GAP INITIATIVE™ AT VIRGINIA TECH
GLOBAL AGRICULTURAL PRODUCTIVITY REPORT™

COLLEGE OF AGRICULTURE AND LIFE SCIENCES VIRGINIA TECH™

2024 GAP Report™

POWERING PRODUCTIVITY

SCALING HIGH IMPACT BUNDLES OF PROVEN AND EMERGING TOOLS

CONTENTS

ABSTRACT

Agricultural total factor productivity (TFP) growth is critical for ensuring that agriculture can meet the growing global demand for agricultural products by 2050. However, since 2013, global average annual TFP growth has fallen to just 0.7 percent. This requires another upward revision of the target TFP growth rate to 2 percent annually to achieve sustainable agricultural production. We urgently need to elevate our efforts to accelerate TFP growth.

While research and development (R&D) remains a vital driver of TFP growth, it is clear that public and private R&D alone will not suffice. The 2024 GAP Report™ emphasizes the importance of bridging the gap between innovation and widespread adoption–referred to as the "Valley of Death"–through the strategic bundling of productivity tools with socio-economic, policy, and distribution mechanisms. This report explores how these bundles, tailored to local contexts and integrated with existing proven tools, can overcome the barriers that prevent farmers from accessing and adopting technologies that drive sustainable productivity growth.

From in-depth research to real-world stories, the 2024 GAP Report™ sheds light on the pathways to unlocking the full potential of TFP growth for the benefit of farmers, society, the environment, and the global economy.

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POWERING PRODUCTIVITY

SCALING HIGH IMPACT BUNDLES OF PROVEN AND EMERGING TOOLS

FOREWORD

This year's Global Agricultural Productivity (GAP) Report™ highlights the widening gap between current agricultural productivity growth rates and what is needed to meet the world's growing demand for food, feed, and fiber. While extensification, bringing new lands into cultivation, continues to account for at least two-thirds of gains in output in sub-Saharan Africa, this worrisome, unsustainable trend does not improve human well-being with respect to poverty reduction, greater affordability of food, and quality diets associated with the growth of total factor productivity (TFP).

Extensification of production works against the discovery of solutions that address growing demand while also reducing the climate footprint of agriculture and food systems, generating critically important "green growth" amid a climate crisis. We know that part of the downturn in TFP growth during the past decade stems from sharp declines associated with the COVID-19 pandemic, which is now resolving. What is less clear is just how much climate shocks contributed to depressing TFP growth. If this is indeed the case, which many suspect, the slope that measures the gains needed for environmentally and climate-smart sustainable growth is increasing, underscoring the need for increased strategic investment.

Despite the scale of the challenge, the message of this year's report is not pessimistic. To the contrary, it highlights several positive prospects where a change in course toward robust and more environmentally friendly growth could be achieved. The report unpacks factors that contribute to sustainable growth. In particular, it highlights the necessary investment pathways–more support for demand-driven agricultural R&D, expanded and strengthened market access, robust regional and global trade, and reduced loss coinciding with gains in quality and value.

Perhaps not surprisingly, these same strategic investments form the basis of Feed the Future, the U.S. Government's flagship program to reduce global hunger and malnutrition through greater food security. The report's focus on "impact bundles" offers further insights into the need for alignment of efforts–integrating innovation and other socio-economic, inclusive interventions. Finally, the report sounds a note of caution of just how important science- and evidence-based policy is to enable the innovation ecosystem the world needs to achieve a sustainable, food secure future.

The audience for this report may have originally been limited to those focused on achieving improvements in food security and nutrition, but it is clear now that it directly concerns a much broader set of stakeholders. Whether your priorities are biodiversity and tropical forest conservation, provision of water, sanitation, and other critical environmental services, combatting the threat of climate change, or reducing extreme poverty, hunger, and malnutrition, the 2024 GAP Report™ underscores just how integrated those goals are. Increasingly, achieving human development goals must reconcile how our species meets its food, feed, and fiber needs, while also hastening progress across a broad set of environmental and climate goals.

Robert Bertram

Chief Scientist, Bureau for Resilience, Environment and Food Security

U. S. Agency for International Development

CHAPTER 1

POWERING PRODUCTIVITY

BRIDGING THE VALLEY OF DEATH TO REACH WIDESPREAD ADOPTION

Globally, the agricultural total factor productivity (TFP) growth rate remains far below the target needed to sustainably meet the world's growing demand for agricultural products. Despite significant advancements in agricultural innovation, many producers and stakeholders across agri-food value chains still lack access to the tools necessary for sustainable productivity growth. Bottlenecks in innovation pipelines continue to delay the adoption of proven solutions, and systemic barriers–including weak enabling environments, behavioral constraints, and external shocks–compound the challenge. These factors create critical obstacles to ensuring every producer has access to the tools they need to increase efficiency and sustainability.

The 2024 GAP Report™ highlights the importance of bridging the "Valley of Death"–the gap between research breakthroughs and their widespread application–through high-impact bundles of productivity-enhancing distribution, socio-economic, and policy tools. It presents lessons from South Asia, a regional leader in TFP growth as a result of public and private investments in R&D, mechanization, and ICT innovations. The report provides a framework to accelerate progress to ensure every farmer has access to every proven, appropriate productivity-enhancing tool. GAP Initiative™ partners offer evidence-based approaches that showcase how collaborative action can drive productivity growth at all scales of production, creating a more resilient and equitable global agriculture sector.

KEY MESSAGES

- The global average annual total factor productivity (TFP) growth rate was only 0.7 percent during 2013-2022.
- The target TFP growth rate needs to be revised upward once again to compensate for persistently sluggish progress. Set at an average annual growth of 2 percent, achieving the level of efficiency necessary for agriculture to meet the growing demand for high-quality, sustainably produced agricultural products will require a shift toward "business as unusual."
- South Asia emerged as a regional leader in average annual TFP growth during 2013-2022 as a result of public and private investment in R&D, mechanization adoption, and ICT innovations.
- Public and private R&D alone will not be sufficient to achieve the target annual 2 percent TFP growth rate. Bridging the "Valley of Death"–the gap between developing innovative solutions and widespread adoption–must be a top priority in the coming decade.
- Bundling productivity tools with distribution mechanisms, socio-economic tools, and policy levers will power productivity growth during the next decade by creating bridges across the Valley of Death that are tailored to local contexts and cultures.

2024 GAP REPORT™ LAUNCH SUMMARY: ILLUSTRATING BRIDGES TO SCALE

The launch of the 2024 GAP Report™, attended by more than 300 participants from 45 countries and 90 organizations, contextualized the importance of bundling productivity, distribution, socio-economic, and policy tools to address agricultural productivity growth challenges. Key themes included the importance of partnerships, market access, climate resilience, and digital tools. Farmers shared success stories—highlighting tailored, localized solutions. Collaboration across public and private sectors is crucial for sustainable, integrated approaches that prioritize farmers' needs.

Dr. Simeon Ehui, IITA. Tom Soladay for Virginia Tech.

In his keynote address, Dr. Simeon Ehui, IITA (International Institute of Tropical Agriculture) director general and CGIAR (Consultative Group on International Agricultural Research) regional director for Africa, emphasized the importance of partnerships in taking innovations across the Valley of Death, noting that “Our partnerships are fundamental to our success. ... We work closely with national governments, research institutions, NGOs, and the private sector to ensure that our research is demand-driven, adapted to local contexts, and scalable. This collaboration allows us to maximize our impact on the ground." These collaborations are crucial to ensuring that bundles of productivity-enhancing tools reach farmers by tailoring innovations to local needs and enabling producers to access solutions that address multi-dimensional agricultural challenges.

Opening the first panel, “Off the Shelf & Into the Field Through High Impact Bundles”, Dr. Rob Bertram, chief scientist for the Bureau of Resilience, Environment, and Food Security of the U.S. Agency for International Development (USAID) emphasized that "if we can get hybrid maize seed in, drought tolerant ideally, with access to better soil fertility, fertilizers and soil health practices, that can be a game changer where people go from one or two tons per hectare to three or four or five. And this is life changing. But it also changes because it drives investment in seed systems, it drives investments by the private sector through agro-dealers, which, of course, in turn become another source of innovation and information." By combining technologies such as seeds with advisory services, farmers in places such as Ethiopia have seen substantial productivity increases.

The second panel of the event, “View from the Field”, featured the voices of farmers from across the world. They shared their experiences with adopting productivity-enhancing technologies. Ms. Rekha Atole from India, for example, described how soil testing through the Krishi Jyoti project, a collaboration of The Mosaic Company and The S M Sehgal Foundation, improved her crop yields and reduced costs. José Luis Gonzalez Chacon from Colombia emphasized the value of blending indigenous knowledge with modern practices. He reflected on the lack of access to technology in his country as the catalyst for his adoption of indigenous farming practices, such as using poultry manure to develop a nutrient layer in their sandy soil. Ms. Belinda Burrier from Maryland, U.S., highlighted how no-till farming and cover cropping helped her maintain soil moisture during drought, crediting these practices for her farm’s resilience. Dr. Tebila Nakelse, originally from Burkina Faso, shared how the introduction of high-yielding cassava varieties in his community transformed lives, tripling revenues, and improving educational opportunities. "The productivity growth changed everything," he remarked, illustrating the far-reaching, generational impacts of new agricultural technologies.

Collectively, farmer panelists called for better access to education, financial support, and policies that enable them to adopt these innovations, underscoring the importance of practical, localized solutions for driving sustainable productivity growth.

The following themes emerged from the event’s discussions.

Climate Resilience is Imperative for Productivity Growth. Climate resilience emerged as a central theme, with panelists stressing the need for climate-smart agricultural practices that enable farmers to mitigate risks and increase productivity in the face of climate challenges. An example from Zambia showcased how bundles of climate-resilient technologies, including early maturing maize varieties and advisory services, helped smallholder farmers weather drought conditions. Dr. Bertam highlighted that

investment is catalyzed by driving down risk through adopting climate-informed planting advice and increasing the potential for productivity growth. The ability to access precise climate information through digital platforms, paired with localized knowledge on soil management, is also crucial for building resilient productivity growth. Dr. Bertram further noted that rainfall management and water conservation are crucial, especially in regions where rain-fed systems are predominant.

Factors Influencing Agricultural Technology Adoption. Panelists discussed profitability and practicality as key adoption factors of new agricultural technologies. Dr. Basil Gooden, Under Secretary for Rural Development of the U.S. Department of Agriculture (USDA), illustrated the importance of learning of these factors during his fireside chat, recalling a fellow farmer's experience of using a hybrid vehicle during a family vacation. Initially skeptical, he found himself impressed by the efficiency and savings, as he only filled his gas tank once on the trip. Similarly, showing farmers how technologies such as precision farming tools or high-yield crop varieties can boost productivity while reducing costs will encourage uptake.

Restrictive regulations also hinder adoption of productivity-enhancing tools. As Mr. Marcus Holtkötter, a farmer from Germany, pointed out, while producers "have a great toolbox with modern techniques, modern seed breeding, and so on, but we have a very restricted regulation in Europe and especially in Germany." This prevents producers from accessing advanced technologies that would contribute to sustainable productivity growth. He went on to say that "the decisions are made by politicians, not on a scientific basis, more … on an ideological basis," which he indicates has had a negative impact on farm productivity and output, leading to increased requirements for imports.

Market Access and Partnerships Create Valley of Death Bridges. Market access and public-private partnerships to scale innovations and make them economically viable for farmers were discussed as key pathways to creating bridges over the adoption Valley of Death. Bertram mentioned how in Malawi, USAID has been partnered with private companies, giving smallholders better access to innovations and markets, enabling these farmers to connect with supply chains and enhance their economic returns. Vice President for International Affairs and Sustainability Strategy for Bayer Crop Science, Dr. Alejandra Castro, pointed out that, "…the needs of different countries are totally different. … The way to move forward is to understand what the farmer needs." Public and private collaboration is thus critical for designing bundled services tailored to the specific needs of farmers and regions.

Digital Tools Bridge Information Gaps. The event underscored the transformative role of digital agriculture in bridging the information gap for farmers, especially in remote areas. By using mobile technologies and digital advisory platforms, farmers can now receive real-time data on factors that impede productivity growth such as environmental conditions, pests, and market trends, empowering them to make more informed decisions. Bertram explained, "Advisory services is the … place where we've been able to leapfrog because of digital

Dr. Robert Bertram, USAID (left); Alejandra Castro, Bayer Crop Science (right). Tom Soladay for Virginia Tech

Belinda Burrier, Maryland Farmer. Tom Soladay for Virginia Tech.

Dean Mario Ferruzzi, Virginia Tech College of Agriculture and Life Sciences. Tom Soladay for Virginia Tech.

advanced communications that enable even farmers, in remote areas, to benefit from information about pests and diseases, but also market information and climate information," illustrating how technology is changing the landscape of agricultural extension services. changing the landscape of agricultural extension services.

No Silver Bullet for Sustainable Agricultural Productivity Growth

The consensus among 2024 GAP Report™ Launch participants is that no single solution will suffice to reach our productivity growth targets. Castro concluded by stressing the need to work together, through partnerships, to deliver sustainable, integrated solutions that are practical for farmers. As Dr. Mario Ortez, collegiate assistant professor in the Department of Agricultural and Applied Economics at Virginia Tech, pointed out, we must consider who has agency in the technology adoption process. He asserted that those with the responsibility for decision making are "...not the wonderful researchers that are working on these great technologies. It is also not the banker that is willing to finance them. It is also not the government that is hoping to increase implementation of these technologies, but it is the agent herself, right? The farmer--the business owner." Accordingly, we must place the farmer at the center of design, R&D, and policy processes.

Moreover, if we are to achieve productivity growth to create returns to producers, society, the environment, and the economy, we need bundles of technologies, climate smart practices, enabling policies, market access, and infrastructure development to unlock productivity growth for nutritious, food security-enhancing crops and livestock. As Mr. Arun Baral, CEO of HarvestPlus, emphasized, "... we have innovations on the shelf in the marketplace, but these innovations need to reach the last mile of the farmers."

Concluding the launch, the Dean of Virginia Tech's College of Agriculture and Life Sciences, Dr. Mario Ferruzzi, emphasized the urgency of the call to action to increase productivity growth, stating, "We want innovations coming from the farm fields that are actually going to drive those markets and economies. We need this critically around the globe. It will require that we work together to develop and promote these tools that can enhance our ability and really get us to the point where we can bridge that Valley of Death."

The GAP Initiative™ at Virginia Tech is poised to lead this effort by promoting collaboration across sectors and ensuring that solutions are comprehensive and user-centric; addressing both the immediate and long-term challenges of agricultural productivity in the face of climate change, resource constraints, and economic volatility.

CHAPTER 2

SETTING THE STAGE FOR PRODUCTIVITY GROWTH

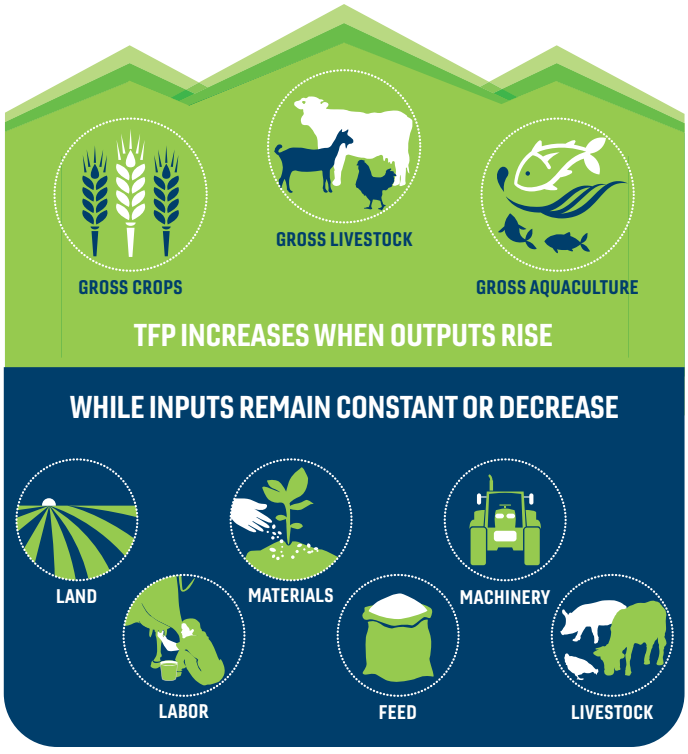
TRACKING TFPG WORLDWIDE: PROGRESS AND PROJECTIONS TOWARD 2050

Agricultural productivity growth isn't just about producing more food–it is about securing the future of global agri-food systems in the face of a growing global population, environmental degradation, economic shocks, and finite resources.

Agriculture is under growing pressure to meet the demands of a projected population of 9.6 billion by 2050 (United Nations, 2024), while also ensuring producer profitability, driving agriculture-led economic growth, enhancing food security, and conserving environmental resources. This will require a significant boost in productivity, a challenging endeavor made even more complex by issues such as limited arable land and water, ecosystem degradation, a shrinking rural labor force, and the adverse effects of climate change (Liu, Y. et al., 2020; Prăvălie et al., 2021).

Agricultural output can be increased by expanding the area under cultivation through the conversion of grasslands, forests, and wetlands into farmland, extending irrigation to existing fields, or intensifying the use of inputs such as fertilizers. Each of these strategies can be appropriate in given situations. However, increasing agricultural total factor productivity offers the most sustainable way to increase agricultural output.

Figure 1. Total Factor Productivity



Agricultural productivity is a measure of how efficiently agricultural resources and inputs such as land, labor, capital, livestock, fertilizers and other inputs, and feed are converted to outputs. Total factor productivity (TFP) considers the overall impact of multiple inputs collectively, rather than just one input. **TFP increases either by generating more output with the same or fewer resources, or by maintaining the same output while using fewer resources (Figure 1).**

TFP growth is driven by the adoption of new and existing technologies, improved practices, reallocating factors of production (e.g., land, labor), and higher value output. A robust enabling environment–including market access to productivity-enhancing tools, effective agricultural and rural advisory services, research and development investment, and evidence-based policies–are critical for enabling and sustaining TFP growth.

Introduced in 2010, the Global Agricultural Productivity (GAP) Index was developed to track trends in TFP growth and forecast the growth required–holding inputs constant–to sustainably meet rising demand for agricultural products by 2050. Based on the assumption that agricultural output would need to double to support a projected population of 10 billion people, the initial target growth rate was set at 1.73 percent annually during 2010-2050 (solid green line, Figure 2). Global annual TFP growth averaged 1.97 percent annually from 2000 to 2010, so this target appeared achievable. However, between 2013 and 2022 the global average annual TFP growth fell to 0.7 percent (dashed orange line, Figure 2)–far below the 2010 target. In light of lagging growth, evolving demographics and demand, and ever-pressing global nutrition security and environmental goals, for a second year in a row, the target growth rate must be revised upward to compensate for this consistently sluggish growth.

TFP growth must now average 2 percent annually from 2024 to 2050 to achieve sustainable agricultural production that meets the changing demand of our global population (dashed green line, Figure 2).

The sharp decline in TFP growth during 2013-2022 is notable for three reasons. First, it marks the end of three decades of output growth driven primarily by efficiency gains. Second, the current average annual growth rate of 0.7 percent is nearing that of the 60s, 70s, and 80s when input intensification was the primary driver of output growth (Figure 3). Third, it may be contributing to slowing output growth, which has fallen to its lowest level since before 1961 (1.7 percent annually).

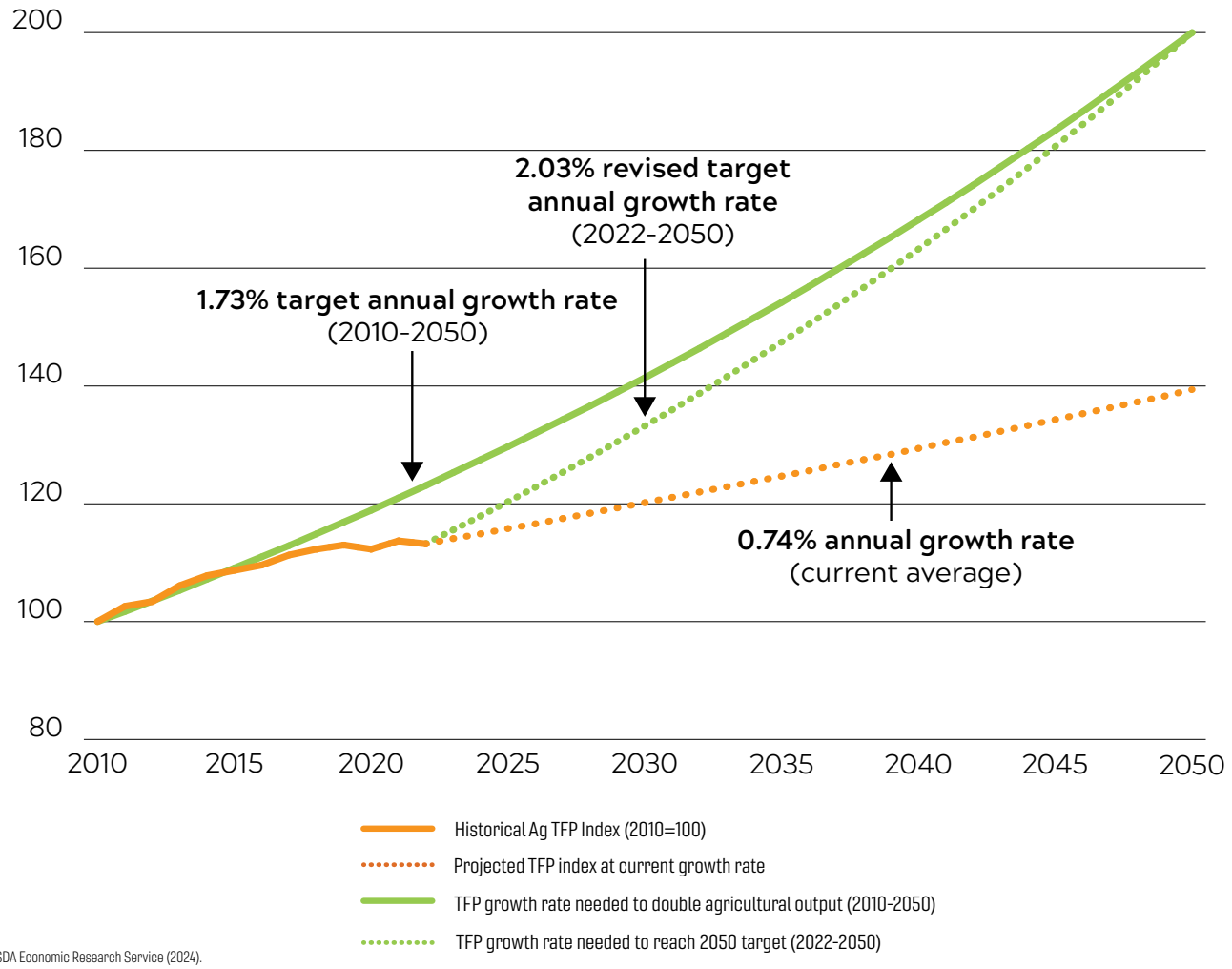
Why is lagging TFP growth such a concern and how can closing the growth gap help secure the economic, social, and environmental vitality of our agri-food systems?

