or blended finance with long-term tenors[1] and assistance at both innovation development and deployment stages, the multinational developers may require an AMC — a pull mechanism that encourages scaling — to incentivize them to address market failures. For adopters in emerging and frontier markets during the duplication-at-scale stage, they are often smallholder farmers who are severely constrained by access to finance to adopting a new technology. Thus, such adopters may need limited subsidies or grants at the early-adoption phase (e.g., see Omotilewa et al., 2019), a derisking facility or credit guarantees to technology distributors to provide credit access to farmers or farmer organizations, and access to banking via digital wallet systems or mobile money, coupled with access to extension and agronomic support services. Thus, different stakeholders are impacted differently by access to credit at different stages of the innovation lifecycle.

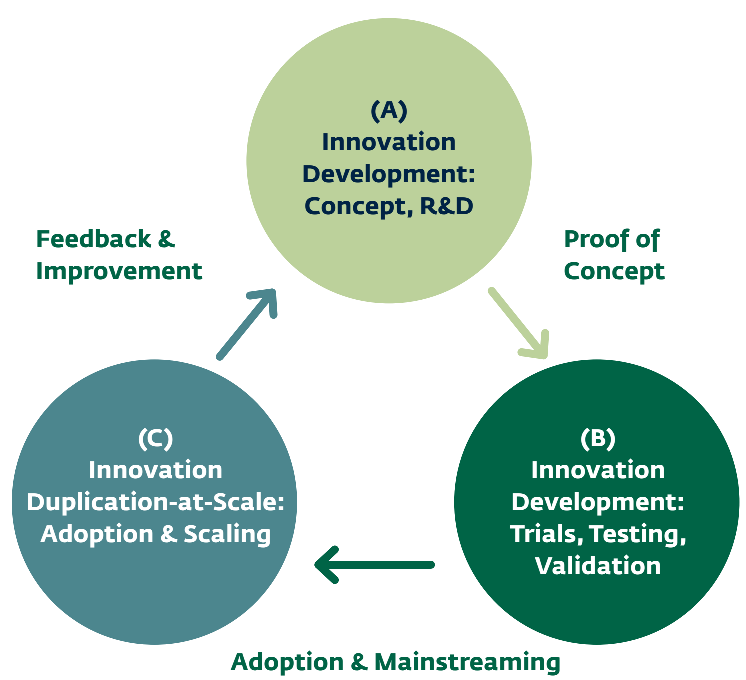

Figure 1: Innovation Lifecycle 3Ds (Development, Deployment, and Duplication-at-Scale)

[1] Blended finance refers to "One of several tools to mitigate risk and facilitate financing for private sector-led projects that have the potential to generate social benefits. Blended finance combines concessional financing—loans that are extended on more generous terms than market loans— and commercial funding."https://ieg.worldbankgroup.org/blog/what-blended-finance-and-how-can-it-help-deliver-successful-high-impact-high-risk-projects

The challenge of agricultural credit constraint is linked to multiple risk factors. These can be categorized into sector-specific issues such as seasonality, high price volatility, and informality. Supply-side issues include limited access to financial services, unfavorable lending terms, and lack of insurance markets. Demand-side challenges include limited financial literacy, lack of collateral and credit history, risk aversion, and gender norms and roles. Policy and regulatory barriers like land policy, agricultural taxes, collateral mandates, and high interest also limit agricultural credit (Komarek et al., 2020).

Furthermore, the financial sector in some countries lacks the level of sophistication and access to data required to underwrite risks associated with multifaceted agricultural activities and stages of the production processes. There are technological innovations and solutions (such as drip irrigation) that can help farmers and improve resilience that are not widely adopted, partly due to a lack of access to finance. In addition, agricultural production in many LMICs is dominated by smallholder farmers. These farmers often face resource-constraints and limited access to markets, making them hesitant to lock-in scarce resources to improve production. Financial institutions are reluctant to finance the smallholder farm sector because of their inherent risks and limited commercialization. Development partners can support increased commercialization of small farms by facilitating farmers and farmers' organizations to increase their capacities to scale-up operations and financial acumen to levels that make them bankable.

Additionally, most smallholder farmers lack the skills to farm as a business and do not keep records of farm operations. Poor financial records and incomplete property rights, such as lack of formal land titles, prevent farmers from accessing collateralized financing. Evidence from West Africa, for example, shows agri-finance for smallholders face both supply-side constraints, such as farmers lacking bankable collateral (e.g., land titles) needed by financial institutions, as well as demand-side constraints, including farmers' risk aversion, high transaction costs, and information asymmetry (Balana and Oyeyemi, 2022). These profound challenges require institutions to work together to deliver on promises to fight food and nutrition insecurity (Sustainable Development Goal 2, Zero Hunger). This paper posits that addressing the challenges require: i) leveraging partnerships to derisk investments and support R&D from innovators (stage A of the innovation lifecycle), ii) financing for testing and demonstration of new innovations (stage B of the innovation lifecycle), and iii) financing smallholder adopters, providing technical assistance and agronomic support services, and developing supply chain infrastructure (stage C of the innovation lifecycle). The following section provides an overview of how policymakers, DFIs, and the private sector can work together to scale adoption of climate-resilient agricultural innovations.

2. Trends in Financing Innovations

Financing solutions differ greatly between stages of the innovation cycle (see Figure 1) due to the level of risk and uncertainty inherent in each stage. As a result, actors involved in financing agricultural innovations and their roles are diverse. Financing for the development and incubation of agricultural innovations in LMICs has come primarily from bilateral and multilateral donors, philanthropic organizations, and public funding (Dalberg Asia, 2021). While boundaries are fluid, actors can be categorized by their importance in the innovation cycle.

At the earliest stage, R&D funding is primarily provided by the public sector, some DFIs, and private multinationals. Agricultural research requires far-sighted investments because of its slow nature and the benefits or returns that accrue over long periods. In developing countries, the public sector is the primary source of funding (e.g., via agri-research institutes), while advanced countries with conducive policy environments (e.g., institutions protecting intellectual property rights) also host for-profit private sector companies that finance innovation in the agri-sector. At this pre-competitive stage, collaboration between public and private actors plays a significant role. Initiatives like the Global Research Alliance and the CGIAR bring together stakeholders to facilitate R&D. For instance, the World Bank (2023) is supporting research institutes in Senegal to develop innovations and policies that encourage development of climate-resilient seeds and improved animal breeds.

Over half a century, investments in international agricultural R&D via the CGIAR were about US$60 billion (2016 dollars), with a benefit-cost ratio of 10:1 (Alston et al., 2022). This funding largely came from the public sector and focused on low- and middle-income countries. Analysis has shown that privately financed R&D has been centered out of developed countries, but a significant portion of the spend has been on products marketed in developing countries (Fuglie, 2016). The largest investments in agri R&D have been in staple commodities, such as corn, soy, and oilseeds. Since 1980, the share of agrifood R&D performed by the private sector has increased, especially in upper-middle-income countries (Alston & Pardey, 2021).

