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, 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 to achieve sustainable agricultural production. We urgently need to elevate our efforts to accelerate TFP growth annually.

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.

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.

SETTING THE STAGE FOR PRODUCTIVITY GROWTH

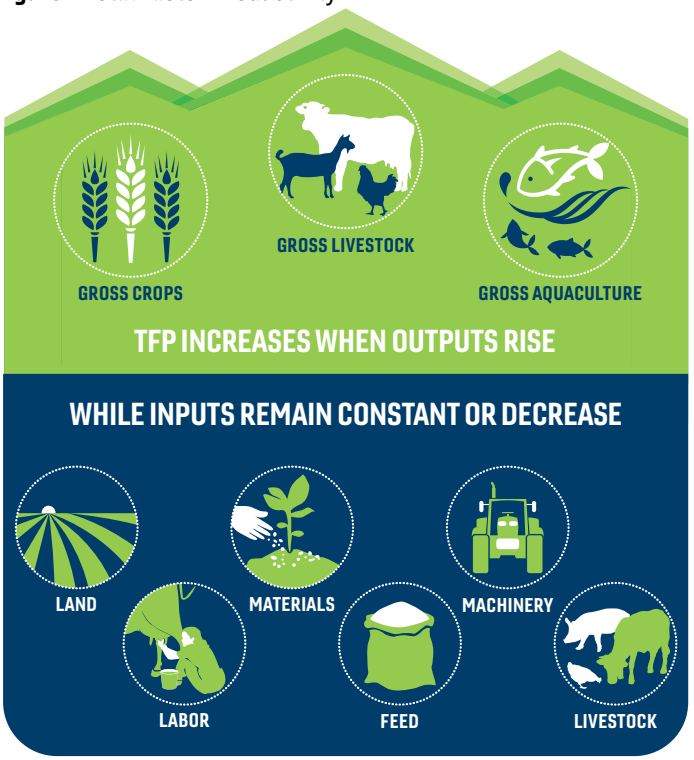
TRACKING TFPG WORLDWIDE: PROGRESS AND PROJECTIONS TOWARD 2050

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 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. 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).**

Figure 1: Total Factor Productivity



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 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. For a second year in a row, the target 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).