Increasing TFP growth is imperative for the world to adequately feed its growing population through sustainable and efficient agricultural practices. Economically, reduced TFP growth diminishes competitiveness in global agricultural markets, adversely affecting trade balances and economic stability. It also deters investment in the agricultural sector, further stifling innovation and growth. Socially, the slowdown exacerbates inequalities, impacting smallholder farmers and rural communities, widening the gap between urban and rural prosperity. Reduced productivity growth also hampers the agricultural sector's ability to adapt to climate impacts, compromising global food supply stability. Failure to reverse the declining TFP growth trend may also lead to rising food prices, disproportionately affecting low-income households and exacerbating poverty and hunger. Environmentally, to compensate for lower productivity growth, countries may overuse inputs or natural resources, causing environmental degradation and long-term ecological damage. These combined economic, social, and environmental impacts highlight the urgent need for action.

Figure 2.

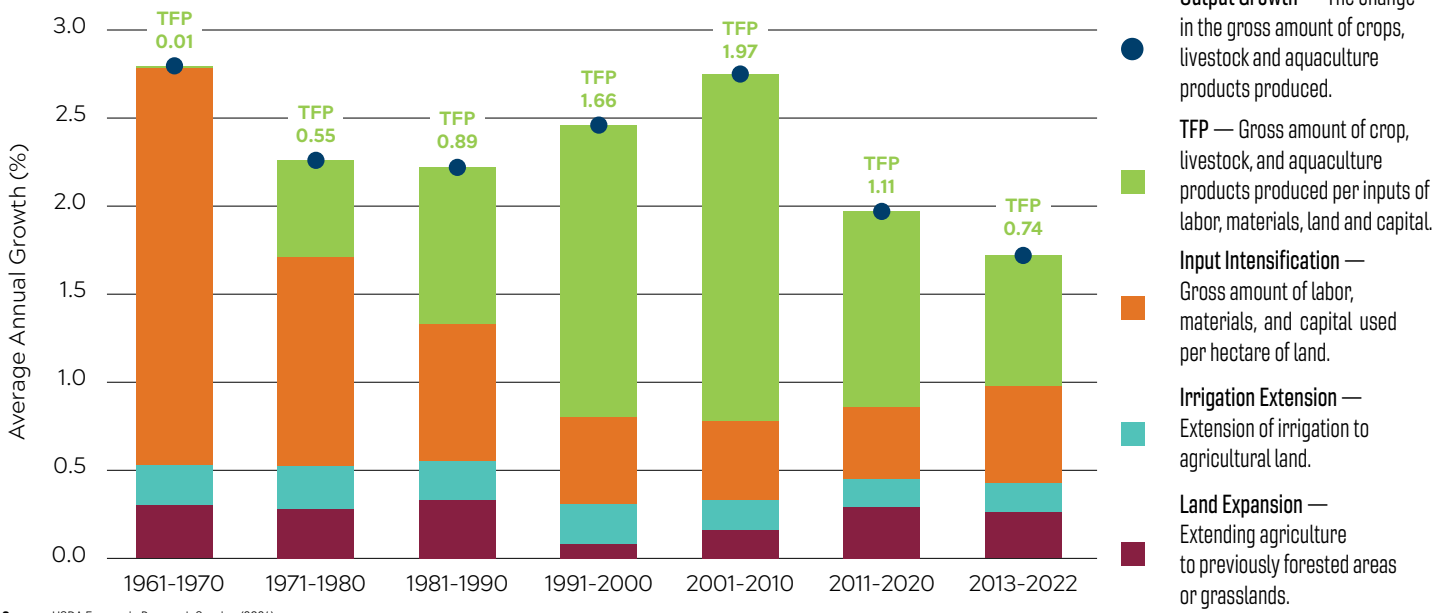
2024 GLOBAL AGRICULTURAL PRODUCTIVITY INDEX

TFP growth rates are based on a 10-year rolling average



Source: USDA Economic Research Service (2024).

Figure 3. Global Sources of Agricultural Output Growth, 1961–2022



Source: USDA Economic Research Service (2024).

REGIONAL TRENDS & LEADING COUNTRIES

During 2013-2022, South Asia led all global regions in average annual agricultural output growth (>3 percent), driven primarily by strong TFP growth, averaging 1.44 percent annually (Figure 4). Input intensification, led by growth in fertilizer use, also contributed significantly to output growth. India was the primary contributor to the regional average, achieving 1.69 percent average annual TFP growth, a result of its efforts to modernize agriculture through increased mechanization and optimized input use (Liu et al., 2020). The adoption of information and communications technology (ICT) to disseminate agricultural information has also been crucial in boosting productivity in the region.

Sub-Saharan Africa (SSA) emerged as a notable contributor to global agricultural output growth, though it lagged in average annual TFP growth at 0.37 percent (Figure 4). In contrast to South Asia, the region's output growth was primarily driven by land expansion and input intensification, as limited technological adoption and underinvestment in agricultural R&D slowed productivity gains. These challenges, compounded by the impacts of climate change (Ortiz-Bobea et al., 2021), have led to widespread land conversion at an alarming rate, with negative effects on biodiversity (Koch et al., 2019). Land expansion for agricultural use accounted for two-thirds of the region's output growth during the past decade (Figure 4). Overall, more than 4 percent of the region's total land was converted to agricultural use during this period. Countries within globally recognized biodiversity hotspots such as Nigeria, Côte d'Ivoire, Ghana, and Uganda have significantly expanded agricultural lands, making the environmental impact of this land use change particularly concerning (Huntley, 2023).

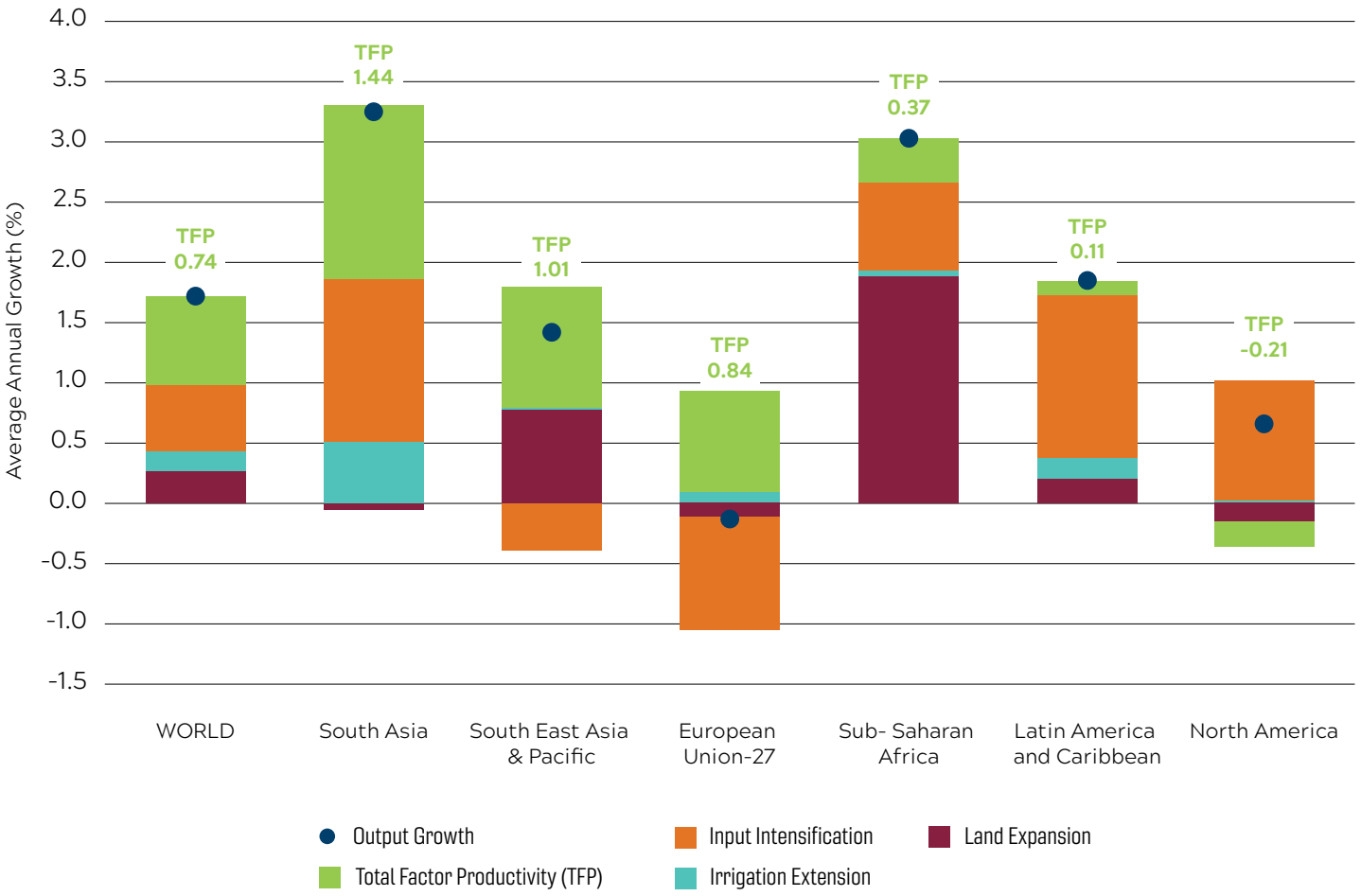
In Southeast Asia and the Pacific, agricultural output growth averaged 1.42 percent annually during 2013-2022. This growth was primarily driven by TFP growth, which contributed 1.01 percent. Land expansion also contributed 0.77 percent to the output growth. Interestingly, input intensification had a negative contribution of -0.39 percent, indicating a reduction in reliance on inputs such as fertilizers. Irrigation extension had a minimal impact with 0.02 percent contribution.

Latin America and the Caribbean (LAC) only had a slight increase in average annual TFP growth during 2013-2022 (0.11 percent). The primary contributor to the 1.85 percent average annual output growth was input intensification (1.35 percent annually). Agricultural land use growth in the region increased by 0.20 percent annually.

The European Union's (EU) average annual TFP growth was 0.84 percent. The average annual input intensification growth rate contracted by a notable 0.94 percent. Even though the EU's "Farm to Fork Strategy" is only now coming into effect, farmers in the region appear to be responding to the expected demands to reduce input use. However, this significant decline in input use and slowing agricultural productivity growth, compared to the previous decade, resulted in a 0.13 percent decrease in the EU's average annual agricultural output growth rate.

North America recorded a modest average annual output growth of just 0.66 percent. This is a considerable drop from the 1.49 percent annual growth seen in the 1990s. During

Figure 4. Sources of Agricultural Output Growth by Region, 2013-2022



Source: USDA Economic Research Service (2024).

the recent period, North America experienced negative TFP growth, averaging -0.21 percent annually, though Canada saw a slightly positive TFP growth, averaging 0.15 percent annually. This downturn in TFP growth can be attributed, in part, to a reduction in public support for agricultural research and development (Nelson & Fuglie, 2022), as well as increasing political and social forces that seek to dictate choices affecting technology adoption (Alston & Pardey, 2020). Given the historically significant and positive global impact of U.S. agricultural innovation, this sharp slowdown in TFP growth should raise concerns about potential global repercussions.

The sharp decline in global average annual TFP growth from the 2000s underscores an urgent need to find ways to return to efficiency-driven gains in agricultural output growth rather than over-reliance on practices such as input intensification and land expansion that may contribute to environmental degradation and biodiversity loss. TFP growth must be raised to an average annual global target of 2 percent. The South Asia region sets a vision of the possibilities with focused investment in research and development, sustainable productivity-enhancing technologies, mechanization, and producer-centric policies demonstrating clear returns to robust TFP growth.

Sustainable agricultural productivity growth during the next 25 years is the only viable pathway for securing an equitable, environmentally sound, and food secure future.

CHAPTER 3

SOUTH ASIA'S AGRICULTURAL SUCCESS

LEADING THE WORLD IN TFP GROWTH THROUGH EFFICIENCY AND INNOVATION (2013-2022)

South Asia's agricultural sector has experienced robust output growth across the past six decades, with an average annual growth rate of 3.25 percent during 2013-2022 (Figure 5). Since the 2000s, the driving force of this increasing output has been total factor productivity (TFP) growth. The region's agricultural productivity growth reveals the complex interplay of technology, policy, environment, and socio-economic factors, offering valuable policy and investment insights for other regions struggling with lagging TFP growth, while pursuing sustainability and food security.

SOUTH ASIA'S AGRICULTURAL TRANSFORMATION

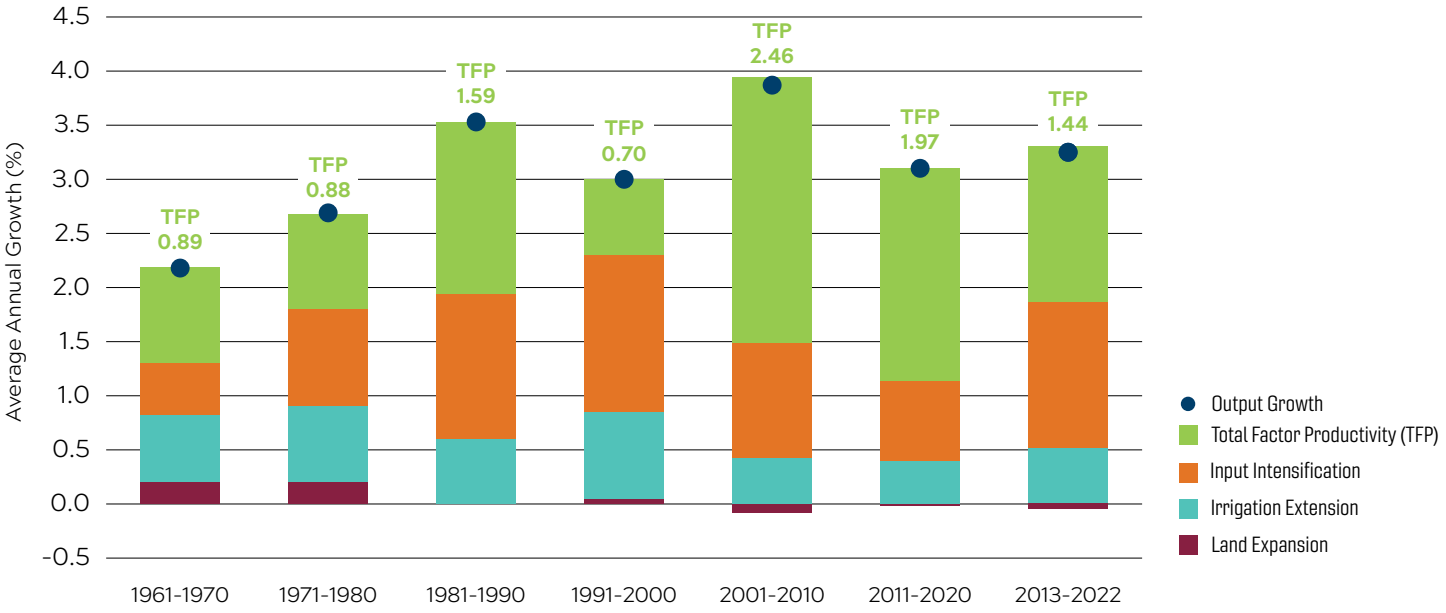
South Asia's TFP growth has consistently been above the world average during the past six decades, with the exception of the 1990s. Average annual TFP growth peaked at 2.46 percent annually during the 2000s before slowing down to an annual average rate of 1.44 percent in 2013-2022 (Figure 5). The region has outpaced many others, including North America and the EU.

South Asia's efficiency gains have kept the average annual agricultural output growth at or above 3 percent since the 1980s. The significant increase in agricultural output relative to input usage (Figure 6) can be attributed to substantial investment in research and development (R&D), technical change, adoption of improved varieties, increased market access, a stronger agro-services sector, and better resource management practices, rather than land expansion.

Although crop and animal output growth have both been steadily rising since the early 1970s, animal output has experienced dramatic growth since the early 1980s (Figure 7). This can be partly attributed to India's successful investment in the dairy sector via the National Dairy Development Board's "Operation Flood," making the country the world's largest producer of milk (Gulati & Juneja, 2021). Rising demand for animal source foods as a result of increased urbanization and wealth also contributed to animal output growth along with improved veterinary services, subsidies for animal feed, government supported breeding programs, and financial assistance for smallholder producers.

South Asia's efficiency gains have resulted from relatively stable labor and land use since the 1980s (Figure 8). Material input, particularly fertilizer use, has surged since the 1970s, growing at an average annual rate of 4 percent (Figure 8). This period coincides with the full realization

Figure 5. Sources of Agricultural Output Growth in South Asia, 1961-2022



Source: USDA Economic Research Service (2024).

of the Green Revolution's impacts, which saw an increase in the use of nitrogen fertilizers required by high-yielding fertilizer-responsive varieties (Aryal et al., 2020; Begho et al., 2022; Bijay-Singh et al., 2022). Additionally, as producers increasingly target higher-value markets for cotton, fruits, and vegetables, more intensive input use may be required (Morita, 2021). The steady rise in capital, particularly since the 1990s, reflects the region's push towards increased machinery use for more commercialized and efficient agriculture (Takeshima & Justice, 2020).

South Asia's sustained success in maintaining TFP growth at or near the global target sets a benchmark for other regions. By effectively integrating modern farming practices, technological innovation, and targeted research and development, South Asia has shown that it is possible to achieve sustained productivity gains while pursuing environmental and social sustainability in agriculture. However, the overall regional decline in TFP growth during 2013-2022 indicates the need for a renewed focus on sustainable agricultural productivity-enhancing practices and policy changes to revitalize TFP growth in the coming years. Enhancing efficiency alongside strategic irrigation extension and input use will be essential for ensuring long-term agricultural resilience and sustainability, positioning South Asia as a leader in global agricultural innovation and sustainability (Liu, J. et al., 2020).

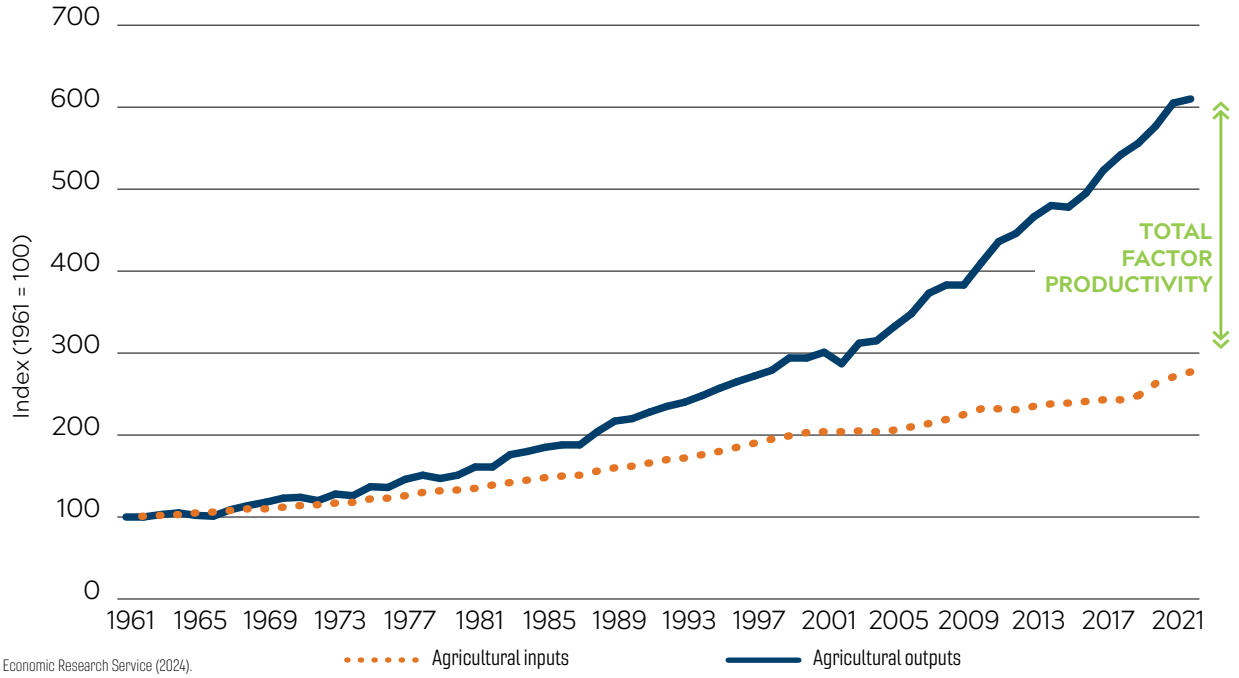
TFP GROWTH IN SOUTH ASIA BY COUNTRY

Between 2013 and 2022, India, Nepal and Pakistan were engines of TFP growth in the region, averaging 1.69, 1.47 and 1.40 percent annual growth respectively (Figure 9). In India and Pakistan, TFP growth was the leading contributor to output growth while in Nepal input intensification was the primary driver of the notable 3.07 percent average annual output growth. For Sri Lanka, output growth averaged 0.83 percent annually, primarily driven by land expansion (0.30 percent) and TFP growth (0.28 percent), while contributions from input intensification and irrigation extension were marginal.

In contrast, Bangladesh suffered an annual TFP growth contraction of 1.52 percent annually with 3.19 percent average annual output growth mainly driven by irrigation extension (3.21 percent) during 2013-2022. Bhutan experienced an output contraction of -0.10 percent annually, predominantly due to significant land growth contraction (-2.38 percent) and TFP growth contraction (-0.28 percent).