At the deployment and piloting stage, philanthropic organizations and donors are an important source of financing. For example, the nonprofit Gates Ag One, funded by the Gates Foundation, acts as an accelerator for ag-tech innovations benefiting smallholder farmers. It provides grants to research initiatives like ENSA, which aims to reduce the volume of fertilizers used by improving nutrient uptake of food crops.

At the adoption and scaling stage, development financiers and private investors such as venture capital firms emerge as a funding source, alongside other development partners addressing demand-side constraints. For example, the SEED initiative supported by UN Environment, UNDP, and IUCN, works with agri-entrepreneurs to grow and scale innovations at the MSME level.

Given the need for continued innovation and scale-up to address challenges such as extreme weather, the private sector has a critical and expansive role to play using a larger pool of financial instruments such as risk guarantees including through blended finance, private equity, and debt financing. All of these can support various stages of the development, adoption, and scaling process.

3. Funding Climate Resilient Innovation in Agriculture

Funding for innovation aimed at addressing resilience to extreme weather continues to rely on partnerships to support a conducive enabling environment. DFIs such as IFC can leverage their convening power to support the development and sustenance of an enabling (policy) environment that promotes growth of agricultural innovations and private sector investment through policy advocacy and public-private partnerships (PPPs).

- **Policy Advocacy:** DFIs and development organizations can work more closely with policymakers to formulate evidence-based policies that encourage the incubation and scale-up of agricultural innovations. This includes lobbying for limited amounts of subsidies, including from developed countries that lead on innovation, tax incentives during early-adoption phases, and regulatory frameworks that facilitate the development and scaling of innovations. Since subsidies tend to be either short-lived or face increasing pressure to be cut, subsidies that support scale-up for smallholders may need to focus on helping farmers to break out of subsistence and low-productivity activities, and adopting technologies that support commercial viability, increased market linkages, and integration with broader markets. In some cases, subsidies could be repurposed from existing programs, some of which may be environmentally harmful, e.g. subsidies that incentivize the overuse of fertilizer.
- **Promoting Public-Private Partnerships:** DFIs can foster PPPs that bring together various stakeholders, leveraging synergies between government, private companies and financial institutions, nongovernmental organizations, and farmer organizations. The partnerships can support agricultural financing and policy reforms to incentivize greater private sector investments. In agricultural value chains, IFC and the World Bank Group have significant experience in helping to expand and deepen market linkages between smallholder farmers, agricultural intermediaries such as cooperatives and last-mile retailers, and larger food companies and financial institutions that can provide the kind of scale and access to technologies and finance many farmers cannot access directly. Guaranteed offtake agreements over longer time periods would also enable farmers to make investments that require longer payback periods, thereby increasing productivity and overall production, particularly in markets with limited risk-mitigation policies for smallholders (Goedde et al., 2019).

IFC and other DFIs can leverage partnerships with the public and private sectors and civil society to bring additional financial instruments. Funding instruments deployed to support agricultural innovations include the following:

- **Derisking Investments, Including Blended Financing Solutions:** DFIs can help derisk investments by providing guarantees and other risk mitigation instruments to incentivize private sector investment in agricultural innovations. For example, the Multilateral Investment Guarantee Agency (MIGA) of the World Bank Group committed recently to provide guarantees of approximately $1.2 billion to support a climate-smart agriculture project in Brazil. The guaranteed loan will ensure access to financing for micro-, small-, and medium-sized farms that use conservation agricultural methods like no-till farming. The African Development Bank introduced the Africa Fertilizer Financing Mechanism (AFFM) in 2015, a special fund targeting innovative solutions in the fertilizer sector in Africa, such as providing credit guarantees to wholesalers, distributors, or retailers of fertilizers.

  IFC leverages blended finance, which combines public and philanthropic funds to derisk investments and attract private capital in cases where risks are higher or expected commercial returns limit private sector participation. IFC, for example, manages several blended finance facilities related to agri-food systems, including the Inclusive Agritech Facility (IAF), the Private Sector Window of the Global Agriculture and Food Security Program (GAFSP), and the Canada Facility for Resilient Food Systems (FRFS). GAFSP supports innovative financing aimed at increasing sustainable agriculture and the commercial potential of MSME agribusinesses and smallholder farmers by integrating them into the local, national, or global agri-value chains in IDA countries. FRFS supports investment and advisory projects related to climate-smart agriculture and agritech, gender, and nutrition.

  In other cases, other blended finance instruments such as local currency financing allow DFIs like IFC to invest by derisking the typical foreign exchange exposure that prevents firms from borrowing from financiers, with risks particularly acute in fragile and conflict-affected states. For example, with support from the IDA Private Sector Window, IFC offered local currency financing to Johnvents, a cocoa offtaker and processor in Nigeria.

  As DFIs partner with traditional and nontraditional sources of blended finance, such as family foundations and others, the scope and number of facilities supporting innovative approaches to food security will continue to grow. With broader partnerships, DFIs can help bridge funding gaps and deepen private sector investment.

- **Early-Stage Equity Financing:** IFC and other DFIs also provide early-stage equity financing to innovators, albeit at a smaller scale than mainstream debt financing. For instance, IFC invested in SP Ventures, a Brazilian venture fund focused on agtech startups. Through SP Ventures, IFC can invest indirectly in companies working on biological fertilizers and pest control, like Promip or Genica. The derisking that blended finance provides can support deployment of early-stage equity and the growth of bankable climate-smart innovations. IAF, for example, aims to derisk

IFC's early-stage equity investments in agriculture technology companies in South Asia and to develop solutions for smallholder farmers by investing in private sector-led agriculture technology and business models that can be deployed at scale. In SSA, IFC leveraged a first-loss guarantee from GAFSP to invest in agCelerant, an agtech in Senegal, helping smallholders access finance, improve productivity, and strengthen supply chains. The project would have been challenging for IFC to finance without additional derisking from GAFSP given the highly innovative nature of some of the technologies and the roll-out in a new environment. IFC was able to invest equity, one of the most demanded forms of finance, despite the risks.

- **Debt Financing:** DFIs can address the lack of medium- to long-term finance, which is crucial for investments that aim to roll out large-scale adoption of emerging technologies. Some of these investments support mainstreaming of tested technologies such as climate-smart irrigation, production, and logistics. This type of financing is limited from commercial banks due to high risks from potentially uncertain rewards and is deployed by DFIs typically at later stages of the innovation cycle (Rockefeller Foundation, 2024).