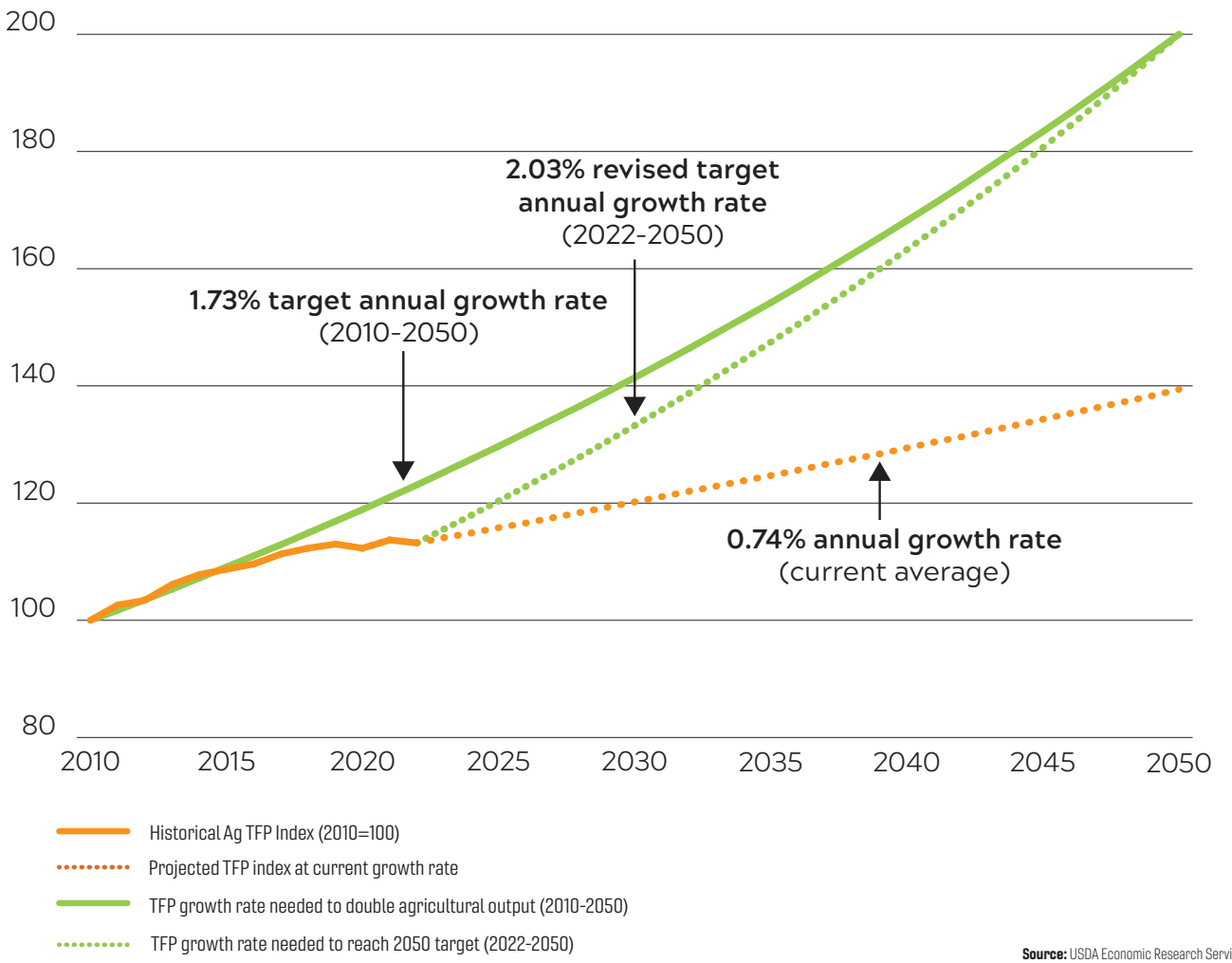
Why is lagging TFP growth such a concern and how can closing the growth gap help secure the economic, social, and environmental vitality of our agri-food systems?

Increasing TFP growth is an 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 change impacts, compromising global food supply stability. A 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).

REGIONAL TRENDS & LEADING COUNTRIES

During 2013-2022, South Asia led all global regions in average annual agricultural output growth, driven primarily by strong TFP growth, averaging 1.4 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 1.7 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.

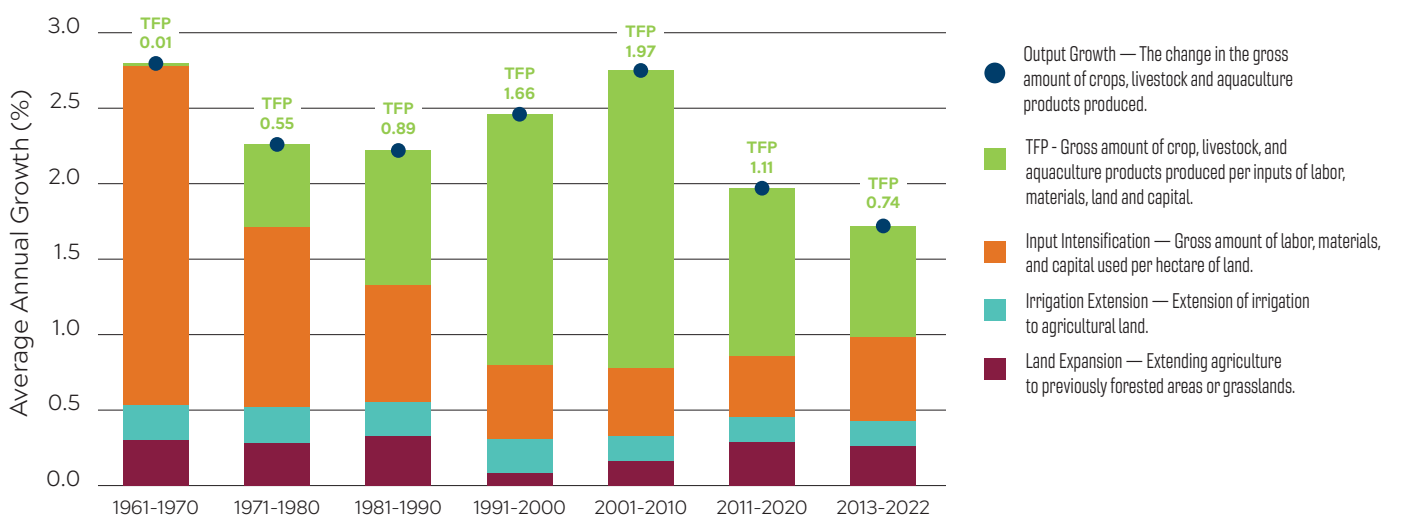
Sub-Saharan Africa (SSA) emerged as a notable contributor to global agricultural output growth, though it lagged in average annual TFP growth at 0.37 percent (Figure 4). In contrast to South Asia, the region's output growth was primarily driven by land expansion and input intensification, as limited 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 1.43 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 increased inputs like fertilizers. Irrigation extension had a minimal impact with a 0.02 percent contribution.