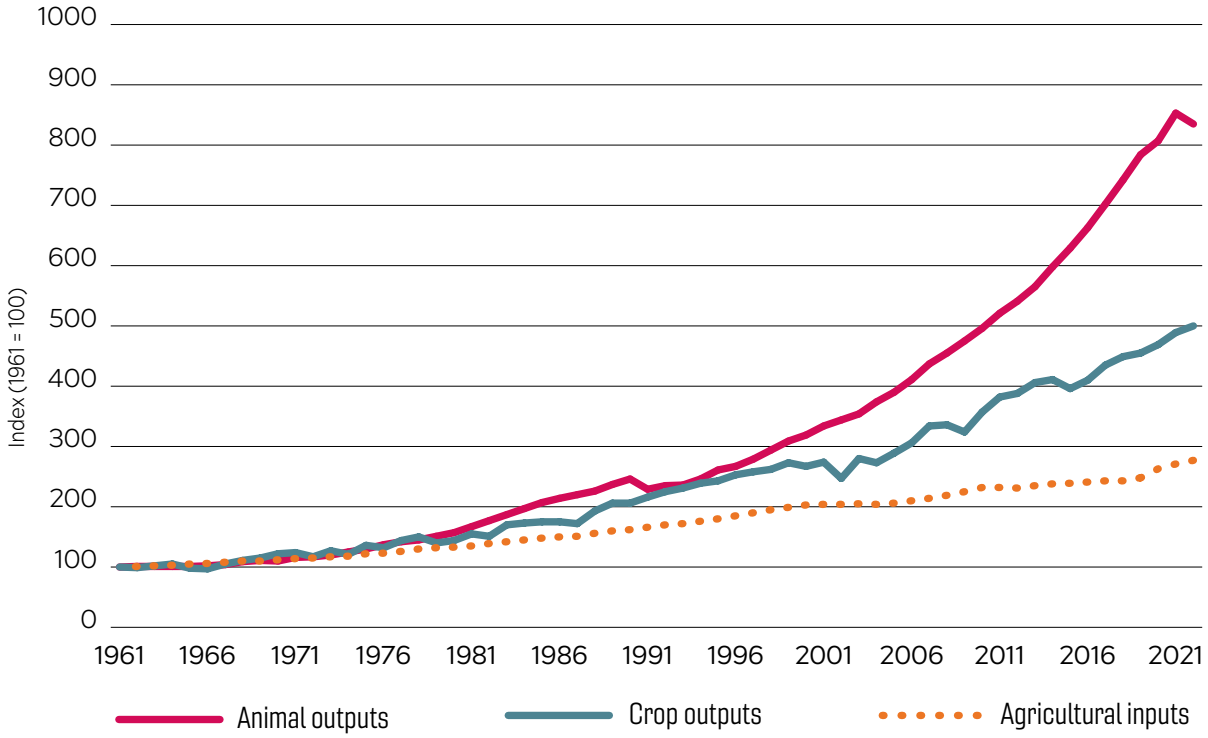
This period saw a downturn in average annual agricultural TFP growth across all South Asian countries compared to the robust average annual TFP growth observed during the 1990s and 2000s. Even India, which has consistently led the region, experienced a deceleration, though it remained ahead of its South Asian neighbors. The widespread slowdown across the region suggests that significant challenges, such as global economic instability and adverse climate events, have negatively impacted efficiency (Ortiz-Bobea et al., 2021). Diminishing returns from previously successful agricultural interventions may also be impacting productivity growth (Fuglie, 2018). The downturn was particularly pronounced in countries like Sri Lanka and Bangladesh, with Bangladesh experiencing a negative TFP growth rate, highlighting underlying vulnerabilities that were likely exacerbated during this period (IFPRI, 2022; World Bank Group & Asian Development Bank, 2021).

Figure 6. South Asia Growth in Agricultural Output, Input, and TFP—1961-2022



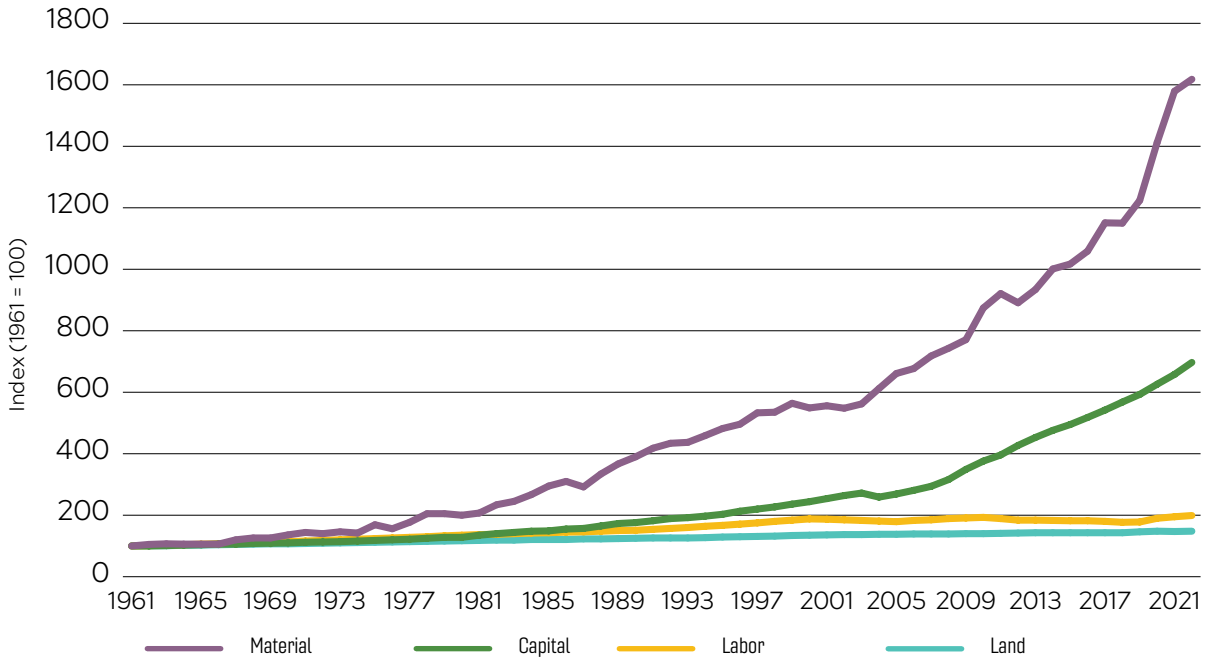
Source: USDA Economic Research Service (2024).

Figure 7. South Asia Agricultural Output Growth by Type—1961-2022



Source: USDA Economic Research Service (2024).

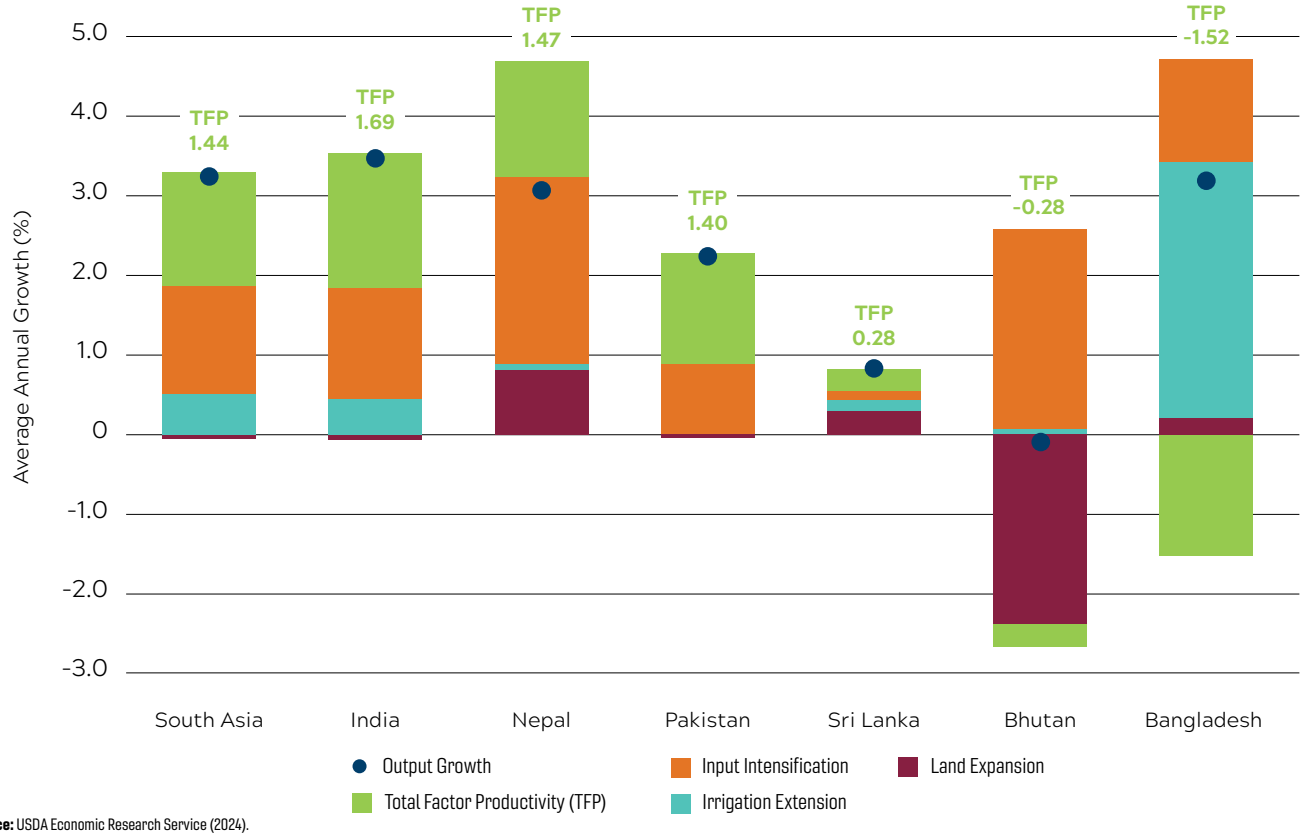
Figure 8. South Asia Agricultural Output and Input Growth—1961-2022



Source: USDA Economic Research Service (2024).

» SOUTH ASIA'S AGRICULTURAL OUTPUT GROWTH HIGHLIGHTS A CRUCIAL REALITY. While we may avoid food shortages by 2050 even if the 2 percent target growth rate isn't achieved, relying on unsustainable methods to meet global demand could have serious consequences. Failing to focus on sustainable productivity growth risks driving production practices, products, and technologies that erode producer profitability and results in resource degradation.

Figure 9. Sources of Agricultural Output Growth by Country – South Asia, 2013-2022



Source: USDA Economic Research Service (2024).

INDIA'S AGRICULTURAL EVOLUTION: FROM RESOURCE-INTENSIVE GROWTH TO INNOVATION-DRIVEN PRODUCTIVITY GAINS

India's agricultural sector has undergone a notable transformation during the past six decades. While input intensification has made significant contributions to output growth since the 1960's, peaking at 1.54 percent annually during 1991-2000, TFP growth emerged as the primary driver in the 2000s onward (Figure 10). The increasing prominence of TFP growth signals a transition towards more efficient and innovative agricultural practices, technologies, and policy supports. During 2001-2010, TFP growth's contribution to output growth peaked at 2.50 percent annually. The country's unprecedented productivity gains bolstered overall agricultural output growth to 3.87 percent annually. During the most recent decade (2013-2022), TFP growth was 1.69 percent annually (Figure 10), reflecting India's continued success in enhancing agricultural productivity through innovation and efficiency.

India's sustained TFP growth can be largely attributed to the nation's extensive investments in agricultural research and development (R&D), particularly during the 2000's. R&D expenditure grew from $4 billion annually in 1996 to $20.8 billion in 2020 (in 2015 U.S. dollars), representing 0.65 percent of GDP (World Bank, 2024). The country invested 0.53 percent of its agricultural GDP into the sector's R&D in 2016, notably higher than the 0.26 percent average in South Asia (Kandpal et al., 2024). Moreover, India is home to the largest and most qualified pool of agricultural researchers in South Asia (Stads & Rahija, 2019).

Private investment in agricultural R&D, as measured by the share of gross domestic expenditure on R&D, has also increased in the past several decades–growing from 24.3 percent annually in 1990-91 to 40.8 percent by 2020-21. The country's private investment in agricultural input R&D increased more than tenfold from $23 million annually in 1985 to $250 million in 2009 (in 2005 U.S. dollars) and further to $1.66 billion in 2020 (Kandpal et al., 2024).

Along with these substantial investments in R&D, India's increasing agricultural productivity has been propelled by advancements in crop improvement, precision agriculture, irrigation technologies, digital agriculture, mechanization, sustainable practices, post-harvest management, financial services, research and extension services, supportive government policies and initiatives, and multi-sectoral collaboration (Figure 11). These developments have enabled producers at all scales of production to access

and adopt cutting-edge technologies, knowledge, and practices, driving significant improvements in agricultural output and efficiency.

Genetic Improvement. Green revolution technologies such as semi-dwarf wheat and rice varieties significantly increased productivity (Reddy, 2024; Singh et al., 2023), while reducing poverty and food insecurity through lower grain prices (John & Babu, 2021; Martin et al., 2024). Continuous development and adoption of high yielding varieties of staple crops such as rice, wheat, and maize have played a significant role in increasing productivity (Fuglie & Echeverria, 2024).

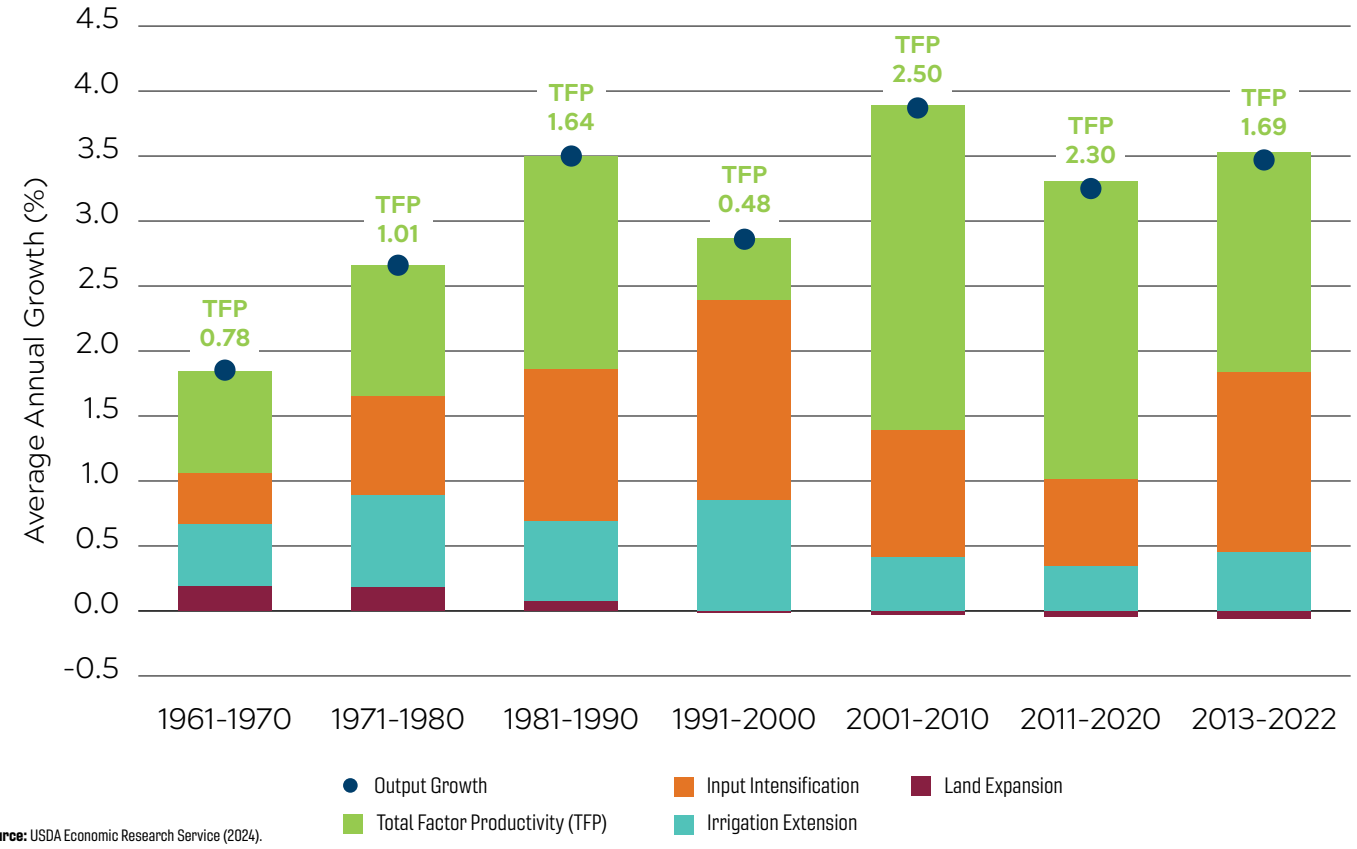
Precision Agriculture. The adoption of precision agriculture techniques and tools in India, though still in its early stages, holds significant potential for improving production quality, optimizing resource utilization, and enhancing environmental protection (Balkrishna et al., 2023). Emerging precision practices and technologies include variable rate technology, precision land leveling, precision planting, and precision nutrient management. Tools such as the leaf color chart, Soil Plant Analysis Development meter, GreenSeeker®, an optical sensor system designed to assess crop health, site-specific nutrient management, and soil test-based crop management are increasingly adopted (Kumar et al., 2024).

Irrigation Technologies. Peaking at 0.85 percent annually during the 1990s, the growth rate of irrigation extension has since fluctuated, dropping to 0.34 percent annually during the 2010s (Figure 10). Despite the challenges of over-extraction and declining groundwater levels, technologies such as micro-irrigation, rainwater harvesting, and watershed management have increased water delivery to crops, particularly in water-scarce regions, while maintaining use efficiency and minimizing run-off (Angom & Viswanathan, 2023; Puppala et al., 2023).

Digital Agriculture and ICT. Indian farmers are increasingly leveraging mobile apps and digital platforms to access real-time weather updates, market information, and advanced farming techniques (Goswami et al., 2023). These tools help producers make more informed decisions, optimizing crop yields and improving profitability. For example, the E-Choupal initiative was launched by the Indian conglomerate ITC, which has benefited rural farming by providing farmers with internet access and empowering them with information on crop prices, weather forecasts, and best agricultural practices, thereby reducing their dependence on middlemen (Sinha, 2024).

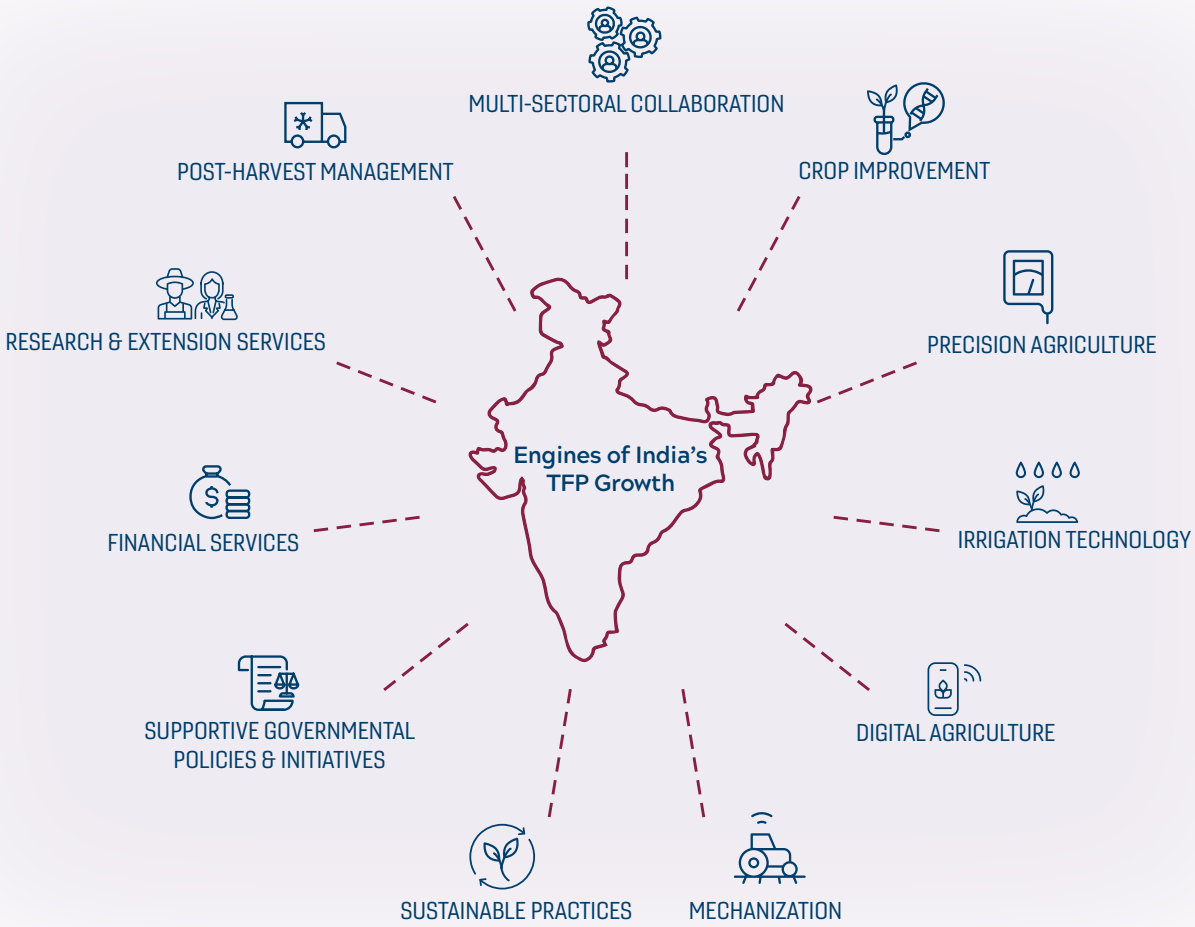
Mechanization. The adoption of modern farm machinery such as tractors and harvesters has boosted efficiency and reduced labor costs in India. Custom hiring centers (CHCs), expanded by government initiatives, make advanced machinery accessible to small farmers, increasing

Figure 10. Sources of Agricultural Output Growth – India, 1961-2022



Source: USDA Economic Research Service (2024).

Figure 11. Engines of India's TFP Growth



productivity while keeping costs manageable. Rajasthan and Madhya Pradesh states have led in establishing thousands of new CHCs, supporting small-scale farmers effectively (Keil et al., 2016).

Sustainable Practices. In India, conservation practices such as minimum or zero-tillage farming, crop rotation, and cover cropping are increasingly being adopted. These practices have led to notable improvements in soil health, which in turn contributes to higher productivity growth (Pradhan et al., 2016). India's National Mission on Sustainable Agriculture, a government initiative aimed at enhancing agricultural productivity, actively promotes these practices, encouraging farmers to adopt zero-tillage and other conservation agriculture techniques to enhance sustainability and long-term agricultural resilience.

Post-Harvest Management and Supply Chain Improvements. The expansion of cold storage facilities and better warehousing practices have reduced post-harvest losses (Kumari & Dhingra, 2024). Growth in the food processing industry has added value to agricultural products, creating additional incentives to producers to invest in productivity-enhancing technologies and practices.

Financial services. Crop insurance schemes, such as the Pradhan Mantria Fasal Bima Yojan, provide insurance coverage against crop losses, helping farmers to access bank loans, mitigate risks, and stabilize incomes (Radhika & Rengarajan, 2024). Direct transfer of subsidies–for fertilizers and seeds for example–to farmer bank accounts has streamlined financial support and reduced leakages in the system (Barnwal, 2018; Laishram & Kumar, 2020).

Research and Extension Services. Ongoing research by institutions such as the Indian Council of Agricultural Research (ICAR) has led to the development of new crop varieties, pest management strategies, and farming practices tailored to India's diverse agro-climatic conditions (ICAR, 2022). Strengthened extension services have improved the dissemination of knowledge and practices, helping farmers adopt new technologies more rapidly (Anil et al., 2024). Public-private partnerships have enhanced extension services and farmer education (Sharma et al., 2020).

Government Policies and Initiatives. From the early 2000s to 2020, government policies significantly boosted the biotechnology sector with tax incentives, funding programs, and subsidies, expanding access to biotechnologies (Singh, 2020). Through the Agricultural Technology Management Agencies, stakeholders participated in decentralized planning, supporting cooperatives and R&D efforts (Manisha et al., 2024).

Multisectoral collaboration. Multisectoral collaboration has been a cornerstone of India's success in agricultural productivity growth. The Green Revolution brought together government support, scientific research, and private industry to boost wheat and rice yields, dramatically reducing food insecurity (Swaminathan, 2006). Similarly, the National Food Security Mission has combined government funding, ICAR research, and local farmer training to improve pulse and oilseed production (ICAR, 2022). Partnerships, such as those under the Pradhan Mantri Krishi Sinchayee Yojana, have enhanced water resources through state and private sector support, benefiting millions of farmers by increasing investments in field-level irrigation, improving on-farm water use efficiency to minimize water wastage, and promoting the adoption of precision irrigation techniques (Government of India, 2021).