The private sector plays a pivotal role in emerging markets in scaling out (transferring innovations across geographies) and scaling up (increasing the number of users, speed, etc.). DFIs can be a catalyst for these investments through these mechanisms:

- **Supporting Innovation and Demonstration Projects:** DFIs fund projects that link strong agribusiness companies with smallholders. These projects can improve coordination, disseminate new techniques and technologies, and enhance market access. For instance, IFC's investment in and ongoing engagement with the management of Omnivore III, a venture capital fund specializing in Indian agtech, serves as catalyst to developing farm-ready agtech solutions aimed at the smallholder farmer ecosystem of India. The project also included blended finance in the form of a first-loss guarantee.[2] The technologies and practices that emerge successfully from Omnivore III will have replication value in other smallholder farm ecosystems beyond India. The World Bank Group is also involved in AgResults, a trust fund that uses prize competitions to incentivize the private sector to invest in development and scaling of agtech innovations.
- **Facilitating Access to Finance via Digital Platforms:** A critical pathway to scale is the use of new digital platforms that enable greater access to finance for farmers and agricultural MSMEs. The platforms lower transaction costs, facilitate timely payments, and build credit history for farmers and MSMEs necessary for formal lending.
- **Technical Assistance:** Stakeholders must be persuaded of the value and efficacy of innovations to ensure broader adoption, particularly with regards to smallholders and MSMEs. Technical assistance or advisory services can help with the transmission of knowledge, tools, and technologies across underserved populations. For example, IFC in conjunction with GAFSP provided a loan package to CIDT, a cotton company in Cote d'Ivoire that sources from smallholder farmers. The investment is accompanied by IFC advisory services that provide training on climate-smart soil and water management practices to smallholders to address intense rainfall, as well as the need to improve soil facing harsh depletion of nutrients and organic matter. The project achieved significant impact by promoting adoption and scaling of such techniques among smallholders.
- **Building Sustainable Supply Chains:** DFIs can support the development by financing essential physical and digital infrastructure such as transport, telecoms, digitalization, irrigation, and storage, as well as providing the technical assistance to aid adoption of best practices.

[2] As per the World Bank Group's Independent Evaluation Group (IEG): "The purpose of a first-loss guarantee is to reduce risk and attract lenders and investors who may be hesitant to participate in a deal because of concerns about the level of risk involved. By offering to cover the first losses, the guarantee provider reduces the risk and increases the confidence of potential lenders and investors." https://ieg.worldbankgroup.org/evaluations/ida-psw/glossary-0.

4

Diagnostic for Innovations to Reduce Livestock Methane Emissions

1. What is the opportunity?

Several innovations in development have the potential to significantly reduce farmgate methane emissions from livestock, which accounted for 8% of annual GHG emissions from 2018 to 2020 (Sutton et al., 2024).

The livestock sector is a key driver of GHG emissions. The largest share of livestock-related emissions comes from production in lower- and upper-middle-income economies. Enteric fermentation from ruminant livestock (a digestive process where microorganisms in the rumen, a specialized stomach compartment, break down plant matter, producing energy and nutrients for the animal, as well as methane as a byproduct) is the largest source of these emissions, accounting for more than two-thirds of livestock farmgate emissions (Sutton et al., 2024). In turn, livestock productivity is adversely affected by extreme weather conditions like heat stress (Polsky and von Keyserlingk, 2017).

This section incorporates input from the Innovation Commission for Food Security, Climate Change, and Agriculture at the University of Chicago and builds on concepts explored in the Innovation Commission Research Briefs (available at https://innovationcommission.uchicago.edu/research_briefs/priority-innovations-and-investment-recommendations-for-cop28/).

Demand for products from livestock is expected to surge. Demand for terrestrial animal products is expected to increase by 20% by 2050 (FAO, 2020). Consumer demand for meat is projected to increase by 80% by 2050 (Nadathur et al., 2017). By the end of the decade, milk output is anticipated to grow by 9% in high-income countries and 33% in low- and middle-income countries (OECD/FAO, 2018).

Reducing methane emissions is an important component of the global response to the interlocking challenges of rising temperatures and extreme weather conditions. Reducing methane emissions by 45% from 2010 levels by 2030 could prevent nearly 0.3 degrees Celsius temperature increase by the 2040s (UNEP, 2021).

Innovative feed additives could reduce methane emissions by up to 26% to 98% (Honan et al., 2021). These additives modify the rumen environment or interfere with methane generation and include algae, lipids, tannins, and other synthetic compounds, like 3-nitrooxypropanol (3-NOP) and the synthetic bromoform-containing compound Rumin8. When added to and consumed with the diet, these additives can alter the chemical reactions that generate methane emissions in an animal's digestive process. Methane production consumes up to 12% of ruminants' gross energy intake, so reducing methane emissions via feed additives could potentially also increase productivity or milk quality by sparing energy in the digestive process and redirecting it toward animal growth and milk production (Alemu et al, 2021; Honan et al., 2021; Melgar et al., 2021) Adding bromoform, a substance found in seaweed, to animal feed has reduced enteric methane emissions by 30% to 50% among grazing beef cattle (Meo-Filho et al., 2024), but further research would determine the safety and health implications for humans and animals. Some feed additives may be challenging to produce at scale, affect output quality, animal fitness, or may pose a toxicity risk that would call for further research before widespread use. Others, like Bovaer ® (3-NOP), are increasingly available in higher-income countries, but still lack regulatory approval and may be unaffordable for most herders in many lower-income countries (DSM, 2023).

Selective breeding and gene editing could also reduce emissions substantially. These innovations could be used by producers that do not regularly use feed systems, such as pastoralists or extensive-system producers. Compared to nutritional strategies, genetic solutions result in long-term progress. Selective breeding for low-methane emission is in early stages of development but could potentially reduce between 11% and 26% of emissions, based on preliminary consultations with experts. Gene-editing technology such as CRISPR-Cas DNA editing and genome-resolved metagenomics could be another tool to reduce methane emissions, allowing for precise changes in ruminant gut microbiomes (Rubin et al., 2022). Further research on these gene-editing techniques could evaluate their potential to reduce methane emissions and assess any effects on human and animal health.

Novel vaccines could achieve similar emissions reductions. Early research suggests that vaccines, including possible mRNA vaccines, can reduce ruminant methane emissions by up to 20% by modifying the gut microbiome, according to expert interviews. One virtue of vaccination is their low recurring costs, since vaccines are relatively cheap to produce (US$1 to $4 per dose) and can be administered when cattle receive routine health vaccinations. However, once an effective vaccine has been developed, it is likely methanogens will develop resistance to it, so the work would continue (DPMC NZ, 2024) .

Advanced farm-management practices, such as improved feeding software, could reduce methane emissions intensity in low-income countries by improving the efficiency of production. Innovations like ration formulation software, which integrates local resources and is adapted for local livestock varieties, could prompt farmers to adopt these practices. In high-income countries, animal diets are often formulated to optimize productivity, which reduces emissions intensity per unit of output. For example, cattle farmers in California reduced emissions intensity of production by 45% relative to 1964, due in part to improvements in genetics and feed efficiency (Naranjo et al., 2020). Besides feed use, farmers can be trained to use other inputs such as land and soil more effectively to increase their productivity and reduce their emissions. A soil conservation training program in Brazil induced farmers to use inputs more intensively, helped them to improve their management and soil conservation practices, and generated private returns of US$1.08 to $1.45 in profits for every US$1 spent on the program (Bragança et al., 2022). IFC has worked with clients to (i) improve waste management by turning animal waste into biofertilizers, (ii) install biodigesters to reduce methane emissions, (iii) reduce feed waste, and other steps such as better livestock management practices.