Latin America and the Caribbean (LAC) saw modest average annual TFP growth during 2013-2022 (0.84 percent), but the primary contributor to average output growth was input intensification (1.35 percent annually). In contrast, agricultural land use growth in the region decreased by 0.68 percent annually. The European Union (EU) matched LAC's average annual TFP growth and 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.

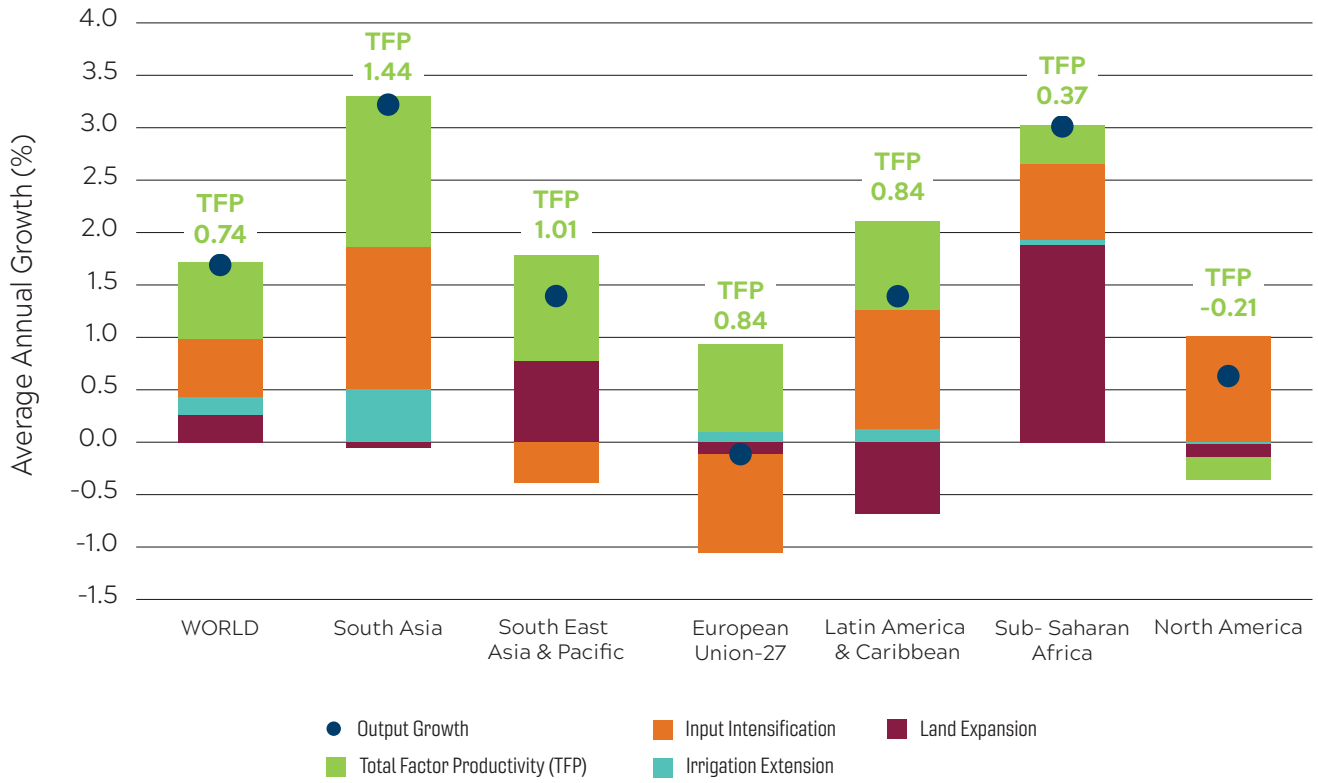
North America recorded a modest average annual output growth of just 0.66 percent. This is a considerable drop from the 1.49 percent annual growth seen in the 1990s. During the recent period, North America experienced