India's agricultural sector evolved from a resource intensive growth model to one increasingly driven by productivity gains. The country's TFP growth trajectory highlights the critical role of R&D and complementary policy and delivery mechanisms to advance agricultural productivity in the face of changing resource availability and environmental challenges. Public and private sector action and investment has driven productivity growth and set the country up for future gains, establishing India as a leader in sustainable agricultural productivity growth in the region and the world.

CHAPTER 4

POLICY AND INVESTMENT PRIORITIES FOR TACKLING THE TFPG SLOWDOWN

The GAP Initiative™ at Virginia Tech offers five evidence-based policy, investment, and research priorities to inform actionable steps for the systems change needed to reinvigorate critically needed sustainable TFP growth. The priorities outlined here provide illustrative action points for policy, investment, and research. Importantly, tackling multiple priorities through high impact bundles of productivity-enhancing technologies and practices, distribution mechanisms, socio-economic tools, and policy levers will power notable productivity growth in the next decade.

PRIORITY 1 - INVEST IN AGRICULTURAL INNOVATION SYSTEMS

To accelerate sustainable TFP growth, it is essential to foster technological advancements, improve practices, and adapt existing technologies to new contexts and environmental conditions through research and development (R&D). This is equally important in regions with robust growth and those where growth has been lagging. Public and private R&D have demonstrated returns to productivity growth. For example, between 1962 and 2011, a 1 percent increase in R&D capital led to a global average 0.18 percent increase in TFP growth. However, the returns on TFP growth vary significantly across regions: high-income countries saw a 0.67 percent increase, compared to 0.38 percent in low- and middle-income countries and just 0.17 percent in sub-Saharan Africa (Fuglie, 2018).

Too often solutions from R&D get stuck 'on the shelf,' never reaching agri-food system actors, especially smallholder producers, that need them the most. Additionally, some existing knowledge, practices, and technologies have not yet reached last-mile farming communities. Market failures and socio-economic disparities limit the adoption of productivity-enhancing technologies (Fuglie et al., 2019).

Investments beyond R&D alone will be needed to realize the target average annual agricultural productivity growth rate of 2 percent. Agriculture innovation systems (AIS) create critically needed dissemination and adoption pathways for existing and new knowledge, technologies, and practices. This includes the infrastructure (social, political, physical), human capital and skills development, financial systems, partnerships, socio-cultural considerations, and environmental conditions required for producers at all scales of production, but especially smallholder producers, to access and sustainably adopt productivity-enhancing tools (e.g., technologies, practices, services). AIS operate as a network of organizations, enterprises, and individuals supported by institutions and policies, all focused on bringing products, processes, and organization innovations into practical use (FAO, 2024; Oliveira, 2024).

Extension services are pivotal in high-performing AIS, serving as the critical link between research institutions, private sector, and farmers. They facilitate the transfer of knowledge, technologies, and best practices, enabling farmers to adopt innovations tailored to their specific needs and local conditions (Kamara et al., 2019).

Appropriate and important for countries at all income levels, investing in AIS functionality will ensure that producers at all scales of production can access productivity-enhancing tools that are attractive, affordable, accessible, and appropriate for their operations, supporting their progression along the productivity frontier. AIS strengthening will require development of efficient, blended, and innovative dissemination pathways such as extension systems, grassroots movements, business models, infrastructure, skills, and motivations of system actors, financing, and institutional ingenuity (including policy) to ensure every farmer has access to every proven and appropriate tool for sustainable productivity growth.

To address barriers to AIS development, multi-disciplinary and cross-sectoral dialogues are essential. By bringing together diverse perspectives, such dialogues will create strong AIS enabling environments, address behavioral factors affecting adoption, and mitigate external shocks. This will ensure that farmers, regardless of scale or production type, have access to the appropriate tools needed for sustainable agricultural productivity growth.

Actions to Invest in Agricultural Innovation Systems

Policy

Strategic alliances and investment plans to close the agricultural R&D intensity gap (~$13 billion according to some estimates) in low- and middle-income countries (Nin-Pratt, 2021).

Multi-disciplinary and cross-sectoral dialogues to bring together diverse perspectives and advance awareness of evolving scientific discoveries and field evidence of impact.

Actionable policy and implementation frameworks to strengthen national extension systems, including innovative ways to deliver foundational agricultural science to last mile producers and feedback mechanisms into national and international agricultural R&D systems.

Policy initiatives to address advanced agricultural challenges, such as labor shortages, market saturation leading to profit loss, and compliance with increasingly stringent sustainability standards.

Investment

Investment incentives to accelerate the delivery of proven solutions to producers at all scales of production.

Private sector incentives for technology transfer to smallholder producers.

Financial models for extension systems to maximize longevity and create entry points for investment.

Funding mechanisms to support the adoption of labor-saving technologies, market expansion strategies, and advanced sustainability practices to meet regulatory demands and consumer expectations.

Research

Fill evidence gaps on effects of the enabling environment, behavioral factors, and external shocks on accessibility, affordability, and attractiveness of existing and new productivity-enhancing products, services, and practices.

Iteratively develop processes for evaluating science and research to inform policy and the enabling environment.

Viable business models that will accelerate delivery of existing and new productivity-enhancing technologies to last-mile agricultural communities and the contexts in which they will maximize impact.

PRIORITY 2 - EXPAND ROBUST AND RESILIENT MARKET ACCESS

Producers at all scales of production must be able to access competitive input and output markets. Price discovery, minimized search costs, and information transparency help producers to make informed decisions on the inputs required to optimize productivity and profitability, while assessing whether the benefits of a particular technology, product, or service will justify the costs of adoption.

Policies have direct effects on the prices that producers face–prices they receive for their agricultural products and the prices they pay for purchased inputs and non-agricultural goods (Hendricks et al., 2023; Nakelse et al., 2018). Transportation, ICT, storage, and financial infrastructure also play a key role in input and output prices. For example, in lower resource settings, producers often face suppressed commodity prices when they cannot store their crops until market conditions improve.

Lack of market access can also exacerbate post-harvest losses, particularly for perishable goods such as fruits, vegetables, dairy, and meat that require cold chain logistics. These high-value, nutrient-dense products are essential for both producer incomes and consumer nutrition.

Distance to markets, availability of storage facilities, access to existing and new technologies, products, and services, ability to finance these tools, and access to reliable market data influence production decisions, often determine a producer's willingness to invest in quality and quantity of production. Therefore, investing in market access infrastructure can incentivize productivity enhancements while supporting producer livelihoods and advancing food and nutrition security goals.

Market access must be robust–enduring across changes in administrations, political agendas, and investment cycles–to support sustainable TFP growth. Too often, producers find themselves caught in the crossfire of shifting policy priorities, leading to reduced productivity and profitability. Market access must also be resilient, capable of withstanding shocks such as extreme weather events, conflicts, and economic downturns. Agriculture sector growth strategies and sustainability commitments need to integrate strong planning and implementation tactics from the outset to expand market access that is both robust and resilient. This is essential for fostering inclusive and sustainable agricultural productivity growth.

Actions to Expand Robust and Resilient Market Access

Policy

Formation, operations, and good governance of producer groups to increase access to input and output markets.

Dissemination of ICTs and other technologies expand access to domestic and international markets for high value products.

Investment in collecting accurate, real-time market data and expand access, especially to smallholder producers.

Investment

Infrastructure investment to increase access to productivity-enhancing tools (e.g., rural road infrastructure, digital marketplaces) and output markets.

Partnerships to overcome structural barriers to market access (e.g., gender, socio-economic status).

Research

Research and development on innovative infrastructure solutions (e.g., drones, transportation, cold storage).

Innovative financial tools and services that will increase access to input and output markets – e.g., smart contracts, blockchain.

Tools to help producers use price and market data in production and business decisions.

PRIORITY 3 - STRENGTHEN REGIONAL AND GLOBAL TRADE

Regional and global trade have demonstrated positive impacts on agricultural productivity growth by opening up larger markets, creating opportunities for specialization, and facilitating the flow of productivity-enhancing tools. Access to regional and international markets enhances competitive prices, which incentivizes investment in improved inputs and technologies. Trade also facilitates the exchange of knowledge, innovations, and best practices across borders, driving productivity gains. Additionally, global trade fosters competition, which pushes producers to enhance their efficiency and quality standards.

Trade liberalization, aligning trade agreements with transparent policies, lowering trade costs, and consistently enforcing regulations are means of strengthening regional and global trade to create returns to TFP growth. For instance, in 13 African countries, evidence shows that reducing trade-distorting agricultural support coupled with good governance can increase TFP growth (Sunge & Ngepah, 2020). While national policies contributed more to output growth, South-South trade produced substantial productivity gains, matching or in some cases surpassing South-North trade benefits. This emphasizes the importance of regional trade, particularly on the African continent (Sunge & Ngepah, 2020).

Efforts to strengthen regional and global trade should account for key factors that can shape the extent of trade's influence on TFP growth. For example, capital formation and a strong institutional environment can amplify the positive effects of trade on TFP. Conversely, high levels of debt may hinder productivity gains (Teweldemedhin & van Schalkwyk, 2010; Zhu et al., 2022).

Actions to Strengthen Regional and Global Trade

Policy

Examine the impact of trade policies that are biased against proven, sustainable productivity-enhancing tools including barriers such as tariffs, quotas, and bans.

Harmonize agricultural standards and regulations related to food safety, quality, and environmental sustainability.

Identify trade policies and interventions that inherently prevent smallholder producers' participation in high value regional and global markets.

Investment

Digitize supply chain logistics, particularly those that include last-mile agricultural communities.

Funding flows to mid-size and large producers and companies to support upgrading to higher value regional and global markets.

Research

Demand trends, trade flows, and barriers to regional and global trade.

Trade barriers and policies with the greatest impact on agricultural productivity. Follow up with multi-sectoral dialogues on next steps to reduce barriers and take advantage of trade opportunities.

Trade mechanisms that could increase flows of production tools to regions where agricultural productivity growth has been lagging.

PRIORITY 4 – REDUCE LOSS AND IMPROVE QUALITY OF OUTPUTS

Reducing food loss and waste (FLW) and improving output quality contribute to agricultural productivity growth by increasing both the value and quantity of usable output from the same or fewer inputs. In particular, reduction of food loss increases land and water use efficiency, particularly when losses originate upstream (Cattaneo et al., 2021). Higher quality outputs attract higher market prices, which creates a positive feedback loop for producers, incentivizing investment in productivity-enhancing tools for higher value goods.

As pressures from changing climate, pests, disease, and limited access to resources such as affordable financing continue to intensify, it is essential to tailor FLW reduction policies and technologies to specific commodities and local contexts. If complemented with producers' knowledge and experience, there is significant value to capture from reduced waste and improved product quality - especially in regions where TFP growth is lagging.

In addition to productivity gains, reducing FLW and improving quality also offers other benefits such as reduced greenhouse gas emissions, GDP growth up to 0.8 percent (Rutten & Verma, 2014), increased food and nutrition security, and improved food safety. However, there is evidence of tension between productivity gains and other positive impacts due to the rebound effect. Efficiency improvements and subsequent price decreases may lead to increased consumption, potentially offsetting the environmental, economic, and food security benefits of reducing FLW (Hegwood et al., 2023). The magnitude of the offset and occurrence of negative externalities depends on where in the supply chain FLW management occurs (Cattaneo et al., 2021). Thus, policy and investment efforts need to include carefully targeted approaches to FLW reduction and quality improvement to maximize system benefits and minimize unintended consequences.

Actions to Reduce Loss and Improve Quality of Outputs

Policy

Intervention points based on rigorous models that consider price transmission mechanisms, economic factors, etc.

Complementary policies and strategy for developing agricultural innovation systems and post-harvest loss reduction.

Investment

Storage, transportation, and processing technologies – particularly for high value, nutritious foods.

Distribution channels that will reduce or eliminate food shortages.

Research

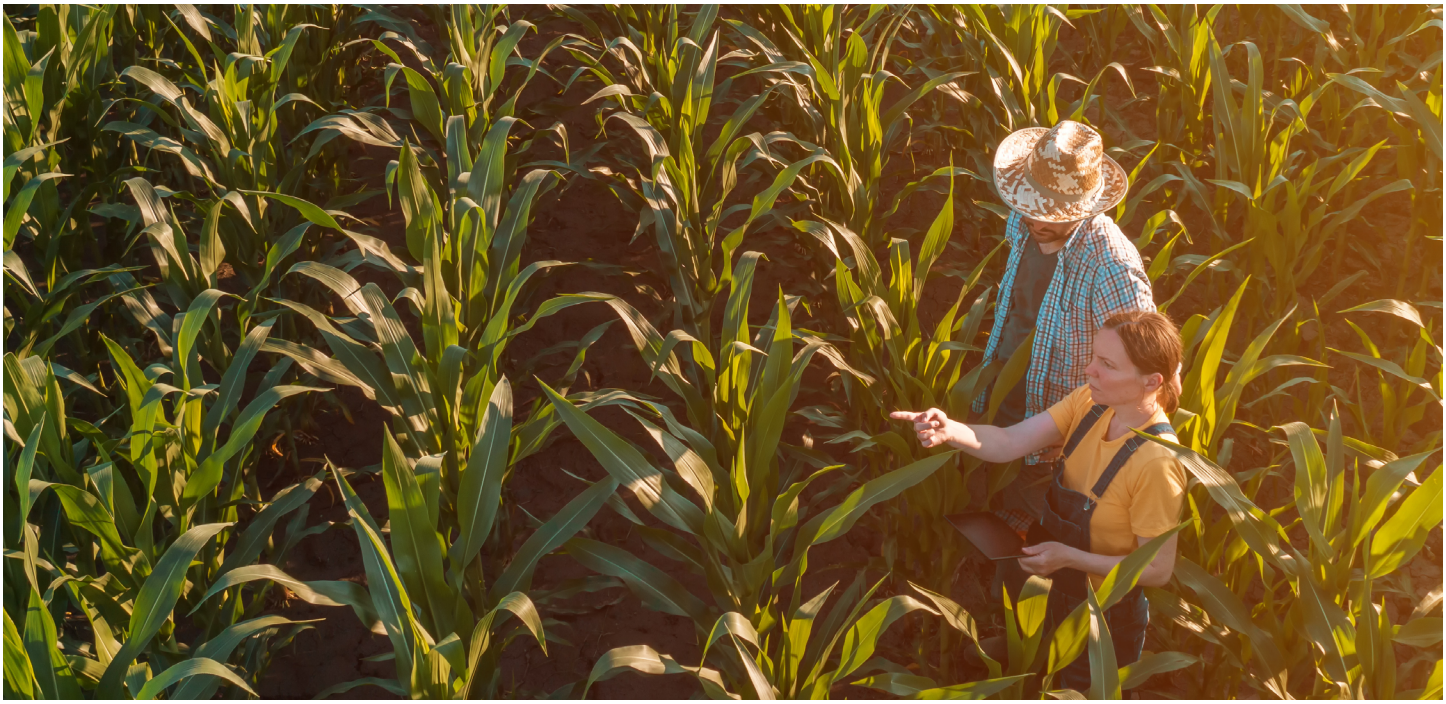
Modeling on the productivity, environmental, and food security impacts of reducing food loss and waste to identify highest impact intervention points.

Define the linkages between food loss, food shortages, and food security to identify action points.

PRIORITY 5 - CULTIVATE PARTNERSHIPS AND COOPERATION

Bringing together stakeholders from across value chains, sectors, and backgrounds to pool resources, share knowledge, and drive innovation will create a multiplier effect in sustainable agricultural productivity growth. Partnerships activate strong innovation systems and accelerate the development and dissemination of technologies, practices, and knowledge by tailoring productivity-enhancing tools for different contexts. Cooperation also facilitates the scaling of best practices and the alignment of goals, ensuring that producer livelihoods, social outcomes such as improved nutrition and reduced gender disparities, environmental protection, and agriculture-led economic growth go hand-in-hand with agricultural productivity growth.

Fostering strategic partnerships will enhance the returns that sustainable productivity growth will have for producers, society, the environment, and the economy. The GAP Initiative™ partners exemplify how collaboration improves producer livelihoods, women's participation, inclusion of smallholder farmers, nutrition and food security, access to robust markets, environmental resource protection and conservation, and delivery of ecosystem services alongside productivity growth.



Actions to Cultivate Partnerships and Cooperation

Policy

Legal frameworks that will support joint ventures, knowledge sharing agreements, and collaborative R&D initiatives.

Policy incentives for collaboration—such as tax breaks, grants, or subsidies for cooperative ventures.

Cross-border cooperation through joint funding frameworks for public R&D, harmonized regulations, and shared infrastructure development.

Investment

Public-private partnerships that include government, private sector, research institutions, and civil society/grassroots organizations to co-develop scaling initiatives.

Regional investment platforms that will pool resources from multi-sectoral partners to expand agricultural productivity initiatives that will require cross-border cooperation.

Research

Develop knowledge sharing platforms and mechanisms to disseminate best practices, innovations, and evidence.

Conduct research on the effectiveness of partnerships and collaborative efforts in boosting agricultural productivity, identifying successful models that can be replicated or scaled in other regions.

Prioritize interdisciplinary research and incorporate embedded research translation processes from the outset to maximize uptake of effective technologies, innovations, services, or knowledge.

HOW GLOBAL TRADE AND INNOVATION SHAPE THE FUTURE OF FARMING

LESSONS FROM GOLDEN RICE

Martha King* and Sandro Steinbach**

*Former vice president of programs and projects at Farm Foundation
**Associate professor, Department of Agribusiness and Applied Economics; director, Center for Agricultural Policy and Trade Studies, North Dakota State University //
2024 Farm Foundation agricultural economics fellow

As climate change and sustainability demands intensify, the future of farming faces environmental challenges and hurdles in adopting innovations that boost total factor productivity (TFP). Golden Rice, a breakthrough agricultural technology, illustrates the promise and pitfalls of scaling such innovations, which are crucial for building a more resilient agricultural future.

Agriculture is increasingly shaped by the complex interactions between trade, innovation policies, and research and development (R&D) investments. As the global population grows to 8.5 billion by 2030 and the effects of climate change become more pronounced, the need for sustainable increases in agricultural productivity is more pressing than ever. Total factor productivity (TFP) growth, which hinges on using resources more efficiently and adopting new technologies to meet this goal, is crucial for ensuring future global food demands. Understanding how trade, innovation policies, and R&D efforts come together to foster this growth is critical to addressing the challenges and benefiting from the opportunities that arise from their interactions.

Golden Rice is a prime example of how these forces can shape agricultural outcomes. Rice is a major staple food for almost half the world's population. Developed due to a global public health initiative, Golden Rice is a breakthrough innovation resulting from significant R&D and international collaboration to address vitamin A deficiency in low- and middle-income countries (LMICs). The innovation and adoption timeline of Golden Rice below presents the critical milestones of its development (Figure R1).

Between the initial initiative of the Rockefeller Foundation in 1982 and the approval in Canada and the United States in 2018, its path from the lab to the fields has been anything but straightforward, encountering regulatory hurdles, trade barriers, and considerable public skepticism. These challenges highlight the critical importance of supportive innovation policies and aligned trade policies in determining whether a technological innovation can achieve its potential impact on agricultural productivity and food security.

Figure R1. Timeline of Golden Rice Innovation

PHASE 1: EARLY TECHNOLOGY DEVELOPMENT						PHASE 2: INTELLECTUAL PROPERTY RIGHTS AND IP TRANSFER		
1984	1980s	1992	1996	1997	1999-2000	2001	2003	2004-2005
Idea born at international agriculture meeting in Phillipines.	Rockefeller Foundation exploratory study.	Specific promoter used to reintroduce biochemical pathways to beta-carotene.	University of Freiburg funding contract including Zeneca (later Syngenta) as partner.	Two daffodil genes and a bacterial gene spliced into rice genome.	Golden Rice first proof of concept. Seminal science paper published.	Golden Rice technology licensed to Sygenta.	Humanitarian Board and Golden Rice Network established. CGIAR launches HarvestPlus.	Replacing a daffodil gene with a maize gene yields 23x more beta-carotene. Golden Rice transferred to the Philippines, India, Bangladesh, and Vietnam to begin back-breeding.

Source: Adapted from Hays and Hall (2019)

Figure R1. Timeline of Golden Rice Innovation (cont.)

PHASE 3: FIELD TRIALS AND REGULATORY APPROVALS						
2008	2013	2018	2019	2021	2023	2024
IRRI starts field trials of Golden Rice backcrossed into IR64.	IRRI and PRRI conduct further field trials. Back-breeding into local varieties continues. Golden Rice3 with more beta-carotene.	Positive food safety evaluations from Food Standards Australia, New Zealand, Health Canada, and the USDA.	Field evaluations successfully completed. Release as a commercial variety expected in Bangladesh. Approved for human and animal consumption and for processing in the Philippines.	The Philippines issues a biosafety permit for the commercial propagation of vitamin A-infused Golden Rice.	Supreme Court of the Philippines orders halt of commercial propagation following MASIPAG petition.	Court of Appeals of the Philippines issues a cease-and-desist order on the commercial propagation of Golden Rice, citing potential health and environmental impacts.

Source: Adapted from Hays and Hall (2019)

Trade as a Driver of Innovation and R&D

International trade is a critical driver of agricultural innovation, enabling the exchange of ideas, technologies, and resources across borders. This exchange is vital for developing new agricultural practices and technologies that boost productivity. Golden Rice is a direct result of international collaboration. Scientists from different countries, including Switzerland, Germany, the United States, and the Philippines, contributed to its development. This cross-border cooperation exemplifies how global networks can accelerate the creation and spread of agricultural innovations that address global challenges to the mutual benefit of trading partners.

Global R&D networks are central to developing such innovations. They connect researchers and institutions worldwide, allowing them to share expertise, resources, and technology. The development of Golden Rice was made possible through such a network involving multiple stakeholders like the International Rice Research Institute (IRRI) in the Philippines, European researchers, and private companies. This global effort ensured that the technology could be adapted to various growing conditions and meet the regulatory requirements of different regions. Trade considerations were crucial during the development process, as the goal was to create a rice variety that could be widely adopted in LMICs, making it essential to consider the diverse agricultural environments and trade regulations.

Innovation Policies and Regulatory Frameworks

Figure R2 illustrates the relationship between R&D investment and agricultural TFP growth in the United States since the 1970s. Between 1970 and 2000, public R&D investment and TFP growth moved in parallel, reflecting the synergy between research funding and agricultural productivity gains. However, since 2000, TFP growth has slowed, coinciding with a decline in public R&D investment. This trend underscores the importance of robust policies that foster innovation in agriculture, which thrive when supported by strong R&D, protection of intellectual property, and clear regulatory frameworks. These policies are crucial for translating scientific discoveries into practical technologies that drive TFP growth. The development of Golden Rice, for instance, was strongly influenced by supportive innovation policies. Funding from both public and private sectors, coupled with collaborations facilitated by clear intellectual property agreements, enabled researchers to advance the technology. Yet, despite these advancements, the transition from laboratory to field has been hampered by regulatory challenges and public backlash, slowing its adoption.