Further development of these innovations could improve their cost-effectiveness and affordability for wider use. Existing feed additives, like Bovaer®, have to be administered daily, making them impractical for many farmers, especially those whose animals graze in pastures. At US$70 to $95 per cow per year (Hanson, 2024), Bovaer® is also expensive for many farmers absent incentives that would reflect environmental benefits. More research on these additives could determine how long their effectiveness lasts over time.

These innovations could also increase productivity, especially for dairy products, which could in turn reduce emissions by reducing the number of cows. Dairy production in Sub-Saharan Africa is more than five times as emissions-intensive per liter than production in North America or Europe, and cows in the region are only 5% to 7% as productive as their counterparts in North America or Europe (FAO and GDP, 2018). From 2005 to 2015, global dairy emissions were 38% lower than they would have been due to an 11% decrease in emission intensity, primarily driven by productivity improvements in Asia and South America (FAO and GDP, 2019). Increasing milk productivity per animal would reduce the number of cows kept for dairy production under plausible assumptions on price elasticities. IFPRI's IMPACT model projects that improving livestock feed-conversion ratios could result in the largest reduction in emissions relative to scenarios that boost crop yields (Fuglie et al., 2022), aligning with other global model estimates (Valin et al., 2013).

2. What is the current landscape for these innovations?

Feed additives exist on the current market, but are not widely available in low- and middle-income countries. Due partly to high costs and lack of proven productivity benefits to ranchers, adoption has been low even in high-income countries where these feed additives are more readily available and production systems accommodate their use. Most research on these additives has also focused on high-yielding temperate cattle, resulting in a lack of data for breeds indigenous to low- and middle-income countries or crossbred tropical cattle.

Efforts to adjust the gut microbiome — whether by vaccination or via breeding — are far more nascent and unlikely to make it to market for several years. While academic research has suggested that methane vaccination is possible, only a small number of companies are working to develop a methane vaccine and none are near commercialization. Similarly, research on breeding and other genetic techniques is emerging in Ireland, New Zealand, and Canada, but is mostly in early stages.

As with many agricultural innovations, novel agricultural and farm management practices may not be adopted even if they are profitable. While several agricultural practices and improved management can lead to higher productivity and higher income, financial constraints, labor shortages, and lack of information may lead farmers to under-adopt them, as with many agricultural technologies (Suri et al., 2024).

3. What are the constraints to developing and scaling these innovations?

Farmers and ranchers lack sufficient incentives to invest in technologies to reduce their emissions because agriculture systems do not price greenhouse gas emissions in final products. While the benefits of reduced methane emissions would accrue to the entire world, individual ranchers do not have sufficient incentives to bear the costs of products that reduce these emissions, except in cases where consumers or processors pay a premium for verified low-emissions production. Despite the social benefits in terms of reduced emissions likely outweighing these costs, companies are unlikely to invest without a sufficient private return. As a result, commercial incentives for R&D on methane mitigation technologies fall far short of the social value of these innovations. The benefits of innovations in breeding, such as identifying genetic traits to reduce emissions, extend beyond the original breeder to others who did not contribute to its development. Once improved genetic traits are shared or sold, others can use and profit from them without compensating the original innovator, making it difficult for an innovator to recover their investment. While reducing emissions is a global public good, national governments alone are likely to underinvest in mitigation efforts. The development of technologies that yield substantial co-benefits for individual farmers or for national or local governments may make these technologies much more likely to be adopted.

Asymmetric information about the impact of new innovations may also limit incentives for innovation. In many markets, purchasers may be unable to verify the impact of a novel innovation. Without reliable science-based measurement techniques, low-emissions claims on products can increase the risk of so-called green washing. If innovators cannot prove to customers that their product is superior to existing offerings, customers will be unwilling to pay a premium that would allow the innovator to justify upfront investments. Even for established products, buyers may not be certain of the quality of the innovation until after purchasing it, reducing the likelihood of product orders. For instance, a rating platform for artificial insemination services provided by veterinarians in Pakistan increased provider effort and resulted in 25% higher insemination success for farmers without any change in prices paid (Hasanain et al., 2023), illustrating the principle that expanding access to information can improve outcomes by allowing consumers to distinguish between products of varying quality.

4. How can policymakers, development finance institutions (including IFC), and the private sector respond to these constraints?

Governments and philanthropists could incentivize R&D through a range of instruments. Public support could expedite the development and testing phases of these innovations, through either up-front funding or through pull mechanisms that signal to private investors that there will be a future market for technologies that reduce livestock emissions. Pull mechanisms, such as prizes or advanced market commitments, harness the energy and creativity of the private sector to address social priorities (Kremer et al., 2020) by committing to reward the development and adoption of new technologies.

The widespread adoption of existing practices and technologies that lead to direct production gains and increased incomes remains an important component of reducing the productivity gap among producers in low- and middle-income countries and those of high-income producers. Enhanced feeding and nutrition, along with improved animal health and husbandry, form the basis of more sustainable and healthy herds. These practices can significantly boost productivity and appeal to farmers by offering immediate financial benefits. Additionally, they may encourage farmers to be more efficient and reduce their herd size, thereby lowering absolute emissions, and make them more likely to adopt novel technologies.

Private actors could be incentivized to support methane emissions reductions from livestock with additional policy tools. Technologies to reduce methane emissions could generate social value that far exceeds commercial value, but farmers' private incentives to reduce methane lag far behind the social value of methane reductions, creating a role for policy tools, such as incentives, regulations, and tax measures, to stimulate adoption.

By announcing in advance they would adopt a package of incentives, taxes, and regulatory actions to encourage the use of cost-effective technologies to reduce emissions, high-income countries could incentivize and propel innovation by signaling there will be demand for such products. Such a package of policies could kick in when a specified cost-effectiveness threshold — linked to the social value of averted emissions — is reached. Such regulations would presumably apply first to larger producers responsible for most emissions.

A cap-and-trade system for methane is an example of a complementary policy innovation to reduce emissions. Technology-agnostic cap-and-trade systems for methane emissions could allow farmers to choose efficiently among methane-reduction approaches and would create strong incentives for innovators to develop methane-reduction technologies (Parry et al., 2022). However, a cap-and-trade system would require monitoring mechanisms. Any such methane cap-and-trade program would presumably be introduced first in high-income countries and would typically be structured so farmers would be allocated permits in proportion to livestock holdings or emissions.