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



Source: USDA Economic Research Service (2024).

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



Source: USDA Economic Research Service (2024).

negative TFP growth, averaging -0.21 percent annually, while Canada saw positive TFP growth, averaging 0.15 percent. 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 early 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.

Photo: Heifer International

Photo: Corteva Agriscience

Increasing Smallholder Farmer Productivity in Brazil

Corteva Agriscience

In 2016, Corteva launched the Prospera program in Northeast Brazil to boost productivity, incomes, and sustainable practices of smallholder farmers and rural communities. Partnering with Yara, Massey Ferguson, Global Communities, and other stakeholders, Prospera has enhanced corn and silage value chains vital for livestock feed, increasing farmers' productivity from 15 to 132 bags/hectare and training over 6,000 farmers, including 32 percent women. Through this collaboration, farmers have increased access to climate-optimized corn seeds, sustainable crop protection, fertilizers, agronomic support, and mechanization.

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.

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-27.

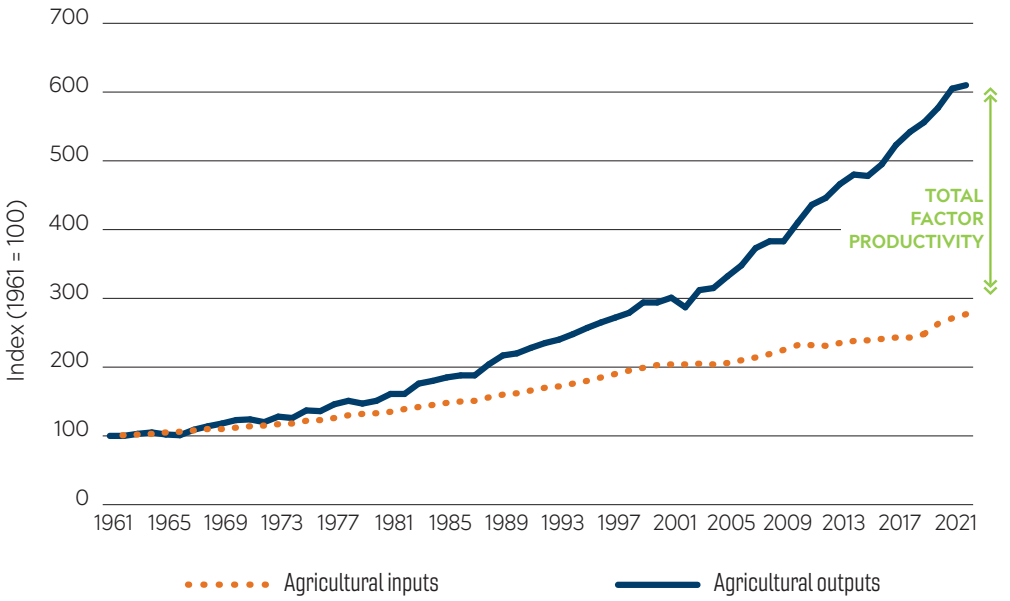
South Asia's efficiency gains have kept the average annual agricultural output growth at or above 3 percent since the 1980s. The significant increase in agricultural output relative to input usage (Figure 6) can be attributed to substantial investment in research and development (R&D), technical change, 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 70s, 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 of the Green Revolution's impacts, which saw an increase in the use of nitrogenous 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 increase in 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 maintaining environmental and social