The example of Golden Rice underscores the critical role that regulatory frameworks play in either enabling or hindering innovation. Despite its potential benefits, Golden Rice faced extensive delays due to stringent biosafety regulations and public concerns about genetically modified organisms (GMOs). For example, while Canada and the United States approved Golden Rice in 2018, with both Health Canada and the U.S. Food and Drug Administration declaring it safe for consumption, other regions were slower to accept it. In 2019, the Philippines approved Golden Rice for human food and animal feed. By 2021, it became the first country in South

and Southeast Asia to issue a biosafety permit for its commercial propagation. However, in April 2023, the country's Supreme Court ordered a halt to its commercial propagation due to a petition citing potential risks to health and the environment, with the Court of Appeals upholding this decision in April 2024.

The challenges in the Philippines highlight the need for adaptive regulatory policies that balance safety with the urgency of addressing global food security issues. In the case of Golden Rice, even strong scientific evidence supporting its safety and benefits has not been enough to overcome the regulatory hurdles and public resistance in some countries. This delay has limited its impact, particularly in regions where vitamin A deficiency is still a severe public health issue.

The Golden Rice experience demonstrates that while supportive innovation policies are crucial for developing new agricultural technologies, the regulatory landscape can meaningfully affect their adoption and impact. Public perception, influenced by how these technologies are presented and understood, also plays a vital role. To ensure that innovations like Golden Rice reach those who need them, there is a clear need for more flexible and responsive regulatory frameworks. These frameworks should safeguard public health and the environment while facilitating the timely dissemination of technologies that can address critical challenges in agriculture and nutrition. By learning from the hurdles Golden Rice faced, policymakers and research teams can improve strategies that support innovation while ensuring that the benefits of new technologies are realized more broadly and swiftly.

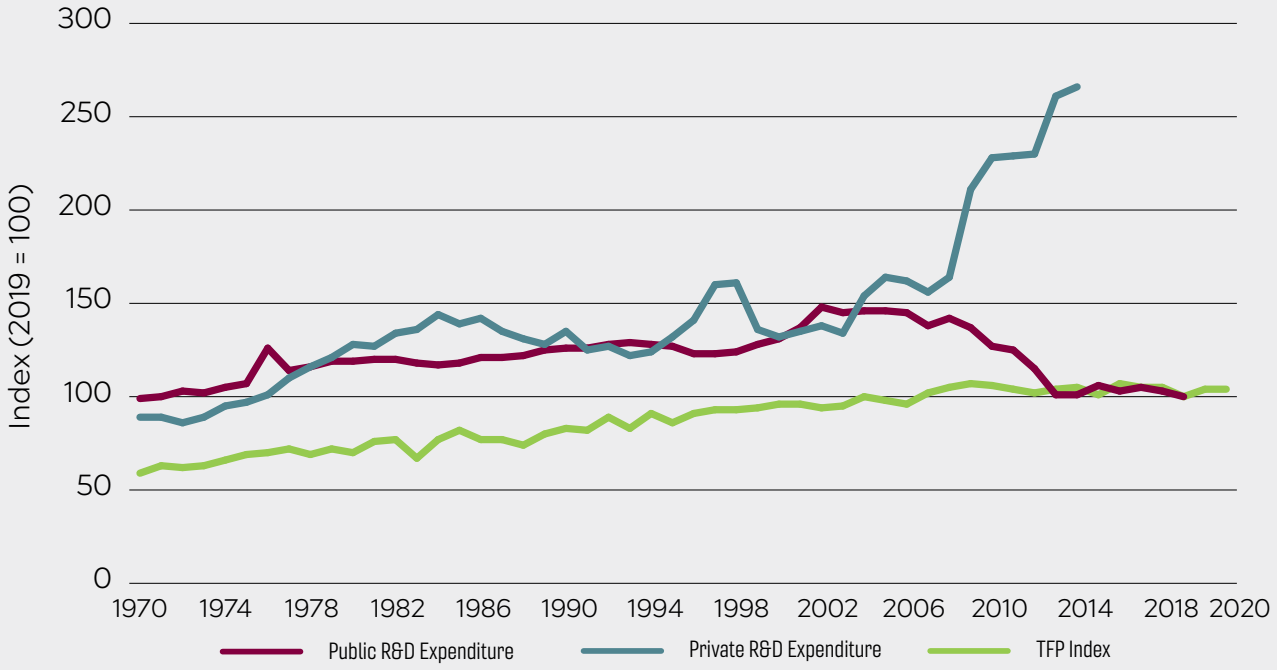
Golden Rice and TFP Growth

Golden Rice has the potential to impact agricultural TFP growth considerably. By enhancing the nutritional value of a staple crop without requiring additional inputs or land, Golden Rice can contribute to more efficient agricultural practices. This efficiency directly ties into TFP growth, allowing farmers to produce more nutritionally valuable food with the same resources. In addition to its nutritional benefits, Golden Rice could lead to broader sustainability impacts by reducing the need for vitamin A supplements and related healthcare costs, thus contributing to a more sustainable agricultural and public health system.

However, the potential of Golden Rice to drive TFP growth is heavily influenced by trade and innovation policies and the ability to disseminate this innovation across borders. International trade plays a critical role in the distribution of agricultural technologies, and in the case of Golden Rice, trade policies have been both a facilitator and a barrier. For instance, countries with open trade policies like Canada and the United States, which create supportive regulatory environments, can adopt Golden Rice more swiftly. Conversely, trade barriers, such as GMO restrictions, have slowed the spread of Golden Rice to certain countries, limiting its potential impact on productivity in regions that could benefit most from its adoption.

The barriers to adopting Golden Rice highlight the importance of aligning trade policies with innovation goals. Regulatory frameworks that are overly cautious or misaligned with scientific evidence can hinder the dissemination of beneficial technologies, reducing

Figure R2. U.S. Agricultural TFP Index vs. Public and Private R&D, 1970-2021



Source: Authors using data from USDA Economic Research Service (2022) and USDA Economic Research Service (2024)

their potential impact on TFP growth. These challenges underscore the need for more streamlined and science-based regulatory approaches that can facilitate the global spread of innovations. By addressing these barriers, public and private decision-makers can ensure that such technologies contribute more effectively to TFP growth and broader sustainability goals.

Barriers to Adoption and Policy Implications

The diffusion of agricultural innovations often encounters significant barriers, which can severely limit their potential to enhance TFP. Golden Rice, despite its clear benefits, has faced numerous challenges in its journey from concept to widespread adoption. Regulatory barriers, particularly those surrounding GMOs, have been among the most important factors in widespread adoption. Many countries have stringent approval processes that delay the release of new technologies, even when they are backed by strong scientific evidence. This regulatory caution, while intended to protect public health and the environment, can stifle innovation and prevent potentially life-saving technologies from reaching those who need them most.

Trade barriers also play a critical role in limiting the diffusion of innovations. Countries with restrictive trade policies regarding GMOs can effectively block the import and use of such technologies, further delaying their adoption. These barriers not only slow down the spread but also hinder the potential TFP gains that could be realized if such technologies were more widely adopted. Socio-economic factors, such as the lack of infrastructure, education, and market access, also contribute to the slow diffusion of innovations in many developing regions. Farmers may be hesitant to adopt new technologies if they lack the necessary support systems or if the economic incentives are not clear.

Key policy recommendations can be drawn from the Golden Rice experience to overcome these barriers and maximize the potential of innovations. First, more harmonized trade policies that facilitate the movement of agricultural innovations across borders are needed. Countries should work together to establish common standards for the approval and trade of GMOs, reducing the fragmentation that currently hampers innovation diffusion.

Second, regulatory frameworks need to be more adaptive and science-based. While safety should always be a priority, regulatory processes must be streamlined to avoid unnecessary delays in adopting beneficial technologies. This could include faster approval processes for innovations that have been thoroughly vetted in other regions or the creation of special provisions for technologies that address critical public health issues and contribute to TFP growth.

Finally, stronger public-private partnerships are essential to support the diffusion of agricultural innovations. Governments, research institutions, and private companies need to collaborate more closely to ensure that new technologies are not only developed but also successfully integrated into farming systems. This includes providing the necessary infrastructure, education, and financial incentives to encourage farmers to adopt new technologies and explore new market opportunities. The Golden Rice experience shows that innovation alone is not enough; without supportive policies and collaboration, the potential of these technologies to enhance TFP growth and contribute to global food security remains unrealized.

Leveraging Trade and Innovation for TFP Growth

The alignment of trade, innovation policies, and R&D is crucial for driving TFP growth in agriculture. Golden Rice is a prime example of how these elements can be harmonized to enhance productivity and address global challenges. By facilitating the cross-border exchange of knowledge, technologies, and resources, trade can accelerate the development and dissemination of innovative agricultural solutions. Innovation policies that support R&D efforts, particularly in areas with public health implications, are vital to ensuring that these advancements reach their full potential. The Golden Rice example highlights how targeted R&D, supported by favorable trade policies and innovation frameworks, can lead to breakthroughs that improve agricultural productivity and contribute to broader social and economic goals.

Conclusion

Looking ahead, there is a growing need for continued alignment of global trade and policy frameworks to support sustainable agricultural productivity. As future innovations emerge, particularly those addressing pressing challenges like climate change and food security, global trade and policy must be leveraged to facilitate the rapid adoption and scaling of these technologies. Policymakers should focus on creating environments that encourage investment in R&D, particularly in areas that promise high returns for TFP growth and social welfare. The Golden Rice experience suggests that policies enabling easier access to global markets and fostering international collaboration will be key to realizing the full potential of future agricultural innovations. By continuing to integrate trade and innovation strategies, the global community can better support sustainable productivity growth and ensure that breakthroughs in agricultural technology contribute to a more resilient and food-secure world.

CHAPTER 6

POWERING PRODUCTIVITY THROUGH HIGH IMPACT BUNDLES

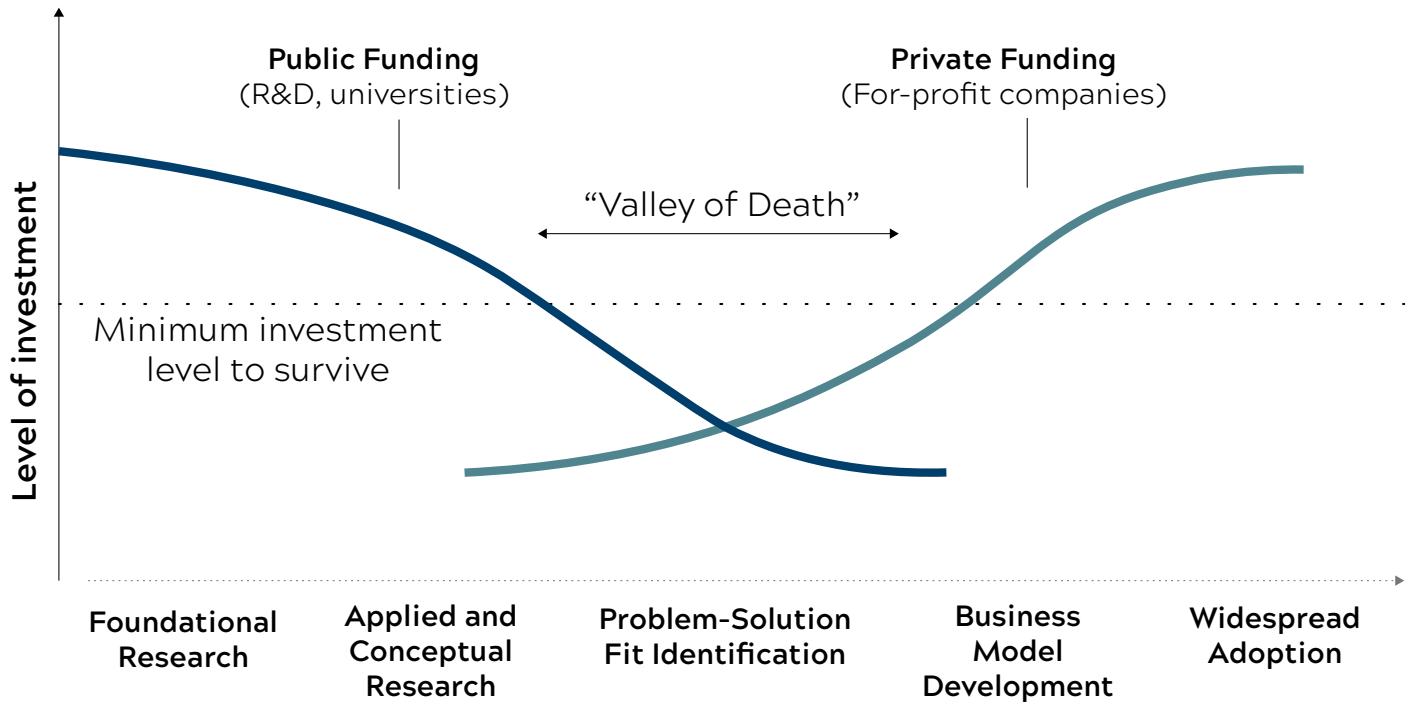
CROSSING THE VALLEY OF DEATH

In the 2023 GAP Report™, *Every Farmer, Every Tool*, we emphasized the central importance for producers, at all scales of production, to be able to access and adopt proven and appropriate productivity-enhancing tools to close the total factor productivity (TFP) growth gap of the past decade. Productivity tools–including technologies, products, practices, services, and knowledge–face barriers to access and adoption arising from the enabling environment, behavioral factors, and external shocks and forces (Agnew & Hendery, 2023).

One of the biggest challenges to boosting TFP growth is that proven and emerging tools often remain stuck on the shelf, unable to advance from the conceptual research to commercialization and widespread adoption–a phenomenon known as the "Valley of Death" (Figure 12) (Ellwood et al., 2022; Frank et al., 1996). The differing objectives and cultures of research and business environments can cause productivity tools to languish in the problem-solution fit identification phase or die out altogether (Ellwood et al., 2022; Vallas & Kleinman, 2008). Moreover, products developed in controlled research settings often face challenges adapting to different environments or farming systems and need to be tested across multiple seasons, geographies, and cultural contexts. These tools often require integration with existing practices, and appropriately sequencing knowledge, skills, and complementary technologies. Especially in low- and middle-income countries (LMICs), technologies designed for high-income contexts often fail to achieve market penetration when introduced in low-resource settings (Moscona & Sastry, 2022).

Achieving the critical mass needed for impact is challenging, as the public sector faces limited budgets, and the private sector is often deterred by risks and concerns over profitability. Even in countries where governments have implemented policy incentives to increase the availability of financing and management support to create bridges between development phases, the scaling conundrum remains (EARTO, 2015; Rasmussen & Sørheim, 2012). Evidence from various country contexts and agricultural systems highlights several factors

Figure 12. The Innovation Valley of Death



Source: Adapted from Skillicorn, 2021.

Factors Impeding Widespread Adoption

Funding

Basic research, field trials, and regulatory compliance are expensive. Further, there is often a lack of mid-level investment that would allow startups and smaller companies, particularly in sub-Saharan Africa, to scale.

Access to capital

Adopting new technologies often requires financing, which can be difficult particularly for smallholder producers to obtain.

Policy

Incentives and subsidies may be required to provide producers a risk buffer, particularly smallholder producers.

Regulation

Regulatory approvals are often lengthy, in some cases taking years, creating complexity, costs, and time that deter market entry. Regulations vary across countries, creating hurdles for technology and financing flows.

Behavioral Factors

User attitudes influence demand creation. Risk averseness, perceived effort, ability to learn and adopt new tools, value for the tool(s), and knowledge influence the adoption time horizon and may require intensive education and support.

Awareness

Producers may not be aware of new or existing tools that can help them solve productivity related challenges.

Appropriateness

Some technologies may only be appropriate for certain scales or types of farming systems. Cultural relevance and socioeconomic accessibility will also influence scalability.

Structure of distribution networks

Production tools may not be consistently available in locations where they are most needed. Distribution networks also need to make the knowledge and skills required to use the tools available in order to sustain adoption.

Supply chain functionality

Disruptions to supply chains or reliance on inputs or infrastructure that are not widely available may prevent adoption even if there is market demand.

Competition

Even if a technology is technically superior, it might struggle to gain market share if there are competing solutions that are already well-entrenched or perceived as more convenient or cost-effective.

Trust and loyalty

Users may prefer to stick with known brands or suppliers, even if new entrants offer better or cheaper alternatives. This can be due to established relationships, perceived reliability, or simply resistance to switching providers.

Ecosystem gaps

Some technologies require a mature ecosystem to thrive. For example, precision agriculture tools might need reliable data infrastructure, while other innovations could depend on a supportive network of service providers or complementary products. If this ecosystem isn't fully developed, the technology might struggle to scale.

Interoperability challenges

If the technology doesn't easily integrate with existing systems, users may be reluctant to adopt it. For example, if farm management software doesn't integrate with machinery or other digital platforms, its value proposition diminishes.

Unclear or delayed benefits

If the benefits of the technology aren't immediately apparent or take time to materialize, users may be hesitant to invest. For example, technologies that require significant upfront costs but promise long-term gains might struggle if the payback period is too long.

Inconsistent performance

Technologies that deliver inconsistent results, especially across different environments, can struggle to build trust. If early adopters experience issues, word of mouth can spread skepticism, further hindering widespread adoption.

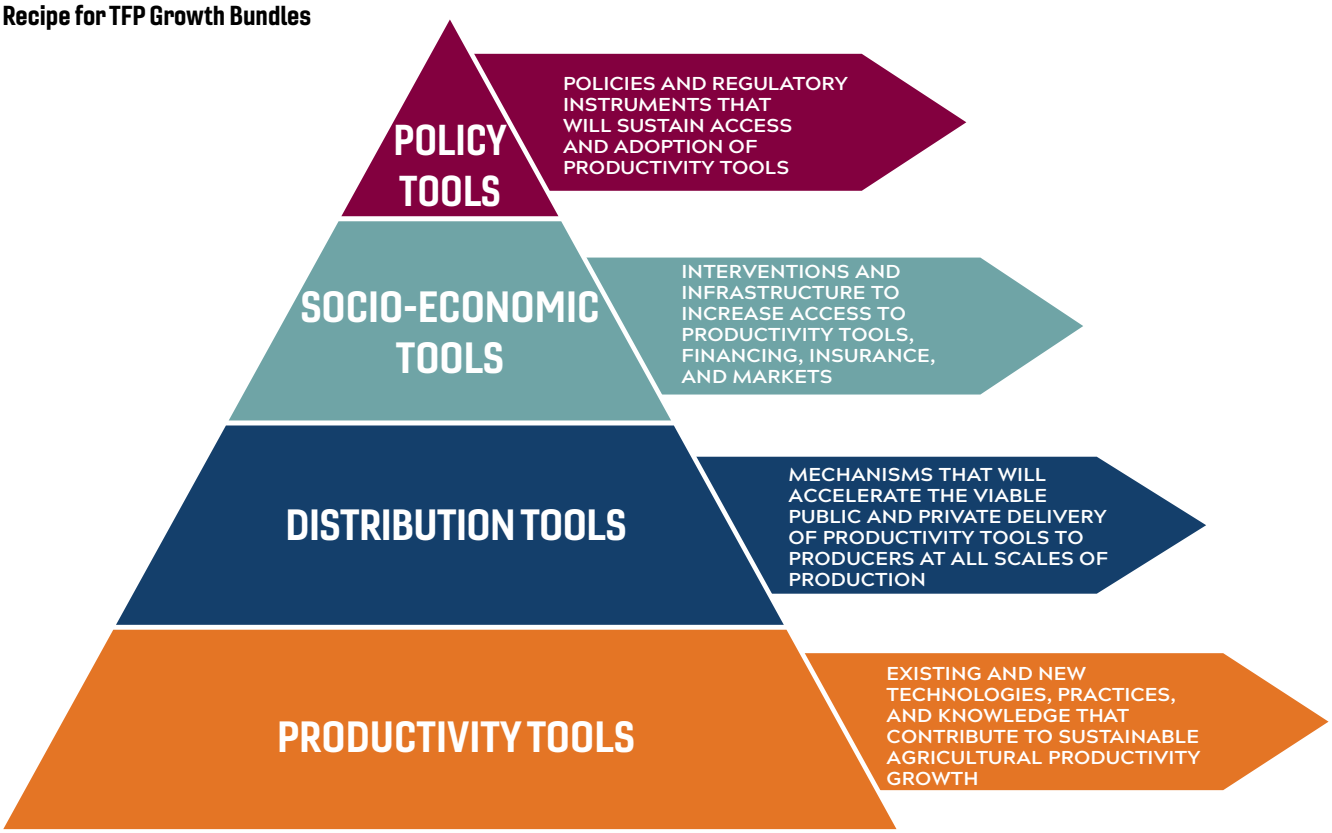
impeding widespread adoption of proven and emerging tools (see box above).

The complexity of each one of these factors, let alone interactions between them, illuminates why the Valley of Death exists and explains why it can take more than 10 years at times for new technologies, products, and knowledge to reach producers that need them the most. Tackling this gap will require integrating demand and supply side interventions to achieve impactful market penetration, cost efficiencies, and user acceptance.

Agricultural productivity tools face a complex interplay of technical, biophysical, political, financial, market, and sociocultural factors and are unlikely to scale without being accompanied by companion interventions, mechanisms, policies, and institutions (Barrett et al., 2020). Leveraging a 'bundling' approach, however, can efficiently build bridges across the Valley of Death. Using social, technical, and institutional tools and processes will create Valley of Death bridges and accelerate widespread adoption of productivity-enhancing tools.

This bundling approach can also create impact across multiple objectives such as enhancing producer livelihoods, increasing societal benefits, expanding access to nutritious foods, improving gender equality, fostering inclusive economic growth, and protecting and improving environmental resources (Barrett et al., 2020, CIAT, 2023). Because technological adoption may lead to unintended impacts on non-target outcomes, there is also a need to understand the tradeoffs and synergies to identify appropriate leverage points (Barrett et al., 2020).

Figure 13. Recipe for TFP Growth Bundles



WHAT IS BUNDLING?

Bundling is the strategic practice of combining complementary innovations, technologies, practices, interventions, and services into a single package. By simultaneously addressing the needs of end-users and barriers to adoption, bundling can efficiently and inclusively bridge the gap between research and scaling to get promising productivity-enhancing tools off the shelf and into the field. The integration of multiple tools with policy, procurement, and market coordination has proven to help emerging technologies to survive the competitive and complex innovation environment (Islam, 2017).

To power agricultural productivity growth, TFP Growth Bundles should include productivity, distribution, socio-economic, and policy tools to build efficient and sturdy bridges across the Valley of Death (Figure 13). These four components address both supply and demand side factors that cause existing and emerging productivity tools to languish in the Valley of Death. These tools also reflect our five policy and investment priorities for advancing productivity growth.

Examples of Tools

As presented in the 2023 GAP Report™, **productivity-enhancing tools** include improved genetics, precision agriculture, soil health and water management, integrated production systems, pest and disease management, mechanization and automation, and knowledge sharing platforms.

Distribution tools may include, but are not limited to, public and private delivery models, blended business models, local entrepreneurship, technology transfer mechanisms, field trials, infrastructure, digital markets, and integrated supply chain coordination.