If a high-income country established a cap-and-trade program for methane, lower-income countries would have considerable incentives to establish their own monitoring systems and enter into agreements with high-income countries to sell emission permits. Assuming permits were allocated based on the initial number of livestock, such trade could result in substantial financial flows to lower-income countries, as producers in high-income countries would have incentives to purchase permits from those in lower-income countries where production is typically more methane intensive per quantity of output, reducing herd sizes in lower-income countries (FAO and GDP, 2018). This, in turn, could potentially reduce over-grazing pressure and farmer-herder conflict (McGuirk and Nunn, 2023).

5.Next steps: Potential path forward

Governments and philanthropists should both make direct investments in R&D and consider other policy tools to accelerate innovation, including market-shaping instruments and a cap-and-trade system.

Direct investments should be considered for R&D activities, including:

1. **Expand testing of new feed additives.** Donors could fund on-farm testing of additives that have promising potential from laboratory results. These trials could involve different breeds, such as those from indigenous to low- and middle-income countries, tropical crossbreeds, and production systems such as extensive grazing systems to assess methane-reduction potential over an extensive period and potential effects on animal health.
2. **Test and expand selective breeding and approaches to edit the genes of the microbes that drive enteric methane emissions from livestock digestive systems.** Further research on animal genetics can improve understanding of which traits in existing breeds are more effective for higher yields and/or lower emissions. Advancing knowledge of microbiome genetic mapping in ruminant digestion could involve laboratory demonstrations to reduce methane in rumen cultures via microbiome community editing, followed by live animal trials, to assess their safety.
3. **Test methods to improve the production efficiency of existing technologies.** Evaluate the cost-effectiveness and adoption of improved farm-management practices and feed software to account for local feed availability, costs and breeds.
4. **Fostering an enabling environment that supports the development, testing, scaling and adoption of these innovations.** Public and private actors and DFIs can work together to achieve this environment by establishing policies and allocating financial resources to support animal research in low- and middle-income economies. This includes providing

tools and equipment, as well as enhancing the technical capacity of research organizations and universities in low- and middle-income countries, designing climate-smart policy programs, and establishing monitoring, evaluation, and verification systems (MRV) to foster innovation and sustainable agricultural practices.

Depending on the results, the scalability of these approaches will depend, among other factors, on the production system. In lower-income, low-emission countries, strategies with substantial co-benefits may be more suitable. Increasing productivity in low-yield settings can still help reduce overall emissions by lowering emission intensity. In larger-scale commercial farms, especially in upper-middle-income countries, other strategies may be more likely to be adopted at scale sooner.

In addition to funding for R&D, it would be beneficial to explore policies to harness the energy and creativity of the private sector in developing innovations to reduce methane emissions. This includes market-shaping instruments, such as AMCs and advance regulatory commitments. Governments could also explore the possibility of creating pricing mechanisms or cap-and-trade systems for methane. Additional investments in improving measurement and monitoring systems for livestock methane emissions, particularly in low- and middle-income countries, could strengthen the effectiveness of these policies significantly. These policy tools could allow farmers to choose efficiently among various methane-reduction approaches, which in turn would incentivize innovators to develop methane-reduction technologies farmers and consumers would accept.

Apart from R&D, ensuring scale-up and adoption of new and existing sustainable technologies is crucial to reduce livestock emissions. To account for this, IFC has formulated seven sustainable agricultural practices for its investments that relate to livestock. For instance, IFC has invested in Alvoar Brazil, a leading dairy producer. The project is accompanied by advisory services to Alvoar's smallholder suppliers, aimed at reducing livestock emissions by providing training to farmers on climate-smart, regenerative agriculture techniques and better nutrition practices. Improving cow productivity and reducing GHG emissions per kilogram of milk output could be achieved by balancing the ration of feed as a first step. Another example where IFC is promoting farmer productivity is its investment in Anyou, a leading animal feed manufacturer in China. The project, accompanied by IFC advisory services, supports Anyou in the development and scaling of eco-feed, aiming to reduce GHG emissions of Chinese pig farms. Additionally, the private sector can incentivize farmers to adopt sustainable agricultural techniques. For example, the multinational dairy company Arla Foods has developed a program called FarmAhead that incentivizes the adoption of climate-smart technologies through farmer rewards, which is sustained by partnerships with technology providers and retailers. This value chain approach can contribute to the reduction of Scope 3 GHG emissions of global food companies.

5

Diagnostic for Innovations on Climate-Resilient Crops

1. What is the opportunity?

Developing climate-resilient crops presents a significant opportunity to address the threat extreme weather poses to agriculture in Sub-Saharan Africa. The increasing frequency of high-heat days, droughts, and floods will result in declining yields for crops crucial to the nutrition and livelihoods of hundreds of millions of people. Without adaptation efforts, estimates suggest staple crop yields could fall 16% by the end of the century and, even with baseline adaptation projections losses, are still expected to be 12% (Hultgren et al., 2022). This challenge is exacerbated by the decades-long stagnation in yields of many staple crops in the region(Wollburg et al., 2024; Ritchie et al., 2022). Developing climate-resilient crop varieties is an essential element in addressing this issue, and targeted funding mechanisms, such as AMCs, can help accelerate this progress.

This section incorporates input from the Center for Global Development and the University of Chicago Market Shaping Accelerator and builds on concepts explored in Glennerster et al. (2024).

The development and widespread adoption of climate-resilient crops — such as heat-, drought-, or flood-tolerant crops — could increase food and nutrition security, and save billions of dollars in production losses. To better understand potential benefits of climate-resilient crops, researchers at the University of Chicago and Tufts University modeled the economic impact of increasing heat tolerance by 1°C. The model combines temperature-yield functions, climate forecasts, and historical data on research costs and success probabilities. Results suggest that investing in climate resilience could generate substantial returns. For instance, in East Africa, increasing the heat tolerance of sorghum by 1°C is projected to generate US$1 billion to US$2.5 billion in benefits. To spur the necessary innovation, an AMC of around US$100 million for each crop-region pairing could be enough to drive progress through conventional breeding. More advanced approaches, like gene editing, might require a larger commitment of roughly US$350 million. In some crop-region pairings, benefit-cost ratios could reach as high as 10-25:1. (Glennerster et al., 2024)

Breeders can utilize both conventional and advanced breeding techniques to develop climate-resilient crop varieties. Given the variation in local agroecological and socioeconomic conditions, it is essential to create crop varieties that are designed with context-specificity in mind. Breeders can make significant progress with conventional breeding practices, but advanced breeding techniques can hasten breeding cycles and enable more rapid genetic gain. CRISPR, for instance, allows for more precise breeding and can increase the likelihood of combining multiple desirable traits (Ledford, 2024). Notably, researchers can use CRISPR to make precise edits within a plant's own genome, avoiding the use of foreign genes and, therefore, the complications associated with traditional GMOs.

Effectively scaling climate-resilient varieties would not only benefit from scientific advancements, but also innovative funding mechanisms such as AMCs. While public breeding programs, including CGIAR, lead crop-breeding efforts, they often lack the legal frameworks and commercial expertise needed to scale new varieties effectively. The private sector has limited incentive to invest in crop breeding and dissemination due to various market failures (Kremer and Zwane, 2005). An AMC — a promise to reward firms for developing varieties based on the varieties' measured adoption — can help prompt the entry of private sector firms, with access to advanced technology, and directly incentivize scaling.