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



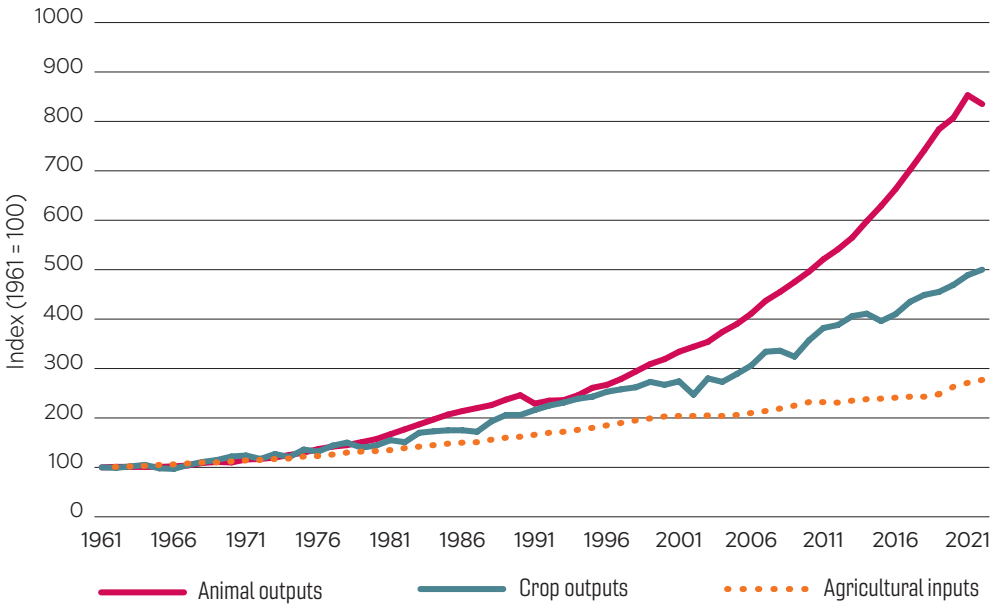
Source: USDA Economic Research Service (2024).

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 et al., 2020).

TFP GROWTH IN SOUTH ASIA BY COUNTRY

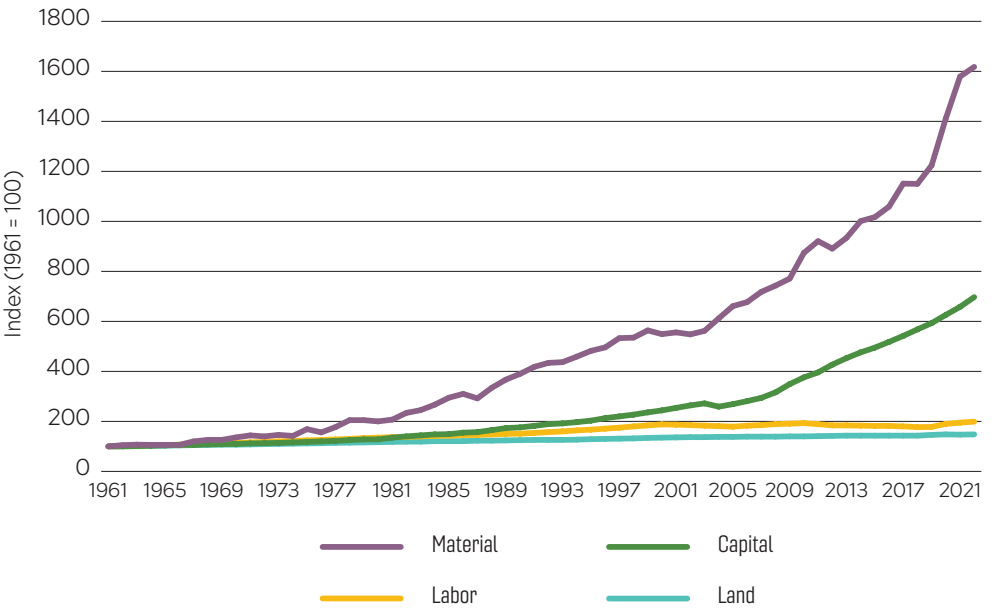
Between 2013 and 2022, India and Pakistan were engines of TFP growth in the region, averaging 1.64 percent and 1.72 percent annual growth respectively (Figure 9). In Pakistan, input intensification was the main contributor to output growth (2 percent annually). Nepal had a modest TFP growth rate of 0.88 percent annually but predominantly realized its average 3.1 percent output growth through irrigation extension as did Bangladesh (3.2 percent). Bangladesh, however, suffered an average TFP growth contraction of 1.5 percent annually during 2013-2022. 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 between 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