Examples of **socio-economic tools** traverse everything from market strengthening mechanisms like traceability and value web coordination, to financial products and services (savings, credit, insurance), to gender and social inclusion (sensitive & transformative) interventions, to adaptation and resilience products such as insurance, to behavior change interventions.

Policy tools include public investment in R&D, subsidies, credit and insurance programs, incentives for private sector investment, markets and trade policies, agriculture innovation system, land reforms, agricultural regulatory reforms, trade harmonization, and social safety nets, among others required for a multi-sectoral approach.

This bundling approach can also create impact across multiple objectives such as enhancing producer livelihoods, increasing societal benefits, expanding access to nutritious foods, improving gender equality, fostering inclusive economic growth, and protecting and improving environmental resources (Barrett et al., 2020; CIAT, 2023). Because technological adoption may lead to unintended impacts on non-target outcomes, there is also a need

to understand the tradeoffs and synergies to identify appropriate leverage (Barrett et al., 2020).

The potential for TFP tool bundles to power sustainable TFP growth is rooted in systems thinking. A recent USAID Notice of Funding Opportunity emphasized that an "integrated design that goes beyond productivity, including identifying systems tradeoffs and synergies, will lead to the development of solutions and approaches that overcome barriers to adoption and systems impacts."

Bundling productivity-enhancing distribution, socio-economic, and policy tools will increase rates of adoption and sustained use by:

Increasing value and convenience. By offering a package of complementary technologies and services, farmers are more likely to adopt innovations, as the bundled solutions provide both value and convenience.

Achieving cost efficiencies. Bundling can serve to lower costs by leveraging economies of scale and reducing transaction costs. This may open up strategies to reduce the costs to farmers. For example, using discounts and taking advantage of logistics efficiencies, tools may be more affordable for producers to adopt.

Reducing risks. Including risk mitigation products and services in the bundles will reduce the risk and uncertainty for producers to adopt new technologies and practices or risks from external forces and shocks. For example, including insurance products in a bundle provides a safety net against crop failures or market fluctuations or integrated pest management solutions would reduce the risk of pest infestations, leading to more stable and predictable yields.

OFF THE SHELF AND INTO THE FIELD

TFP Growth Bundles can generate high impact for sustainable productivity growth by getting important productivity tools off the shelf and into the field. To be considered as having 'high impact', the bundles need to create **substantial efficiency gains** at a **disruptive scale** among producers and world regions that have experienced **lagging productivity growth**. It must be considered that impact will also vary based on the local context and may change over time. For example, a high impact bundle in sub-Saharan Africa today may differ from one five years from now, or from what constitutes a high impact bundle in the United States or India.

Drawing on evidence and lessons learned from successful bundling approaches, innovation management research, and observations from The GAP Initiative™ and its partners, we recommend the following ingredients to build a high impact TFP Growth Bundle.

Defined roles and responsibilities. A high impact bundle must include clearly defined roles and responsibilities of key stakeholders in the scaling journey from the outset. Intermediary organizations and ecosystem stakeholders play a key role in stewarding productivity tools across the Valley of Death (Islam, 2017). Stakeholders may include government bodies, research institutions, private sector partners, and local farming communities.

Courtesy of Tanager International.

Innovation actor leadership. According to research by Ellwood et al. (2022), innovation actors such as scientists, engineers, analysts, business managers, and industrialists must have the requisite skills to take the tool(s) to market, have established partnerships with other actors that will provide a cost and time efficient route to market, be able to define the regulatory pathway, and define the cost recovery and market access scenarios (Walsh et al., 2002).

Market research. Building and deploying successful bundles requires a deep understanding of the target market, including customer needs, buying behaviors, economic conditions, and competitive landscapes. Regular market research, customer feedback, and competitive analysis are critical in identifying the right moments and locations for implementing bundling strategies effectively.

Bundle co-creation. A human-centered design approach, that incorporates end users and stakeholders in the development and delivery of bundles, will enable new technologies and practices to emerge, adapt, and scale across diverse contexts. This approach generates positive impacts while minimizing adverse effects and overcoming

Logan Wallace for Virginia Tech.

structural barriers that have excluded some users, such as women, from fully benefiting from productivity gains (Barrett et al., 2020).

Spatial considerations and opportunity windows. The effectiveness of bundle deployment can vary significantly depending on the geographical and temporal context. Identifying the optimal locations and timing–referred to as "opportunity windows"–is crucial for maximizing the positive effects on TFP growth. Strategic decisions regarding where and when to implement these bundles can lead to substantial gains in productivity.

Technology-push and market-pull. Technology-push innovation strategies create market demand by offering creative and disruptive solutions to user needs. In contrast, market-pull is generated by search for replacements or substitutes. Integrating these demand generation approaches can create highly effective bridges across the Valley of Death (Walsh et al., 2002).

Innovative financing and business models for LMICs. Financing models that reflect economic and institutional realities in LMICs are needed to de-risk investments and attract public and private capital. Innovative financial instruments need to be coupled with inclusive business models that focus on affordability, scalability, and community ownership to ensure productivity-enhancing tools reach underserved populations and generate sustainable impact.

Innovation and related policy. Intellectual property (IP) policy and procedures provide innovators with legal protection for their inventions, which incentivizes investment in commercialization. Patents, trademarks, and copyrights help ensure that developers can reap the financial rewards of their innovations, encouraging both public and private sector support. Additionally, clear IP frameworks facilitate partnerships and can create inclusive impacts, enabling the transfer of technologies from research institutions to market actors.

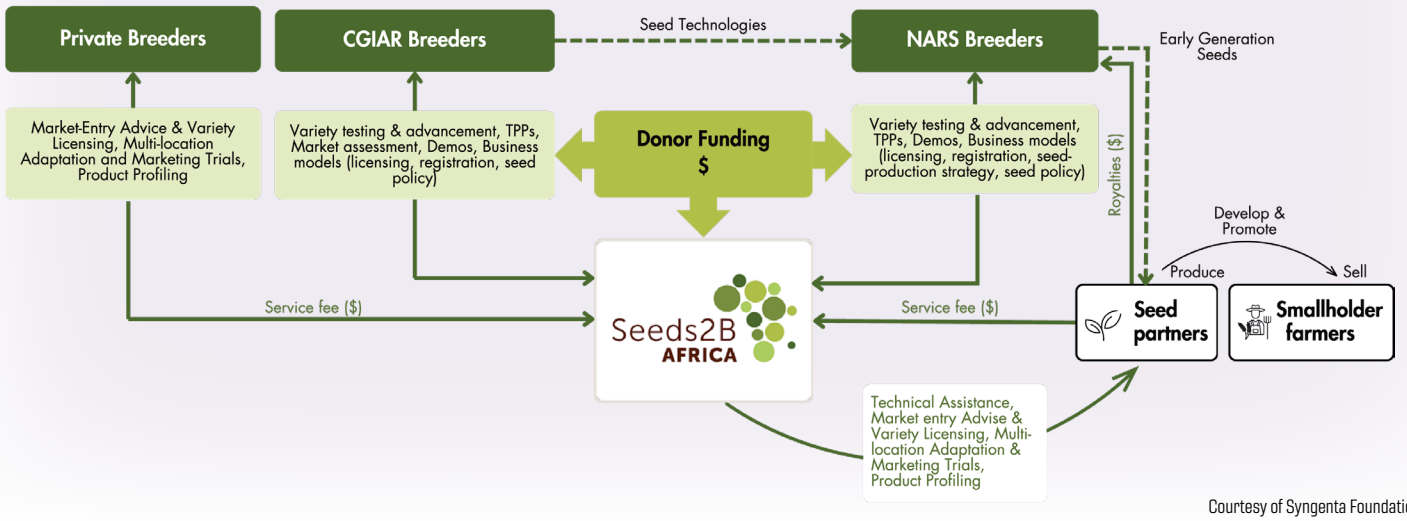
Strategies for a coordinated approach. A successful deployment strategy involves the integration of various stakeholders' efforts to ensure a cohesive and unified approach. This coordination not only enhances the efficiency of the implementation process but also amplifies the overall impact on TFP growth. By aligning resources, expertise, and goals, the collective effort can lead to more sustainable and scalable outcomes.

CONTRIBUTOR STORY

Crossing the Valley of Death in Practice

Seeds2B, Syngenta Foundation

A prevailing issue affecting widespread adoption of new seed technologies is the disconnect between research and private seed commercialization. Seeds2B (Seeds-to-Business) Africa plays a catalytic role by building both public and private sector stakeholders' capacity, providing end-to-end, on-the-ground varietal commercialization solutions, and fostering an enabling environment for long-term collaboration between private and public sectors. Seeds2B employs a methodology that is based on the product lifecycle of a variety and uses specific stage-gates to only support and advance marketappropriate seed varieties through the pipeline, based on specific objectives defined in Target Product Profiles. Its mission is to provide seed to 1.5 million smallholder farmers, onboard 40 new African seed companies, and together with public sector partners, produce 50,000 tons of seed, valued at an estimated US $100 million.



Courtesy of Syngenta Foundation.

CONTRIBUTOR STORY

The AGRA Consortia Model: A Case of Tanzania

AGRA

Investments in Tanzania's agricultural systems over the years were disparate, truncated and handled by various players: the government, private sector, and non-profit institutions. However, under a ground-breaking initiative dubbed "Partnership for Inclusive Agricultural Transformation in Africa (PIATA)", a group of carefully vetted rural organizations and businesses agreed to work together to deliver the benefits of the critical components for agricultural transformation (seed, fertilizer, agro-dealership, extension, markets, and agri-finance) to a specific group of farmers in a defined geography. AGRA and the implementing partners provided an integrated suite of services for 756,872 farmers, providing them with better access to markets and inputs through financing arrangements between off-takers, input companies and financial institutions. AGRA spent/committed $8,706,821 to support 4 integrated consortia. The value created by these consortia from 2017 to 2019 was $158,187,984, meaning that for each $1 spent, it created $18.

AGRA
Sustainably Growing Africa's Food Systems

CONCLUSION

The 2024 GAP Report™ underscores the critical need to reinvigorate agricultural productivity growth. With global TFP growth slowing to an average annual rate of 0.7 percent during the past decade, achieving the revised target of 2 percent average annual growth by 2050 remains a formidable challenge. The report emphasizes that this slowdown, if left unaddressed, threatens not only global food security but also the economic, environmental, and social stability of agricultural systems worldwide.

The report stresses that reversing this trend will require more than just incremental improvements. A comprehensive, multifaceted approach is essential–one that integrates both public and private R&D investments, robust policy frameworks, and the deployment of socio-economic tools. Bridging the "Valley of Death"–the gap between technological innovation and widespread adoption–remains one of the most pressing challenges. In this context, the concept of bundling productivity-enhancing tools with appropriate socio-economic, policy, and market mechanisms has emerged as a powerful strategy. This approach can help overcome the systemic barriers that prevent smallholder farmers, particularly in low- and middle-income countries, from accessing and adopting critical technologies.

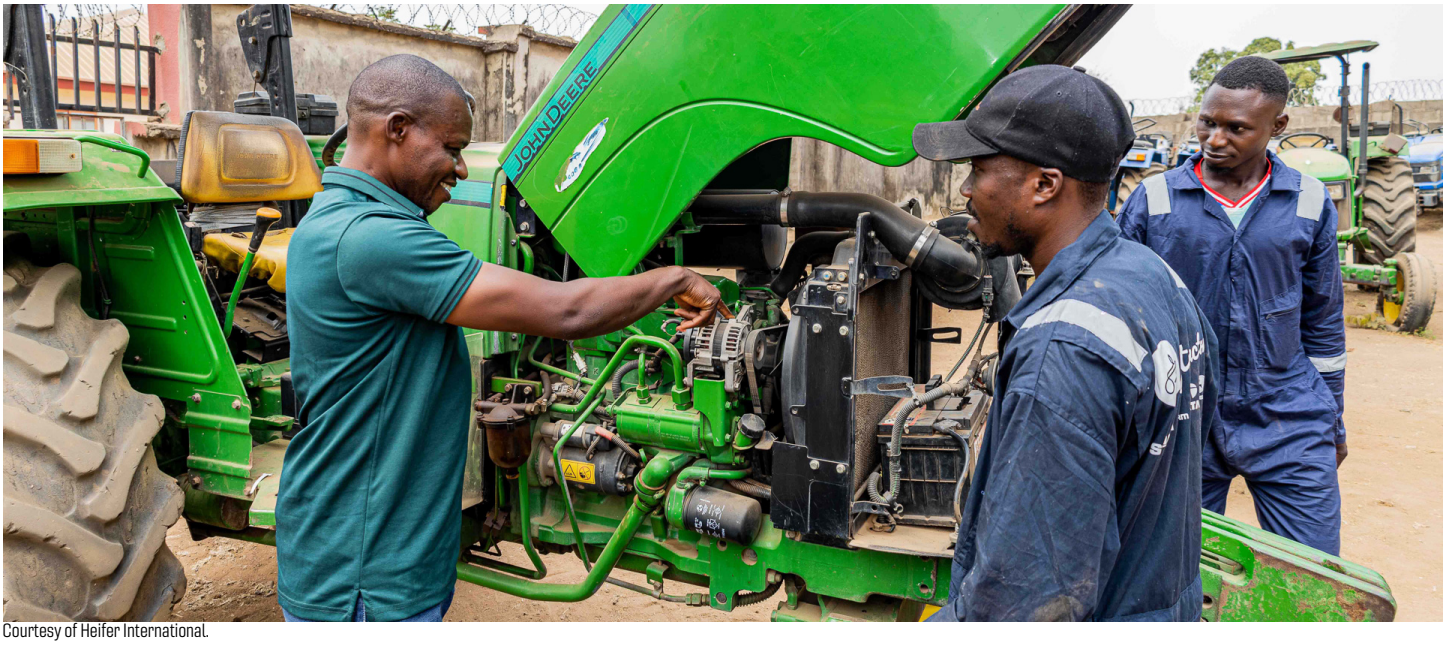
A key insight from the report is the recognition that the slowdown in TFP growth is not only a technological issue but also deeply rooted in market failures, socio-economic disparities, and policy gaps. The report highlights the importance of strengthening market access, addressing trade barriers, and fostering regional cooperation as critical levers for unlocking TFP growth potential. For example, improving infrastructure such as rural roads, storage facilities, and digital platforms can enhance producers' access to both input and output markets, boosting their productivity and profitability. Moreover, tackling post-harvest losses and improving the quality of agricultural outputs will further contribute to global productivity gains.

So, what's next?

Looking ahead, The GAP Initiative™ will continue to advocate for evidence-based policies, enhanced public-private collaboration, and the widespread dissemination of innovations that not only increase productivity but also promote inclusivity, environmental stewardship, and economic resilience.

The GAP Initiative™ will also continue to expand its analytical power to provide policy makers, investors, and decision makers highly actionable, data-driven insights for action.

Achieving sustainable agricultural productivity growth is not merely an agricultural challenge but a global imperative. It is central to ensuring food security, reducing poverty, and addressing broader environmental goals like climate change adaptation and biodiversity conservation. The 2024 GAP Report™ makes it clear: achieving the target TFP growth is essential for a more resilient, equitable, and sustainable global food system.



Courtesy of Heifer International.

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PARTNER STORIES

The GAP Initiative™ partners offer real-world examples of innovations that improve the access to and adoption of proven productivity-enhancing tools. Their work demonstrates that bundling appropriate and science-based innovations, technologies, practices, interventions, and services improve farmer livelihoods, and strengthens environmental resilience and economic stability. The success of these programs affirms our policy and investment priorities- investment in agricultural innovation systems, expanding robust and resilient market access, strengthening global and regional trade, reduced loss and improved quality of outputs, and cultivation of partnership and cooperation- are key to driving agricultural productivity growth for farmers at all scales of production.

Bundling for Farmer Productivity and Food and Nutrition Security in Africa

AATF

The African Agricultural Technology Foundation (AATF) is a technology transfer organization that facilitates technology uptake for food and nutrition security and to enhance smallholder farmer livelihoods in Africa through public-private partnerships (PPP).

Maize and cowpea are two important staples for improving food and nutrition security in Africa. Maize accounts for 30–50 percent of low-income household expenditures and provides 30 percent of total calorie intake for the more than 300 million people who depend on it. Cowpea is a versatile nutritious legume for food, income, and soil fertility improvement, providing protein for more than 200 million people and income for millions of smallholder farmers. Despite their importance, productivity of both crops has remained low in Africa, with millions of dollars spent on grain importation to meet demand. Pests, drought, heat stress, and poor soil fertility are the major constraints causing low yields especially under climate change. Further, poor agronomic practices in farmers' fields reduce yield performance of improved drought and pest tolerant varieties by 50 percent or less of the potential.

Through PPP's, AATF develops and transfers diverse agricultural technologies for improved genetics and biotic resistance in Africa. Examples include the conventional drought tolerant (DroughtTEGO®) maize hybrids and the biotech pod-borer resistant (PBR) cowpea. These technologies, bundled and complemented with good agronomic practices for weed control, soil health management practices, integrated pest management, supplementary irrigation, and mechanized farming operations, have improved yields for both crops. Enhanced linkages to ICT tools and input/output market systems have also helped farmers determine the best planting time and market prices for their produce. Targeted advocacy and communication aimed at creating an enabling policy and business environment helps to build awareness and understanding of the technologies for informed decision making by country leadership, technology developers, regulators, promoters, and users.

In Kenya, DroughtTEGO® hybrids increased maize yields by 33-54 percent (5.5-6.3 tons/ha) with 4.9 tons/ha average across the country compared with 3.2 tons/ha for non-drought tolerant commercial hybrids, and 1.7 tons/ha national average. In Ethiopia, one DroughtTEGO® hybrid recorded a 16-23 percent yield advantage over other commercial varieties. In Nigeria, DroughtTEGO® hybrids gave 15-39 percent yield advantage over best commercial hybrid. The adoption of PBR Cowpea in Nigeria has significantly increased farmers' average yield by 63 percent from 0.35 to 0.57 tons/ha with a maximum yield of 1.1 t/ha.

AATF commercializes and creates awareness on the benefits of the technologies among farmers and consumers through on-farm demonstrations and farmer field-days. Capacity strengthening of seed companies, agro-dealers and extension staff enables the successful dissemination, adoption, and use of the technologies. Farmers adopting these new improved varieties through a bundling approach increase yields and thus improve the prospects for food and nutrition security.

Courtesy of AATF.

Fostering Inclusive Agriculture: Private Sector Engagement to Address Resource Needs of Women and Youth

ACDI/VOCA

ACDI/VOCA uses a comprehensive, market systems approach to increase efficiencies in everything from crop production to marketing along a value chain. This approach leverages collaboration with private sector actors to foster systemic change for lasting impact. ACDI/VOCA's private sector engagement approaches aim to create inclusive models to increase the adoption of agricultural innovations. These models address resource constraints faced by women and youth, such as a lack of access to capital, capacity building, innovative technologies, and land, which are critical for closing the global gap in crop yields achieved by male producers versus women and youth producers.

The Feed the Future Honduras Food Security, Agriculture, and Resilient Market Systems (FARMS) Activity promotes inclusive agriculture systems by implementing production models like agroparks–privately funded production hubs that provide producers with land, innovative technologies, financing, technical support, and access to markets for high-value crops such as sweet potato. These models ensure access to essential resources for vulnerable groups and minorities, enhancing their agricultural productivity. Private sector actors benefit from a vertically integrated and more transparent value chain. The initiative also supports inclusion through economic development clusters. Mancomunidades, or associations of municipalities that carry out joint projects, consolidate resources and services, addressing barriers to participation in lucrative agricultural markets. ACDI/VOCA's partnership with Inversiones Amalgamadas (INALMA), a local agroindustry export company, is a key example of this initiative. In 2022, INALMA assisted farmers to produce vegetables for the food processing export market. By 2023, 74 new growers joined the agropark model (of which 14 are women, 16 are youth, and 11 representing ethnic minorities), with INALMA investing over $313,000 in productive infrastructure. This model provides logistics, market access, and business training, enabling women and youth to engage in profitable production activities despite limited capital and land ownership.

Courtesy of ACDI/VOCA.

The USAID Zambia Enterprise Development and Growth Enhanced (EDGE) Activity aims to increase the profitability of agricultural small- and medium-sized enterprises (SMEs) by addressing investment constraints, such as access to finance, business management skills, technology, and markets. The initiative linked two women's savings groups with 35 members to Farmers' Outgrower Foundation (FOF), an Activity-supported SME. FOF supports these savings groups with high-quality seeds and guarantees an offtake market for their produce. This ensures that women's savings groups have ready markets for their final produce, addressing one of the biggest challenges producers face, particularly in rural areas.

The Feed the Future Ghana Market Systems and Resilience (MSR) Activity has developed inclusive outgrower models for smallholder farmers in collaboration with leaders from established outgrower businesses and their networks by expanding access to information, training, inputs, and market opportunities for women, youth, and persons with disabilities. The outgrower businesses are primarily commercial farmers who serve as centralized connection points for the smallholder farmers who work with them. These businesses provide critical agricultural services, such as market and technical information, technical and management training, financing, inputs, land preparation services, aggregation, and access to markets for smallholder farmers. The initiative coaches outgrower businesses to develop and apply more inclusive training approaches (e.g. hosting demonstration activities at times and locations more accessible for women), support women to take on lead farmer roles within their networks, hosting field days and messaging approaches to reach women, expand engagement with established women's savings groups to improve women's access to higher quality inputs and land preparation services.

ACDI/VOCA's private sector engagement demonstrates a clear impact on inclusive adoption of bundles of agricultural innovations to overcome market-based barriers to sustainable productivity growth. By addressing key resource constraints and fostering partnerships to develop more inclusive services, ACDI/VOCA enables women and youth to participate fully in agricultural markets, driving increased productivity and profitability.

Courtesy of Bayer Crop Science.

Courtesy of Bayer Crop Science.

Boosting Yields and Incomes in India

Bayer Crop Science

India is home to one-quarter of all smallholder farmers in the world. Despite the small size of their farms, Indian smallholders grow around one-third of the food available in India. Yet they face significant challenges on and beyond the farm-from lack of access to training, micro financing, modern inputs and market linkages to extreme weather events. Better Life Farming (BLF), an alliance of Bayer, the World Bank's International Finance Corporation, Netafim, Yara, and local partners, has been supporting smallholders in India with a successful ecosystem approach since 2018.

BLF Centers are at the heart of the effort and solve what is often referred to as "last-mile delivery challenges". At the Centers, smallholders from surrounding villages gain access to capacity building around sustainable farming practices, seeds, fertilizer, and crop protection solutions, micro financing, digital tools, or other locally relevant services. The Centers are run by local agri-entrepreneurs, creating jobs and contributing to the modernization of farming in remote areas.

To better assess the value of the BLF interventions, we measured the impact on yield, farmer income, and quality of life. In a 2022 baseline and a 2023 follow-up study, 60 Decibels, an independent social impact measurement company, interviewed vegetable farmers associated with BLF in Uttar Pradesh/Jharkhand.

In 2023, 90 percent of the farmers mentioned increased crop production, 77 percent referenced improved farming practices and 87 percent reported a higher income. These farmers reported their quality of life had improved with increased incomes, for example in the ability to afford education for their children.