2. What is the current landscape for these innovations?

The crop innovation landscape in Sub-Saharan African countries has regional disparities but is more fragmented and has greater public sector involvement compared to higher-income countries. In some countries, such as South Sudan and the Democratic Republic of Congo, the seed sector is rudimentary with little formal infrastructure or regulatory frameworks in place. Seeds are often saved from prior harvests, distributed as part of humanitarian relief programs, or imported from regional and international sources. Other countries, such as Niger and Mali, have breeding programs and formal variety release processes in place, but operate with limited resources and reach, and thus depend on the public sector and nonprofit organizations for production, distribution, and farmer outreach. In relatively more advanced markets, such as Kenya, Zambia, and Nigeria, breeding programs for certain crops are well established, and the private sector's role is expanding across the seed sector. South Africa has the region's only mature seed industry (Ariga et al., 2019).

In a handful of countries, such as Zambia and Zimbabwe, private sector competition is significant, with both multinational and domestic seed companies providing high-quality seeds to farmers and competing on prices, traits, and after-sales support. However, in other countries such as Kenya and Ethiopia, there is considerable evidence that state-owned seed enterprises continue to crowd out private investment. In other countries, the public sector's role changes from year to year, making for an unpredictable investment climate for private seed companies (Mabaya et al., 2023).

Broadly speaking, CGIAR and national agricultural research systems (NARS) are the primary drivers of crop breeding in Sub-Saharan Africa, whereas the private sector, when present, plays a larger role in multiplication and distribution. The CGIAR/NARS conduct crop improvement R&D with what is effectively push funding, which involves upfront funding of R&D. For example, CIMMYT, a CGIAR breeding center, developed over 100 drought-tolerant varieties with at least US$32 million in push funding (CIMMYT, 2015; Gates Foundation, 2014).When present, private breeders generally build on CGIAR/NARS R&D or private sector R&D conducted in other countries. Large-scale private sector R&D investments in individual countries remains limited. Only 11 companies breed in Western and Central Africa, and private innovation focuses almost exclusively on maize across Sub-Saharan Africa (Access to Seeds, 2019).

Despite CGIAR, NARS, and private sector successes, certain staple crops remain neglected. Crops like sorghum and groundnuts, which are vital in West Africa, see few releases of new varieties. For example, Niger, a large consumer of sorghum, saw no releases of new varieties of sorghum between 2000 and 2013 (CGIAR DIIVA, 2013).

Even where new varieties are available, adoption rates are often low. For instance, in Nigeria, only 20% of sorghum fields use modern varieties, and the average age of the varieties sold is 14 years (CGIAR DIIVA, 2013; TASAI, 2022). In contrast, in Asia, crops with similar levels of importance to diet have twice as many new releases and broader adoption of modern varieties (Marieda et al., 2016).

3. What are the constraints to developing and scaling these innovations?

Developing and scaling crop innovations in Sub-Saharan Africa face several challenges, such as difficulties in capturing returns from innovation and a disconnect between breeders and downstream firms. Across the agriculture supply chain, firms struggle to capture financial value from innovations in part because farmers typically use open-pollinated and self-pollinated plant varieties (Kremer and Zwane, 2005). These varieties can be reused, shared, and traded informally, limiting repeat purchases and making it difficult to profit from improved varieties. As a result, seed firms have little incentive to invest in developing improved open-pollinated and self-pollinated varieties. Furthermore, farmers' reluctance to pay premiums for traits that are not immediately visible makes it especially challenging for firms to recoup investments in traits like climate resilience, which only reveal their value during extreme weather events (Carter et al., 2021; Boucher et al., 2024). These factors also make it challenging for private firms to set prices for new crop varieties high enough to recover their R&D investments, which ultimately hampers the development of new products.

Even after new crop varieties are developed, scaling them remains a challenge due to the disconnect between breeders, seed producers, and marketing and distribution firms. In Sub-Saharan Africa, CGIAR and NARS, relying on push funding, dominate the market for both crop breeding and seed distribution. Push funding alone may result in varieties that do not align with farmer preferences. For example, NERICA rice has the potential for significantly higher yields relative to traditional varieties, but complex crop cycle management meant such higher yields only occurred with training. Such barriers hinder uptake (Glennerster, et al., 2016). These challenges are addressed by organizations like AGRA, which is supporting several efforts on agricultural innovations in Africa, focusing on smallholder farmers. For instance, its Center of Excellence for Seed Systems in Africa (CESSA) is a platform supporting public and private stakeholders in forming effective and resilient seed systems in Africa, providing a knowledge database, advisory services and coordination (Wellard et al., 2019; DeVries, 2019).

4. How can policymakers, DFIs (including IFC) and the private sector respond to these constraints?

Policymakers, DFIs, and the private sector can each play unique roles in overcoming barriers to agricultural innovation. Policymakers can fund organizations to develop innovations. DFIs and the private sector can build on this by investing across the seed value chain including in breeding, multiplication, distribution, and extension services.

Policymakers and philanthropic organizations can focus on their comparative advantages such as enforcing regulatory standards and supporting R&D. To bolster R&D of improved seeds and accelerate adoption, the public sector can use a combination of push and pull funding. A previous meta analysis suggests that CGIAR's portfolio has generated a benefit-cost ratio of around 10:1, underscoring the value of continued push funding of these breeding centers (Alston et al., 2022). Pull funding, in contrast, rewards firms only if they develop successful innovations such as new varieties that meet yield and adoption thresholds.

An AMC is a type of pull funding mechanism that incentivizes firms to develop and distribute innovations by rewarding them based on measurable adoption rates. By paying firms based on adoption, AMCs encourage firms not only to innovate but also to invest in effective marketing and distribution strategies. This model can help ensure that seeds are designed to align closely with farmer preferences — whether through ease of planting or taste similarities to traditional crops. Beyond climate resilience, AMCs have the potential to stimulate the development of seeds with other advantageous traits, like pest and disease resistance.

DFIs and private sector actors can further accelerate innovation by helping finance private sector initiatives spanning crop breeding, seed multiplication and distribution, and farmer extension. DFIs can invest in firms that respond to pull mechanisms. These investments could include supporting breeders to help tailor seed varieties to local contexts, improving the capacity of seed multipliers with production and marketing, and aiding the development of effective farmer extension programs. DFIs can also help facilitate coordination between market actors such as breeders with market research firms. These investments could build on existing investments in Sub-Saharan Africa agriculture supply chains such as the IFC's investments in Mahyco and Jubali Agrotec Group. Mahyco is an Indian agriculture firm focused on crop breeding, seed production, and seed distribution. It has operations in several countries including Zimbabwe (Mahyco, 2018). The private sector remains small, but an AMC could provide incentives for firms to enter.