We also saw very high ratings related to knowledge transfer in the adoption of trainings rising from 57 percent in 2022 to 93 percent in 2023. Most farmers felt more confident than before they joined BLF centers to invest in their agricultural operations due to the availability of good quality inputs, access to training, new information and techniques, and observed crop yields.

These studies and others conducted by 60 Decibels in Kenya, Mexico, Honduras, and Bangladesh demonstrate the benefit of bringing proven and locally relevant productivity-enhancing innovations to smallholders. There are significant opportunities to turn small-scale farming operations into viable businesses leading also to higher incomes and improved quality of life for the farmers and their families.

Today, more than 2,700 BLF Centers serve about 1 million smallholders across India, Indonesia, Bangladesh, Mexico, Honduras, Côte d'Ivoire and Tanzania. We will continue to scale the program and leverage the proven concept of bundling tools and know-how for smallholders to sustainably increase productivity and help improve livelihoods.

Agriculture is transforming and we need to bring the millions of smallholders along on the journey towards a more sustainable and regenerative future.

Courtesy of CIP.

Mulching Over Tilling Revolutionizes Potato Farming

International Potato Center (CIP)

In the agricultural landscapes of India, Bangladesh, Cambodia, and Peru, an initiative spearheaded by the International Potato Center (CIP) is reshaping the future of potato farming. The project, known as Potato Zero Tillage through Rice Straw Mulch (PZTM), is centered around a novel farming technique that is a beacon of hope for smallholder farmers grappling with land degradation, water scarcity, and the harsh realities of climate change.

At the heart of the PZTM approach lies a simple yet revolutionary idea–plant potatoes directly into untilled soil and shield them with a layer of rice straw. This departure from conventional tillage practices conserves soil structure, enhances fertility, boosts carbon stocks, extends the potato growing season, and increases yield. The benefits are manifold, offering a lifeline to farmers battling environmental degradation and food insecurity. It also allows potato production in non-traditional potato growing areas such as the Asian deltas.

In Cambodia and Peru, where smallholder farmers struggle with land degradation and water scarcity, the PZTM project offers hope. By embracing innovative farming techniques that harness the power of nature rather than depleting it, these communities are charting a path toward a more sustainable future. Through hands-on training, field demonstrations, and knowledge exchange platforms, the project empowers farmers to become stewards of their land, preserving it for future generations.

One of the project's primary objectives is to empower smallholder farmers, particularly women, by training them on sustainable agricultural practices. In India, where women often bear the brunt of agricultural labor, the PZTM project integrates gender-sensitive training, acknowledging women's vital role in agricultural communities. Women's self-help groups are hubs for sharing insights and experiences, while locally produced videos featuring women offer practical guidance on implementing PZTM techniques. In Bangladesh, the project enlists the support of "Nutrition Scholars"–local female farmers who champion PZTM and nutrition education. These women offer their first-hand knowledge and experience to educate their peers on the benefits of sustainable, productivity-enhancing farming practices. By intertwining agriculture with nutrition, the project ensures food security and promotes holistic well-being within communities. Prioritizing gender sensitivity in the PTZM projects ensures that the benefits of sustainable, productivity-enhancing farming practices are equitably realized by both men and women, thereby fostering inclusive development. The success of the PZTM project hinges on bundling these approaches with collaboration, knowledge sharing, and partnerships at local and global levels to increase and sustain adoption of the practices. By forging partnerships across borders, the project leverages diverse expertise and resources to address complex agricultural challenges.

As the global population continues to grow, the demand for food will intensify, placing unprecedented pressure on agricultural systems. Initiatives such as the PZTM project serve as beacons of innovation, offering sustainable solutions to food production's complex challenges. By embracing a holistic approach that combines environmental stewardship with social empowerment, the project transforms potato farming and paves the way for a more sustainable, resilient, and productive agricultural future. The PZTM project represents more than just a farming technique; it embodies a vision of sustainable development that prioritizes people and the planet. By harnessing the power of partnership, innovation, and gender equity, the project offers a blueprint for transforming agricultural communities and building a more food-secure world.

Empowering Women Smallholder Dairy Farmers in East Africa

Corteva Agriscience

Animal nutrition is a key component to making livestock systems in East Africa more efficient and sustainable. Through the Nourishing Prosperity Alliance (NPA), Corteva is collaborating with the Bill & Melinda Gates Foundation, Land O'Lakes Venture37, Forage Genetics International, and the International Livestock Research Institute to improve animal nutrition by advancing an inclusive and sustainable commercial forage market for women smallholder dairy farmers in Kenya & Ethiopia.

Critical to the success of NPA is Corteva's climate-optimized hybrid corn seeds which increase the yield and quality of corn silage, an important type of forage for dairy cows. In addition, Corteva agronomists are training corn silage farmers on sustainable agriculture methods for optimal production, harvesting and storing.

Recognized as an Innovation Sprint by the AIM for Climate initiative, NPA's private sector-driven model empowers women to be the primary agents of change. The program has trained over 7,000 smallholder dairy farmers to bolster the use of climate-smart, nutrient-rich forage and improve overall dairy production. As a result, farmers have achieved a 46 percent increase in liters of milk produced annually, and a 26 percent reduction in estimated emissions intensity. Furthermore, NPA is increasing the supply of dairy for local markets in East Africa, which is key to addressing chronic nutritional challenges in the region.

Courtesy of Corteva Agriscience.

Through our Agricultural Development collaborations such as NPA, Corteva is helping to improve the productivity, incomes, and sustainable agronomic practices of farmers around the world, and enriching the lives of those who produce and those who consume for generations to come.

Increasing Smallholder Farmer Productivity in Brazil

Corteva Agriscience

In 2016, Corteva launched an Ag Development program called Prospera in the Northeast of Brazil to enrich the lives smallholder farmers and empower rural communities. The program has since grown into a flagship collaboration with Yara, Massey Ferguson, Global Communities, and other key public and private stakeholders. Together, we are strengthening corn and silage value chains which are critical sources of feed for livestock. As a result of this collaboration, smallholder farmers have increased their productivity from 15 to 132 bags/hectare. Collaborations such as this help Corteva to meet the diverse needs of our customers as well as expand markets and grow our business.

Brazilian smallholder farmers in the Northeast states of Pernambuco and Ceará lack access to optimized inputs, agronomic training, and mechanization. Furthermore, farmers face challenging climatic conditions, including a spring rainy season that is followed by a lengthy dry season.

To help farmers address some of these challenges, Prospera is increasing access to climate-optimized Pioneer® and Brevant® corn seed hybrids, sustainable crop protection products, improved fertilizer, agronomic support, and mechanization. Additionally, the program has trained more than 6,000 smallholder farmers, 32 percent of whom are women, impacting over 15,000 people in 258 locations. Plans are in place to expand the program to more states and collaborate with additional organizations to help improve access to financial services and digital training tools and strengthen market linkages.

Courtesy of Corteva Agriscience.

Through our Agricultural Development collaborations, Corteva is helping to improve the productivity, incomes, and sustainable farming practices of farmers around the world and enriching the lives of those who produce and those who consume for generations to come.

Courtesy of Daugherty Water for Food Global Institute.

Driving Agricultural Productivity Growth Through Entrepreneurs and Startups

The Daugherty Water for Food Global Institute at the University of Nebraska

The agricultural industry plays a crucial role in the global economy, and increasing agricultural productivity is essential to meet the growing demand for food. Agtech entrepreneurs have the potential to drive significant productivity growth in the agricultural sector by taking on greater risks than large corporations and by rapidly testing innovations, compared to larger, more established corporations. However, scaling these innovations from proof of concept to profitable market shares requires the support of a large business ecosystem with diverse stakeholders, including investors, policymakers, and researchers.

Understanding the complexity of the agricultural landscape is vital for fostering innovation. Distribution networks in agriculture are often intricate; customer relationships rely on trust and can span generations; and product development timelines can extend over several years. Therefore, analyzing regional ecosystems that support agtech entrepreneurship is crucial to identify opportunities and challenges for both entrepreneurs and the entities interacting with them.

A comprehensive understanding of the agtech ecosystem in a local context can help identify functional gaps and opportunities that entrepreneurs and other stakeholders can address. By expediting the necessary relationships, the ecosystem can facilitate the successful commercialization and widespread adoption of innovative goods and services. It also allows startup founders to leverage existing supporting resources and to explore potential relocation or new market locations. Investors seeking agtech companies in which to invest can also benefit from a well-defined ecosystem. Policymakers can make informed decisions that positively impact entrepreneurs, investors, and the community.

The Nebraska Agtech Ecosystem Map, a localized case study conducted in collaboration with researchers at the Daugherty Water for Food Global Institute (DWFI) at the University of Nebraska and The Combine by Invest Nebraska, provides a visual representation of the various players and resources that make up the state's agtech landscape and the interconnections between them. The map enables stakeholders to identify potential synergies and areas for improvement, while fostering innovation, communication and collaboration.

DWFI researchers have extended the global reach of their work and demonstrated the importance of understanding the broader context in which agtech entrepreneurs operate. In Rwanda, they explored the business ecosystem for smallholder irrigation, focusing on ways to support entrepreneurs who are developing affordable and accessible irrigation solutions for small-scale farmers. Similarly, a DWFI study of agtech startups and the business ecosystem for agricultural water use in India has shed light on the regional-specific challenges and opportunities facing entrepreneurs.

As the world faces the challenges of climate change, population growth and resource scarcity, fostering a thriving agtech ecosystem is key to driving agricultural productivity growth. By supporting entrepreneurs and start-ups and having a clear understanding of the space in which they operate, we can unlock the potential for innovation and create a more sustainable and resilient agricultural sector. Mapping and analyzing local business ecosystems, visualizing them effectively and understanding broader contexts are essential steps in this process. By working together, stakeholders can create an environment that nurtures agtech entrepreneurship and accelerates the development and adoption of innovative solutions to address the challenges facing agriculture today.

Public-Private Partnerships to Deploy Biofortified Wheat in Pakistan

HarvestPlus

Malnutrition is rampant among women, children, and adolescents in Pakistan. As per the National Nutrition Survey 2018, over a fifth of all women of reproductive age (22.1 percent) and 19 percent of children are deficient in zinc with serious consequences to their health.

HarvestPlus worked with CGIAR, the National Agriculture Research System, and private sector partners to develop and rapidly deploy biofortified crop varieties to tackle the pervasive levels of malnutrition in Pakistan–contributing to rapid variety adoption, improved livelihoods, and strengthened agricultural resilience. In 2019, the release of the zinc-biofortified wheat variety, Akbar 2019, marked the beginning of zinc wheat cultivation in Pakistan at a large scale. The success of Akbar 2019 hinged on the bundling of seed technologies with science-based policies, socio-economic interventions, and dissemination pipelines, ensuring that smallholders could improve productivity and women could benefit nutritionally.

The rise of Akbar 2019 is a significant milestone in Pakistan's agricultural development and has emerged as the leading choice among wheat varieties in the country because of its nutritional value, disease resistance, and better yield potential. According to HarvestPlus tracking, the output of this variety alone shall benefit over 97 million people in one year in Pakistan–increasing access affordable nutrition and improving livelihoods.

HarvestPlus and its public and private sector partners' collaboration propelled Akbar 2019 to its status as the mega variety of Pakistan. Their decade-long partnership with the Wheat Research Institute at Ayub Agriculture Research Institute, Faisalabad, and a strategic investment in Early Generation Seed (EGS) production facilitated the development and scaling of Akbar 2019. Dr. Javed Iqbal, director at Wheat Research Institute at Ayub Agriculture Research Institute, Faisalabad, Pakistan said, "*Akbar 2019 has been cultivated on nearly 42 percent of the wheat cropping area of Pakistan this year. The success is a testament to over a decade long continued partnership with HarvestPlus.*"

Recognizing the pivotal role of public and private sector seed companies, HarvestPlus embarked on capacity-strengthening initiatives to enhance the production and distribution of certified zinc-enriched wheat seed in Pakistan. Over 120 seed companies partnered with HarvestPlus, facilitating widespread adoption of Akbar 2019 and ensuring access to certified seed, even in the aftermath of natural disasters such as the 2022 floods. Over 175,000 metric tons of approved seed of Akbar 2019 was planted during 2023-24 cropping season.

HarvestPlus reached millions of farmers and rural communities by deploying regular digital media campaigns. Leveraging partnerships with organizations such as Precision Development, they fostered an increase in awareness and an uptake of zinc-enriched wheat varieties. Collaborative efforts, including journalist training programs, value chain actors' seminars, farmer field days, and demo plots, amplified the reach and impact of the demand creation initiatives. HarvestPlus also conducted several capacity building training sessions for smallholder farmers to empower the cultivation of zinc-enriched wheat varieties. The training sessions included essential nutrition education and highlighted the benefits of biofortified crops to combat malnutrition and improve family health. The hands-on trainings featured the latest agricultural practices, input use, weed control, post-harvest storage techniques, product development, and marketing of nutritious crops.

HarvestPlus advocacy efforts culminated in the integration of biofortified zinc-enriched wheat varieties into Punjab's annual wheat production plan. The Punjab government's inclusion of Akbar 2019 in seed subsidy programs exemplifies the tangible impact of policy advocacy in promoting the adoption of nutrient-rich wheat varieties.

The swift ascent of Akbar 2019– and its outpacing of non-biofortified varieties–underscores the pivotal role of HarvestPlus programming in accelerating variety turnover at the farmer level. As a result, the availability and consumption of zinc-enriched wheat has increased, and millions of consumers have access to more nutritious foods in Pakistan.

Courtesy of HarvestPlus.

Courtesy of Heifer International.

Tractors, Tech and Transformation

Heifer International

There are estimated to be about 13 tractors per 100 square kilometers (10,000 hectares) of arable, African farmland in comparison to the global average of 200 tractors per hectare of arable land. The Journal of Human Ecology (2022) found that only 28 percent of smallholder farmers in Nigeria use tractors for their farm operations because no tractors are locally available, farmers lack the knowledge and financing to access these machines, and the ecosystem of support (spare parts, mechanics, fuel, etc) necessary to service and maintain large equipment is largely non-existent.

Heifer International's AYuTe Africa Challenge, an annual competition that awards cash grants and business mentorship to promising young African agritech innovators, aims to close the gap between innovation and the needs of farming communities by embracing African ingenuity to solve the challenges faced by African farmers.

AYuTe offers entrepreneurs support to scale their ideas and disrupt traditional market forces holding rural economies back in the hope that bundling mentorship and entrepreneurship skills with innovations will accelerate the contribution of African ingenuity to tackle obstacles to sustainable productivity growth.

Hello Tractor, one of two winners of the first AYuTe Africa Challenge in 2021, is now a partner with Heifer International on a project that aims to transform rural economies in Nigeria, Uganda, and Kenya by supporting farmers and rural entrepreneurs to join the digital economy and grow more crops more productively. The project, called "Mechanization for Africa," is structured to create sustainable demand and supply for tractors through an initial investment from Heifer International and its partners for the machinery. The tractors can then be purchased by smallholder farmers who meet the criteria for financing through the project's exible "pay-as-you-go" financing model.

Participant farmers and service providers are then equipped with inputs and training as they work to repay their loans and manage their businesses. Once a tractor or tractors are available for hire within a rural community, it unlocks the by-the-hour rental service through the Hello Tractor marketplace app on the smartphones of participant farmers and local booking agents. The app connects smallholder farmers who need to hire a tractor with service providers like operators, community booking agents, mechanics and other providers on the ecosystem, and enables land mapping, data collection and an efficient payment and request system.

Farmers who do not have a smartphone transact through a trained booking agent. Farmers can also call a customer service line for additional support, though project technicians encourage booking agents to coordinate closely with farmers and book tractor time on their behalf to prevent overbooking and overcome scheduling issues.

The service creates transparency around fees and transactions for farmers who can "rent" a tractor and a tractor operator by the hour according to their needs and available resources. Owners and operators maximize their investment with better scheduling. This increases the productivity of multiple actors in the production value chain to create lasting impact.

Enhancing Smallholder Farming Through Integrated Agricultural Support

International Fertilizer Development Center

As the world's population continues to grow, farmers need ways to produce more food while ensuring that their farms' soil is not depleted of nutrients. In the Kaduna and Kano states of Nigeria, farmers look to IFDC and its HortiNigeria program to teach them new ways to fertilize their crops for increased productivity and soil health. Funded by the Embassy of the Kingdom of the Netherlands in Nigeria, HortiNigeria's team works with partners such as East-West Seed Knowledge Transfer Foundation to connect directly with farmers, educate them, and help them find ways to finance their businesses. In doing so, HortiNigeria reduces barriers to sustainable and productive farming techniques.

HortiNigeria's training initiative expanded significantly in 2023 to engage over 40,000 farmers, a diverse demographic that met 55 percent of the program's goal to reach women, and 133 percent of the goal to reach youth. The increase in trained Technical Field Officers and agro-dealers facilitated a broader reach and deeper impact, resulting in substantial improvements in crop yields across multiple varieties. By adopting an integrated training approach that combines traditional agronomic practices with modern technical insights, farmers not only doubled their tomato and cabbage yields but also significantly reduced post-harvest losses by adopting new storage and handling techniques.

Digital extension services also play a pivotal role in overcoming geographical barriers, allowing HortiNigeria to reach an extensive farmer base with timely and relevant agronomic advice. Platforms such as Facebook, WhatsApp, Telegram, and YouTube, along with traditional media such as radio, bring expert knowledge directly to farmers so they can make informed decisions about crop management and market readiness.

HortiNigeria brings productivity-enhancing tools to farmers in part by training farmers on environmentally sustainable agronomic practices. Upon completing training, farmers can participate in pilot programs that give them hands-on knowledge of these practices. Pilots have included experimentation with new crops, technologies, and agronomic methods that farmers may find unfamiliar. Reflection activities once pilots are completed uncover successes across Nigerian landscapes and markets.

HortiNigeria's pilot programs showcase how a combination of new crops, technologies, and agronomic methods could be effectively integrated into traditional farming systems. These pilots are instrumental in demonstrating the viability and benefits of new practices, ensuring that farmers are confident in their continued investment in these technologies.

To address financial barriers, HortiNigeria enhances farmers' access to financial services, training them in financial literacy and connecting them with banks and financial institutions. This crucial support enables farmers to invest in and sustain the use of new agricultural technologies and practices and improve their businesses' prosperity.

Through a bundled approach that combines practical training, innovative technologies, robust support systems, and improved access to financial services, HortiNigeria has created a sustainable model that encourages the ongoing adoption of productivity-enhancing tools by smallholder farmers. Moving forward, the program's commitment remains strong to refine these strategies and continue expanding its impact, ensuring that smallholder farmers not only thrive but also sustain their success in the ever-evolving agricultural landscape of Nigeria.

Courtesy of IFDC.

Bundling Nature-Based Solutions to Strengthen Caribbean Climate Resilience

Inter-American Institute for Cooperation in Agriculture

In 2020, the Inter-American Institute for Cooperation on Agriculture (IICA), through funding from the Caribbean Biodiversity Fund (CBF), implemented a project for community-based climate adaptation and poverty alleviation through biodiversity conservation and ecosystems management across four vulnerable islands: Antigua & Barbuda, Dominica, St. Lucia and Tobago. The project, entitled "Strengthening Coastal and Marine Climate Resilience Though Upland and Coastal Ecosystem-based Adaptation (EbA) and Community Engagement," leveraged nature-based solutions, using ecosystem conservation, sustainable management and restoration to benefit biodiversity and local economies.

A key project focus is the use of vetiver grass production in a systems approach to achieve multiple natural and community benefits including a green engineering system. With roots that can reach 10 feet deep, vetiver grass stabilizes soils for erosion control, groundwater retention, and removal of soil and water pollutants, as well as natural crop protection. Best practices using vetiver can prevent landslides, topsoil loss, drought, and sedimentation of waterways. Vetiver grass is also a 'C4' plant which absorbs an extra atom of carbon from the air compared with 'C3' plants, providing added carbon sequestration value. Vetiver leaves and oils also provide unique material for handicrafts, skincare products and soaps.

The project began by replicating a vetiver system technology package from the IAMovement in Trinidad and Tobago and building on the familiarity and traditional knowledge of vetiver among community beneficiaries and collaborators. Involvement in project activities–training, field work, business development, and peer-to-peer sharing of experiences–led to new knowledge and was curated to create handbooks containing practical and simple guidelines for: re-engineering vetiver for geoengineering in different landscapes, growing green business from vetiver, farmer climate readiness and community-led climate resilience actions.

The project provided field-based evidence that vetiver grass is an appropriate nature-based or geoengineering solution for soil erosion and stimulus for livelihoods in rural communities.

IICA and its partners provided a bundled support package of training, networking, tools and other tangibles to community stakeholders in these four islands. This included establishing nurseries, vetiver crafting and green business development, and application of technology such as GIS and drone imagery, through the University of Florida. Progress in landscape restoration was measured and tracked. IICA also facilitated the strong involvement of communities in every phase of the project to lead to successful outcomes.

Courtesy of IICA.

Courtesy of IICA.

Courtesy of John Deere.

Cutting-edge, Retrofit Technology Enhances Productivity on the Farm

John Deere

Farmers get one chance each year to produce the best possible crop. The stakes are high–every decision, from the depth and spacing of seeds during planting to the timing and types of herbicides used during spraying, can support or detract from the season's success. With less than 2 percent of the U.S. population involved in agriculture, farmers must maximize productivity with limited resources. Advanced technology solutions from John Deere, such as the John Deere Operations Center and Precision Upgrade kits, are essential to improve real-time decision making and enhance productivity.

Access to real-time data is critical for farmers. Today, advanced farm machines can gather large amounts of data in real time, sort it automatically, and store it securely in the John Deere Operations Center, an opt-in cloud platform that helps farmers to analyze data and make informed decisions in the moment and throughout the year.

For example, harvest marks the culmination of a growing season, providing a report card on the decisions made throughout the year. This time of year involves many factors, from managing the logistics and location of machines in a field with GPS technology to transporting the harvested crops to facilities for storage and distribution. To do so effectively, John Deere's Precision Ag Essentials kit gives farmers the tools to monitor, manage, and optimize their equipment using the latest receiver, modem, and display technology. This capability offers farmers data-driven insights to enhance their decision-making.

Technology is and has always been a driver of agricultural productivity growth, but high upfront costs make it challenging for farmers to invest in some of the latest technologies. By retrofitting technology onto existing machinery with John Deere Precision Upgrades, more farmers can access advanced tools and unlock the full potential of their equipment without an overwhelming upfront investment.

John Deere's See & Spray Premium allows farmers to upgrade existing sprayers with an advanced camera and artificial intelligence system that can detect the location of every weed within a field, and apply herbicide only and exactly where it's needed. This reduces herbicide use by up to two-thirds, benefiting the environment, lowering cost for farmers, thus contributing to productivity growth.

John Deere's ExactEmerge is another example of retrofit technology. Paired with field boundaries, guidance lines, and other data provided by the John Deere Operations Center, the machine can place hundreds of seeds per second at the precise depth and spacing needed for a healthy crop. Farmers can cover more ground, plant in the optimal planting window, and finish planting faster than traditional planters–all without sacrificing quality and yield.

Productivity-enhancing innovations, like retro-fit upgrade kits, provide farmers access to real-time data for precise decision making, helping them to be more efficient with time and inputs, thus improving their productivity.

Increasing Nutrient Use Efficiency by Integrating Biological Technologies with Existing Fertilizer Products

The Mosaic Company

A new era of understanding soil microbiome and its functionality with growing agricultural crops has emerged. New cross-disciplinary research is focused on soil health, regenerative agriculture, and how agricultural practices impact water quality, biodiversity, carbon sequestration, and greenhouse gas emissions.

This research is leading to new technology and products, that, combined with existing technologies can increase productivity by reducing the need for more crop inputs and reduce the environmental impacts of production agriculture.

In fact, science is quickly uncovering the connected potential between the soil, the plant and the microbiome to efficiently increase crop health. In 2023, The Mosaic Company launched Mosaic Biosciences™ to advance the potential of biological products bundled with existing fertilizer technologies. Mosaic's decades of scientific discovery and expertise in crop nutrition have led us to one important truth: biologicals work.

The Mosaic Biosciences™ portfolio of products protects and promotes plant growth while supporting the critical microbiome responsible for plant health and resilience by activating the connection between microbes and nutrients in the soil. Their symbiotic relationship helps break down soil-bound nutrients to make them more accessible and available to plants, while enhancing the microbial activity in the soil. Adding a nutrient use enhancement product to a crop nutrition plan helps increase fertilizer efficiency, ultimately increasing the return on fertilizer investment.

With over fifteen years of proven research on 2,300 plus global field research trials, two products, BioPath® and PowerCoat™ are exceeding expectations. BioPath® is a biological fertilizer complement formulated with proven strains of Plant Growth Promoting Rhizobacteria (PGPR), that

Courtesy of The Mosaic Company.

Courtesy of The Mosaic Company.

increases nutrient availability, uptake, and utilization and improves early-season plant growth and vigor, optimizing yield potential in crops. It makes soil and fertilizer work harder allowing crops to grow stronger, increasing return on fertilizer investment (ROFI) and overall profitability with a yield advantage ROI of over 3 to 1.

Similarly, PowerCoat™ is a biological fertilizer complement formulated with proven strains of PGPR, Plant Growth Promoting Rhizobacteria, that improves nutrient utilization for greater plant growth and vigor. The select strains of Bacillus in PowerCoat™ produce organic acids and enzymes that improve the solubilization of dry fertilizer into plant-available forms, helping maximize Return-on-Investment (ROI) from fertilizer inputs. When combined with BioPath®, Powercoat is an economical way to improve ROFI with a yield advantage ROI of 4.9 to 1.

The results are encouraging. In the Upper Midwest region of the United States, two agricultural retailers are using BioPath® and PowerCoat™ with existing dry granular fertilizers to boost corn yields without the use of additional fertilizer. In one situation, BioPath® was used on 120,000 acres, increasing corn yields by 3.8 bushel per acre, resulting in 456,000 bushels of additional corn.

Not only did the bundling of this new biological technology with existing fertilizer products increase corn yields, it also added another $2 million additional dollars to the farmers' pockets. In another situation both BioPath® and PowerCoat™ were applied to corn acres netting an additional 7.3 bushels of corn per acre without the use of additional fertilizer on existing nutrient management recommendations.

Farmers and agricultural crop advisors will need to evaluate what products will work best for their soils, cropping systems, and potential interactions with their existing crop input products and management practices to discover how these products will benefit their crop yield, overall farm profitability, and stewardship goals.

Courtesy of NASDA.

Targeting Trade Barriers in Indonesia with Communication and Innovation

National Association of State Departments of Agriculture

The National Association of State Departments of Agriculture's (NASDA) mission is to enhance American food and agricultural communities through policy, partnerships and public engagement. NASDA works continuously to fulfill this mission by fostering trust and relationships across the global agriculture marketplace. NASDA's trade missions to emerging markets showcase the intrinsic, long-term value of relationship-building and open dialogue, which sets the stage for innovation. This process for creating a nonpartisan forum of exchange is a core competency of NASDA, and innovation–indeed, streamlining or bundling innovation–always results when NASDA members connect with a challenge.

In 2022, NASDA was awarded $925,000 through the U.S. Department of Agriculture Foreign Agricultural Service Emerging Markets Program. The Emerging Markets Program helps organizations promote exports of U.S. agricultural products to developing countries with strong growth potential. Through this program, NASDA led members and industry experts on trade missions to four countries in 2023, including Indonesia in August 2023. The U.S. delegation to Indonesia included NASDA President and Oklahoma Agriculture Secretary Blayne Arthur, Arkansas Agriculture Secretary Wes Ward, New Mexico Agriculture Secretary Jeff Witte, Massachusetts Agriculture Commissioner Ashley Randle, California Agriculture Secretary Karen Ross, NASDA CEO Ted McKinney and U.S. Dairy Export Council (USDEC) President & CEO Krysta Harden.

The NASDA delegation met with government and private sector leaders in the agriculture industry to discuss critical topics including animal care standards, expediting dairy facility registration and the strong desire of Indonesians to do business with the U.S. One action item from these meetings focused on how Indonesia's Halal certification program would require the U.S. dairy industry to re-certify more than 120 dairy processors that currently export to Indonesia by October 2024. These dairy processors currently account for 15 percent of dairy products available to Indonesians. Addressing this major barrier while preparing the U.S. dairy industry to grow market share in Indonesia will reduce inefficiencies and food waste and create a forum for knowledge sharing that may lead to improving other aspects of dairy production for both countries. Additionally, the group discussed that Indonesian agricultural businesses and farmers desired technical support from the U.S.

Upon returning to the U.S., Secretary Witte and Harden organized a technical working group that created a channel for information sharing, technical assistance and trainings for the U.S.-Indonesian dairy industries. In January 2024, the technical working group traveled to Indonesia to meet with Indonesian officials and organizations, and expand the technical education curriculum for Indonesian dairy farmers. From these meetings, the technical working group decided on four modules: farm management, nutrition, increasing quality and yields, and animal health. The group also identified three Indonesian partners to vet and disseminate these modules once complete. The final product is a series of short videos with standardized trainings that Indonesian farmers can access on their cell phones. Additionally, the Wisconsin Department of Agriculture, Trade, and Consumer Protection joined the partnership to lend expertise on genetics, and Northern Illinois University Professor Dr. Eric Jones supported the transition with the new incoming Indonesian administration.

NASDA fosters partnerships that span state, federal, and private entities to reduce knowledge loss from election cycles, establish realistic goals and timelines, and integrate solutions that reflect the diversity of our producers and consumers. By addressing trade barriers, fostering open dialogue, and forming partnerships, NASDA's trade missions in Indonesia fostered a collaborative, multi-state effort that continues to provide an open exchange network, advancing the bottom line for agricultural producers in both the U.S. and Indonesia. NASDA fosters collaboration, policy innovations, and knowledge-sharing to pave the way for a more sustainable and productive global agriculture industry.

Courtesy of NASDA.

Courtesy of SAA.

Agro-dealership Program Boosts Productivity by Strengthening Farmers' Access to Quality Inputs

Sasakawa Africa Association

The Agro-dealership Program spearheaded by the Sasakawa Africa Association (SAA) has significantly improved producer livelihoods in 25 districts and 115 kebeles across Ethiopia's Amhara, Central Ethiopia, Oromia, and Tigray regions. With an investment of over USD $105,588, the program has supported 26 agro-dealer groups, providing essential agricultural supplies and training. These groups have served over 61,868 farmers, generating USD $636,148 in annual sales over the 3 years. The initiative, coupled with interventions such as improved seeds and fertilizers, has strengthened market connections and contributed to the enhancement of smallholder farmers' productivity, with reported yield increases of up to 57 percent in teff, 23 percent in wheat, and 56 percent in maize, effectively addressing agricultural challenges and boosting economic resilience.

Across the Amhara, Central Ethiopia, Oromia, and Tigray regions of Ethiopia, the Sasakawa Africa Association (SAA) has transformed livelihoods of youth in 25 districts and 115 kebeles through visionary partnerships that resulted in an investment of more than USD $105,000 in 26 agro-dealer groups over the past seven years. SAA has facilitated these groups' access to crucial agricultural supplies, including agro-chemicals, personal protective equipment, vegetable seeds, hybrid maize seeds, farm tools, hermetic grain storage bags (PICS), and sprayers, among others, from reliable sources.

Members of these agro-dealer groups received comprehensive training on the safe and responsible use of crop protection chemicals, including application techniques, precautionary measures, and emergency response protocols in case of poisoning. They were also trained in business skills and agro-input management and received assistance in adhering to trade and quarantine standards. These efforts have been instrumental in enhancing the groups' operational efficiency and compliance with regulatory requirements.

The agro-dealer groups have served over 61,868 farmers across different regions of Ethiopia, generating USD 636,148 in annual sales or 24,467 per agro-dealer group over the 3 years. Despite facing challenges such as inflation and capital constraints, the groups demonstrated resilience. Their early success in delivering inputs and providing appropriate extension and advisory services to farmers has been a significant motivation, resulting in substantial income generation.

SAA also played a critical role in facilitating connections between agro-dealer groups, wholesalers, and distributors, ensuring reliable access to quality agricultural inputs. This network has been vital in maintaining a steady supply of necessary resources for farmers.

The initiative continues to improve access to reliable agricultural inputs and advisory services, significantly boosting the productivity of smallholder farmers. Coupled with other interventions such as improved seeds and fertilizers, the agro-input supply has led to notable increases in grain yields. Farmers reported harvesting up to 57 percent more teff, 23 percent more wheat, and 56 percent more maize on their plots using improved technologies compared to community practices.

Smallholder farmers often face challenges such as insect pests like the maize stalk borer, diseases such as rust in wheat, and grassy weeds in teff. The availability of agricultural inputs is crucial in enabling farmers to protect their crops from these threats and contribute to the enhancement of their overall yields.

The Agro-dealership Program, facilitated by the Sasakawa Africa Association, has proven to be a transformative initiative for youth and smallholder farmers across several regions in Ethiopia. By strengthening access to essential agricultural inputs and providing vital training and market connections, the program has significantly enhanced agricultural productivity and economic resilience. As a result, farmers are better equipped to manage agricultural challenges and improve their livelihoods through increased crop yields and income.

Crop Residue Management: Combating Stubble Burning for Environmental Sustainability

SM Seghal Foundation

S M Sehgal Foundation adopted a long-term vision in 2021 to address the issue of crop residue burning in northern India with a holistic model that can be replicated and scaled up. This project aligns with the foundation's commitment to improving agricultural productivity through building capacities of small and marginal farmers across rural India.

Sehgal's grassroots activities include sensitizing farmers about soil health and the importance of organic content with demonstrations and regular capacity-building sessions on good agricultural practices in wheat and paddy; establishing Village Development Committees (VDC) and Women Leadership Schools (WLS) as part of the project learning and sustainability; and promoting the use of super-seeder machines for effective management of paddy residue.

Crop residue management helps improve soil structure and organic content matter in the soil and avoids nutrient losses due to burning. These practices have the potential to increase long-term agricultural productivity growth while enhancing food security (SDG2) and improving air quality (SDG13), which has an indirect relation to reduced human health risks caused by the air pollution post stubble burning (SDG3).

In the last two years, over 30,000+ acres of land were covered without crop burning after implementation of Seghal Foundation activities.

In 2023, one hundred villages in Haryana's Kaithal and Kurukshetra districts saw improved crop residue management practices, covering 25.75 percent and 28.28 percent of the total paddy production respectively, with support from 27 machines and existing machine owners.

Package of Practices (PoP) for paddy, a bundled training approach, was conducted for 624 farmers, revealing an average yield of 27.61 kg per acre on the demo plot and 25.27 kg per acre on the control plot. This indicates a percentage increase in yield of 9.35 percent.

Short-duration paddy varieties were promoted to 900+ farmers. Using short duration paddy varieties helps in crop residue management by allowing farmers to harvest earlier. This provides sufficient time to prepare the field for the next crop, reducing the need for burning residues. Early harvesting also facilitates timely sowing of the next crop, improving soil health and productivity. These varieties enhance yields and productivity by swiftly adapting to diverse climatic conditions and enabling multiple cropping cycles within a year.

In the last twenty-five years, the foundation has reached 4.94 million people across twelve states to empower rural farming communities. The heart of S M Seghal Foundation's work is to enable smallholder farmers to embrace and ultimately take forward their own development.

Courtesy of Seghal Foundation.

Courtesy of Seghal Foundation.

From Lab to Land: Making Science Work for Farmers

Tanager International

Despite the potential of advanced technologies to revolutionize sustainable agricultural productivity growth, Tanager's 15-plus years of experience in India have shown that these innovations are not a silver bullet. High investment requirements, technological complexity, and farmers' risk aversion curtail adoption. In the state of Uttar Pradesh, 82 percent of farmers own less than 1 hectare of land and monthly incomes were INR 8,061 (USD $96) in 2019–INR 2,157 (USD $26) less than monthly agricultural incomes nationwide. Instead, farmers prefer simpler, tangible practices that reduce their cost, labor, or effort.

Tanager is therefore innovating by adapting the principles of agricultural science to meet smallholder conditions, through on-site, targeted small plot research and the provision of high-quality planting material paired with a strong extension team and digital message to reinforce practice adoption.

Under the Shubh Mint project, funded by Mars Wrigley, Tanager has been using a lab-to-land approach with more than 24,000 farmers to test, learn from, and scale practical innovations in mint cultivation. This method leverages scientific rigor to identify the factors that can improve mint oil quality and yield within farmers' financial limitations. It also provides proof of concept to skeptical farmers who have relied on generations of farming tradition.

Each year, Tanager opens opportunities for "research farmers" who agree to collaborate by devoting a portion of their lands for research. Farmers donate their labor, and Tanager supplies mint planting material, agricultural inputs, and technical assistance. At harvest time, Tanager takes a small sample to analyze results; farmers get to sell the rest of the harvest for profit.

These research fields are divided into plots ranging in size from 25m^2 up to 60m^2, with each plot testing a different factor–such as variations in fertilizer quantity or micronutrient combinations–using randomized block designs. Practices that yield the best results–decreased labor or costs, agricultural productivity from the perspective of increased mint oil yield and quality–are shared with the larger farmer supply base for Mars Wrigley's supply chains, via extension services, demonstration plots, and digital messaging.

Seven years of this lab-to-land approach has yielded smallholder farmer-validated innovations from soil micronutrient management to water efficiency techniques. The project's efforts have also significantly reduced usage of expensive fertilizers by minimizing dosages and switching farmers to regimens that increase nutrient uptake from mint plants, thereby increasing productivity. Even the direction in which rows of mint are planted has been tested to leverage sun and wind patterns for maximum photo- and oil synthesis.

Courtesy of Tanager International.

Ram Samujh Yadav, a 76-year-old research farmer, demonstrates the success of this approach in improving productivity. When he was asked to plant chili in between mint rows last year, he said, *"I was initially thinking I might lose money."* Instead, he earned INR15,000 (USD $180) from sales of his chili harvest, reduced his cultivation costs, and increased his oil yield to 72 kg per acre, compared to 38-40 kg per acre when the research program first began.

Another innovation arising from the lab-to-land approach is quality stolons. Tanager knew that quality planting material was key to mint yield but was also aware of how difficult it was to access. Tanager partnered with the government's Central Institute of Medicinal and Aromatic Plants (CIMAP) to propagate quality mother planting material, then paired quality stolons with practical technical advice to engage farmers in mint multiplication.

This process has generated a new, sustainable line of business and income for mint multipliers while expanding general access to quality stolons. For the 2024 planting season, a total of 600 multipliers grew enough quality planting material–932,728 kg–to cover an estimated 30,000 acres. Tanager's Shubh Mint project now represents the largest planting material supply chain for mint globally.

These seemingly small adjustments have led to significant improvements in mint production while helping farmers to better maintain the long-term productivity of their land. Participating farmers have reduced their irrigation frequency by 15-30 percent, reduced their production costs by 20 percent, have increased yields by 20 percent, and increased their average net incomes by a whopping 125 percent.

Importantly, project farmers are becoming ambassadors for change. Yadav and other research farmers, for example, are discussing intercropping on their lands not dedicated to research. Multipliers are sharing the technical advice they receive from Tanager with their clients. These farmers are independently scaling up sustainable agricultural innovations for the region's benefit.

Public-Private Collaboration to Combat Land Conversion in Brazil

The Nature Conservancy

Beef production in Brazil has been driving a decades-long trend habitat loss, over a million hectares annually, accounting for roughly 24 percent of global tropical deforestation every year. To counter this, The Nature Conservancy (TNC) has united diverse stakeholders across the Brazilian beef industry, including local governments, producers, industry associations, and civil society, under a bold common vision to halt this trend.

In November 2023, the state of Pará signed an Executive Decree mandating statewide individual cattle traceability for both environmental and animal health control. This step was announced by Governor Barbalho as part of the state's Cattle Integrity and Development program launched at COP28. The program's goals include transparency, compliance, productivity, inclusion, and intensification.

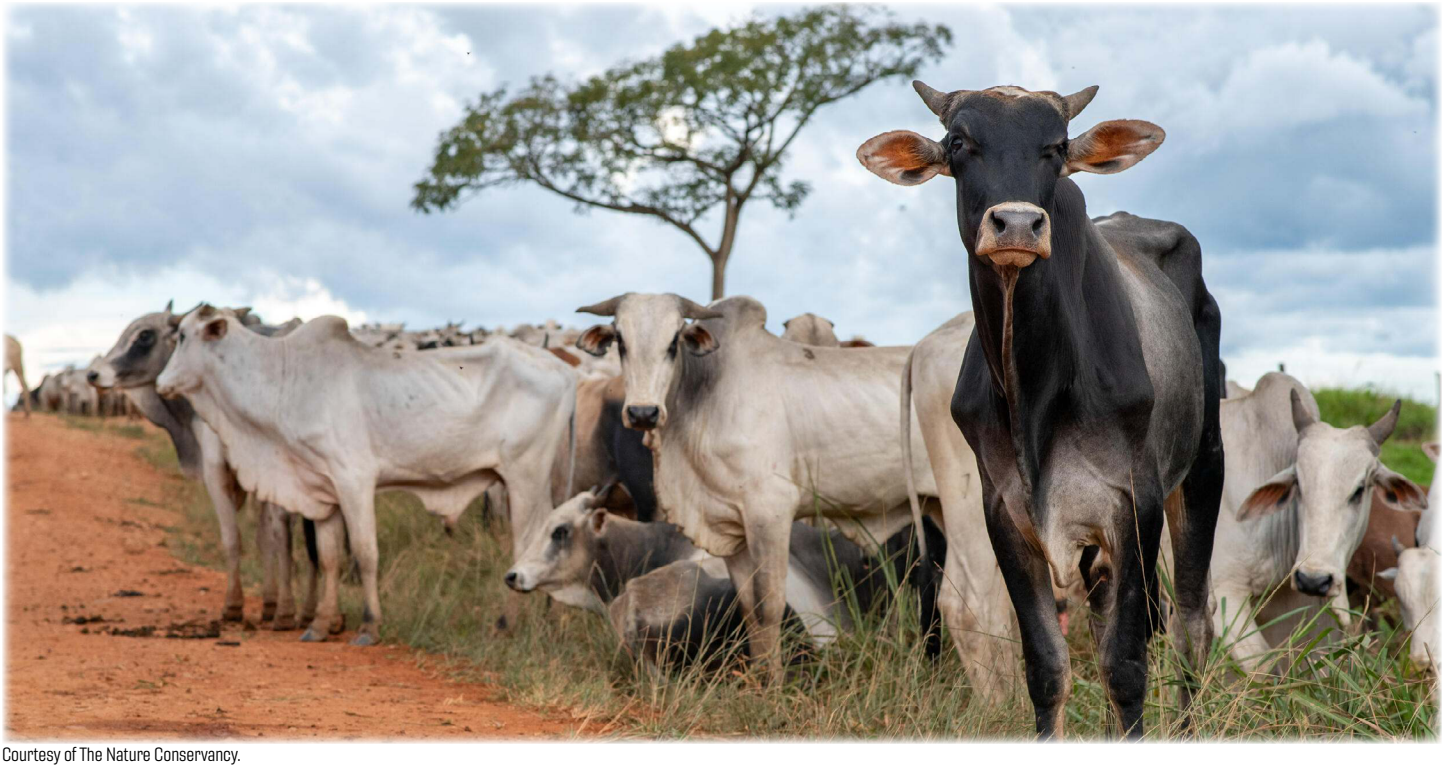
This policy, the first of its kind in the world, is now inspiring a race-to-the-top momentum and has caught the attention of national and international policymakers, along with global market players. The program has received significant financial backing, including an initial $16M commitment from the Bezos Earth Fund and $1M from meatpacker giant JBS. These funds are set to galvanize further funding flows, scaling partners, and a public-private force that will execute a broader program on the scale of $150-200M.

Carlos Fávaro, minister of agriculture for Brazil, offered enthusiastic endorsement and opportunity for scale, stating, "*We are going to transform it into a program for all Brazilian states, in the certainty that this will become a reference in Brazil and … for the world*." At least one other Brazilian state is considering similar legislation in 2024, and similar national programs are also under consideration.

In December, Pará officially named TNC as the NGO representative to the advisory board. This recognition underscores the pivotal role TNC plays in this initiative and its commitment to bringing deforestation to the forefront of our priorities for fundraising and leveraging resources through 2030.

Deforestation reduction and productivity growth are interconnected. The Pará Cattle Integrity Program encourages ranchers to increase the productivity of their already-cleared land rather than expand into intact forest. The Pará government is exploring different incentive mechanisms for producers that make it more financially viable to increase the productive output on pastureland. Tracing and tracking the total output of cattle in Pará opens the possibility of further interventions to measure and boost rancher productivity down the line, as well.

TNC's success in this endeavor - avoiding 5 million hectares of habitat loss by 2030 - depends upon galvanizing funding flows, scaling partners, and a public-private force of will. This initiative serves as a beacon of hope and a testament to what can be achieved when we engage boldly, deeply, and in ways that can scale quickly to halt the devastating impacts of climate change.



Courtesy of The Nature Conservancy.

GAP INITIATIVE™ AT VIRGINIA TECH

The GAP Initiative™ at Virginia Tech brings together expertise from universities, the private and public sectors, civil society organizations, and global research institutions to align efforts to accelerate agricultural productivity growth around the world.

Our vision is that every farmer has access to every proven tool for creating sustainable agricultural productivity growth. The GAP Initiative™ motivates action and investment to accelerate agricultural productivity growth at all scales of production to create returns to farmers, society, the economy, and the environment.

We achieve our mission through:

- Creating outstanding communication resources, especially the annual GAP Report™
- Convening and attending internationally recognized events
- Conducting and catalyzing research and data analysis
- Promoting evidence-based solutions
- Building a network of global champions and innovators

The GAP Report™ draws on expertise from the private sector, international agencies, civil society organizations, conservation and nutrition groups, universities, and research institutions. It is the heart of the work we do through the GAP Initiative™.

Supporting Partners provide financial support and offer perspectives on critical issues facing the world's agricultural systems. **Technical Partners** provide insights on areas essential for productivity growth: agricultural research and development and extension systems, natural resource management and conservation, human nutrition and animal health, community-led development, gender equity, trade, and climate change.

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