5. Next Steps: Potential Way Forward

Future steps could include the establishment of a working group to develop detailed proposals for implementation of a climate-resilient crop AMC. These proposals would set out candidate innovation-region pairs to target, and how payment mechanisms would operate in practice. The working group would be analogous to the Center for Global Development Working Group, which produced a report proposing an AMC for the pneumococcal vaccine (Center for Global Development, 2005).

In parallel, DFIs and private sector firms can continue investing in agriculture supply chains. This can include breeders, seed multipliers, farm extension services, market research firms, and other organizations that can help develop innovations designed to meet the unique needs of specific regions and communities. Apart from climate-resilient seed varieties themselves, other types of technology can be leveraged to promote the resilience of crops. For example, IFC has had several projects with Netafim, a company specializing in smart irrigation technology. Netafim provides microirrigation systems to smallholder farmers, promoting their productivity and climate resilience. Promoting innovation does not only entail scaling of new products, but also originating new markets for existing climate-resilient crops like fonio or teff. For example, USAID has made several investments in fonio production and marketing in West Africa, and IFC, supported by blended finance and global equipment suppliers, has prioritized financing commercialization and value addition in the fonio value chain, and design and installation of state-of-the-art processing equipment.

6

Diagnostic for Innovations on Microbial Fertilizers

1. What is the opportunity?

Synthetic fertilizer is key to increasing yields in many regions, but its overuse is a major source of emissions and environmental degradation. Fertilizer use varies significantly across regions. The fertilizer application rate in kilograms per hectare in Africa is approximately one-seventh that of South Asia and one-tenth of the rate in East Asia (Ritchie et al., 2022). Many African farmers, particularly smallholders, tend to underuse fertilizers, which limits agronomic productivity (Ritchie, 2021), while heavy use of synthetic fertilizers in Asia leads to adverse environmental effects, in addition to high fiscal costs from subsidies (Holden, 2019; Garg and Saxena, 2023). Globally, the production and use of synthetic fertilizer generates between 2% and 5% of global carbon dioxide emissions (Gao and Serrenho, 2023). Increasing use of fertilizer in Sub-Saharan Africa will drive this number higher.

This section incorporates input from the Innovation Commission for Food Security, Climate Change, and Agriculture at the University of Chicago and builds on concepts explored in the Innovation Commission Research Briefs (available at https://innovationcommission.uchicago.edu/research_briefs/priority-innovations-and-investment-recommendations-for-cop28/).

Microbial fertilizers use bacteria to facilitate the absorption and increase the availability of nutrients (atmospheric nitrogen fixation) necessary for plant and soil health. These fertilizers do not replace synthetic options, but they can lower the amount required for optimal plant and soil health. Different types of microbial fertilizers are tailored to specific crops and nutrients. Some formulations use a single bacterium, such as Rhizobium or Azospirillum, while others combine two or more bacteria. Most microbial fertilizers target biological nitrogen fixation, though new formulations also facilitate phosphorus and potassium absorption.

Microbial fertilizers could reduce emissions from synthetic fertilizers, generating billions in social benefits (Bomfim et al., 2021). Furthermore, through a reduction in usage of synthetic fertilizers, microbial fertilizer could have beneficial effects on soil health and potentially improve the economic situation of farmers, e.g. by stabilizing input costs through a reduced dependence on traditional fertilizers, which have displayed significant price volatility in recent years (World Bank, 2024).

2. What is the landscape for these innovations?

Rhizobial inoculants are an effective fertilizer for legumes and are widely adopted in some regions. In the 1990s, the Brazilian Agricultural Research Corporation (Embrapa) developed a microbial fertilizer using Rhizobium to enhance biological nitrogen fixation in soybeans. To date, around 100 million acres of planted soybean in Brazil use Rhizobium, which not only increase yields by 10% to 30% in chickpeas, common beans, cowpeas, fava beans, peanuts, and soybeans, but also promotes soil nutrient cycling, which helps restore the ecosystem and improves the growth of other crops (Adediran et al. 2018; Adjei-Nsiah, 2018; Adjei-Nsiah et al., 2019; Belete et al., 2019; Colussi et al., 2023; Chekanai et al., 2018; Hungria et al., 2020; Mwenda, 2017; Ronner et al., 2016; Ronner, 2018; Rurangwa et al., 2018; Rurangwa, 2019; Samora, 2023; Schütz et al., 2018; Tolorunse, 2017; van Heerwaarden et al., 2018; van Vugt, 2018; Wolde-meskel et al., 2018). However, soil conditions influence its effectiveness. For example, Rhizobium may have limited or no effect in acutely degraded soils (Chekanai et al., 2018). Rhizobium provides proof of concept that microbial fertilizers can reach scale in middle-income countries.

Commercialization of rhizobial inoculants is very limited in Sub-Saharan Africa. Native rhizobia strains have been modified as inoculants, but commercialization is limited and primarily concentrated in South Africa (Aloo et al., 2021). Efforts such as N2Africa aim to develop and test microbial fertilizers for legumes across Sub-Saharan Africa, focusing on improving soil health and nutrient availability, which can support growth of other crops during rotations. However, none of these initiatives have achieved large-scale commercialization.

New technologies could potentially reduce the need for synthetic fertilizer in other staple crops. For example, PivotBio reprograms microbes to reduce or replace the need for nitrogen fertilizer.[3] Its main product, Proven40, combines 40 microbes to enhance biological nitrogen fixation in maize. Proven40 is used on about 10 million acres of corn in the U.S. At an earlier stage of development, Kula Bio is working on a technique that allows the bacterium Xanthobacter autotrophicus to facilitate nitrogen fixation in any crop. This technique uses bioreactors to increase the microbial density of autotrophicus, allowing bacteria to survive for longer periods in the soil, which can be a challenge with microbial fertilizers.

While lab research shows promise for new bacterial inoculants fixing nitrogen for nonleguminous crops, results from field trials have been mixed. A 2023 review of 12 trials across 10 U.S. states found no impact on yields from applying asymbiotic nitrogen-fixing products, including PivotBio's Proven40, on maize, spring wheat, sugar beet, and canola in 49 of 51 sites (Franzen et al., 2023). Other trials show impacts on yields, but with variation across settings in the profitability of replacing N fertilizer (Beck's, 2023). Additionally, despite decades of research, the primary benefits of these inoculants often come from plant growth promotion rather than nitrogen fixation (Giller et al., 2024). Numerous companies assert that their products can fulfill the majority of crop nitrogen requirements, attracting substantial investment and targeting large-scale farmers in their marketing efforts. However, independent studies frequently report limited yield benefits. Investing in further research can build the evidence base on mechanisms and effectiveness of microbial fertilizers across different soil conditions, such as nitrogen-limited or fertilized soils. Given the state of research, clear regulations can help ensure manufacturers provide robust evidence of these products' mechanisms and effectiveness under various conditions before moving to scale-up (Giller et al., 2024).

3. What are the constraints to developing and scaling up these innovations?

More research is needed to understand the most appropriate crops and settings for microbial fertilizers. While Rhizobium has a long track record and high adoption in Brazil, it is less common in other regions. More research is needed to understand these mechanisms and appropriateness for different types of soils, including nitrogen-poor soils.

While microbial fertilizers offer significant potential for reducing emissions from synthetic fertilizers and improving soil health, some potential challenges to their pathways to scale remain. Given their reliance on live microorganisms, appropriate storage and transportation methods are important factors to preserve their effectiveness (Fadiji et al., 2024; Berninger et al., 2018). Moreover, temperature and environmental conditions during application could affect their performance (Pirttilä et al., 2021; Fadiji et al., 2024). Addressing these logistical and technical barriers will be important to scale microbial fertilizers effectively among smallholder farmers in LMICs, particularly in regions with limited infrastructure and less-advanced farming practices.

4. How can policymakers, DFIs including the IFC, and the private sector respond to these constraints?

Funding could support the testing and adaptation of microbial fertilizers for low- and middle-income countries. While microbial fertilizers have been widely adopted in the U.S., Brazil, and other upper-middle- and high-income countries, existing field trials have demonstrated positive results for leguminous crops, primarily through enhanced nitrogen fixation, which benefits soil fertility for subsequent crops. However, the yield impacts for maize in the U.S. have been more mixed. Further research could evaluate their cost-effectiveness and suitability for a wider range of crop varieties and contexts beyond these countries. However, given significant upfront costs and potentially lower expected returns, the private sector will likely underinvest in adapting microbial fertilizers for use in many low- and middle-income contexts. As a first step, donors could support the testing and adaptation of microbial fertilizers that have a proven record. It would be important for this testing to take place across different countries and across a range of crop varieties, climates, and soil types — such as nitrogen-limited or fertilized soils — to ensure effectiveness in diverse agricultural contexts. If testing yields successful results and microbial fertilizer is adopted by a substantial number of farmers in some countries, testing could be expanded to other countries and complemented with sequenced investments to transition the technology to scale.

DFIs including the IFC can play a pivotal role in scaling microbial fertilizers in LMICs by addressing both the financial and technical barriers to adoption. Working with research programs such as the CGIAR, donors can provide early-stage funding for testing and adapting microbial fertilizers to local crops and environmental conditions; however, DFIs can scale this work using blended finance models to derisk private sector investment and encourage wider adoption of proven solutions. DFIs can also support the creation of local infrastructure, such as distribution networks and manufacturing facilities, to reduce logistical barriers and make the technology

[3] The microbes are gene-edited but do not contain foreign DNA.

more accessible. Furthermore, they can offer technical assistance to farmers and partners, ensuring effective use of microbial fertilizers, while engaging in policy advocacy to create favorable regulatory environments. Given the open questions raised in the 2023 meta analysis on microbial fertilizers, financiers will need to follow the scientific discussion about the efficacy of these products given mixed results to date in UMICs. In the short-run, financing may focus on further testing and limited scale-up as these questions are resolved. Through sequenced investments, DFIs can help transition the technology from successful trials to widespread adoption, ensuring that microbial fertilizers reach scale and contribute to long-term agricultural sustainability and food security in LMICs.

5. Next steps: Potential paths forward

Funding for microbial fertilizers should be sequenced and tracked based on the success of local trials. As an initial step, donors and agri-research centers such as CGIAR can support the testing and adaptation of microbial fertilizers across different low- and lower-middle-income countries.

The testing process used for PivotBio in Kenya could potentially be replicated in Angola, Ethiopia, Ghana, Kenya, Malawi, Mali, Nigeria, South Africa, Tanzania, and Zambia, which collectively produce almost 80% of maize in the region. Similarly, rhizobial inoculant trials in leguminous crops could adapt the product to new settings. Donors and research centers can test and prove technical and financial feasibility of new technology under local conditions, and DFIs could consider partially or fully supporting the scale-up of these solutions:

- Research station trials to test the technology under local conditions.
- If research trials are successful, they could be followed by farm trials covering a substantial geographical area. Such trials would ensure representative biological data on plants and microbes, and would enable measuring the stability and persistence of microbial fertilizers in the soil across space and time.
- Incorporating local strains of bacteria from each country to optimize microbial fertilizers for the local context. Even if research station trials and farmer trials demonstrate that the technology works well, incorporating local strains of bacteria could further enhance its performance.

Public sector support for farmers to purchase microbial fertilizers, once they have been successfully tested and adapted, could reduce the use of synthetic fertilizer, reducing emissions and environmental degradation. Subsidizing microbial fertilizers could reduce the use of synthetic fertilizers, which have negative environmental externalities. Many governments now subsidize synthetic fertilizers, creating further incentives for farmers to overapply synthetic fertilizers without substantial yield gains (Ritchie, 2021). This imposes significant environmental and fiscal costs. While rolling back subsidies can be challenging politically, repurposing potentially harmful subsidies for synthetic fertilizers with locally appropriate microbial varieties could be a more palatable measure, while still reducing environmental and fiscal costs. Such subsidies would have to follow rigorous evidence of cost-effectiveness in adapting the technology to different crops and settings.

7

The Way Forward

The report attests that the development, scaling, and financing of innovative agricultural technologies aimed at addressing food security and resilience to extreme weather exhibit several uncertainties and areas that need further examination. Thorough research and discussion are needed to understand the scientific, social, environmental, and financing consequences and challenges, not only of the technologies discussed in this paper but agricultural innovations in general. Recognizing and understanding these questions will help stakeholders in identifying the best solutions, given that there are numerous technologies and innovations in parallel development beyond the ones mentioned here.

While all three technologies discussed in this report are at different stages in the innovation cycle, there are several questions that remain open at the scientific level, with researchers still examining the effectiveness of the technologies in different contexts. For example, a review across 12 trials in 10 U.S. states on microbial fertilizers found that their effectiveness did not surpass traditional petrochemical-based fertilizers in 49 out of 51 sites (Franzen et al., 2023).

Furthermore, social and environmental effects of scaling and adopting the three innovations require further exploration and research. For example, questions regarding the distributional effects of access to the benefits of these technologies remain open. Oftentimes, difficulties arise in bringing innovations to smallholders and base-of-the-pyramid customers. Some technologies may need significant scale to become viable economically, but that might prove problematic for farmers and businesses in some markets, including small island states. To ensure adoption, it's crucial to ensure farmers can switch to new technologies and are incentivized to do so via appropriate policy and effective advisory and extension approaches. Lastly, finding the right balance between public financing for R&D and scaling of innovations remains a contested area. The degree of involvement of the public sector in providing incentives could range from regulatory and policy reforms to risk sharing and subsidies. While DFIs have increasingly leveraged blended finance, a strict adherence to shared principles regarding subsidies, e.g. the OECD DAC or IFC Blended Finance Principles, is needed.

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