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).

(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 growth rate, highlighting underlying vulnerabilities that were likely exacerbated during this period (IFPRI, 2022; World Bank Group & Asian Development Bank, 2021).

SOUTH ASIA'S AGRICULTURAL OUTPUT GROWTH HIGHLIGHTS A CRUCIAL REALITY. While we may avoid immediate 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.

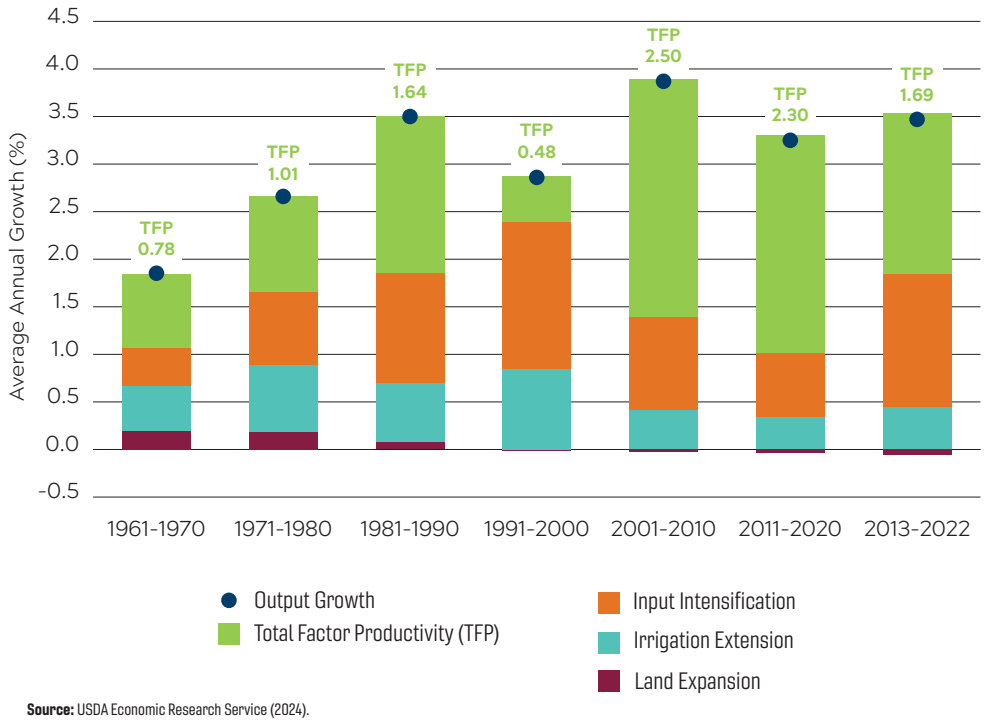
INDIA'S AGRICULTURAL TRANSFORMATION: FROM RESOURCE-INTENSIVE GROWTH TO INNOVATION-DRIVEN PRODUCTIVITY GAINS

India's agricultural sector has undergone a notable transformation over the past six decades. While input intensification made significant contributions to output growth since the 1960's, peaking at 1.54 percent in 1991-2000, TFP growth emerged as the primary driver since the 2000s (Figure 10). The increasing prominence of TFP growth signals a transition towards more efficient and innovative agricultural practices, technologies, and sustainable policy supports. In 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.

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

Source: USDA Economic Research Service (2024).

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

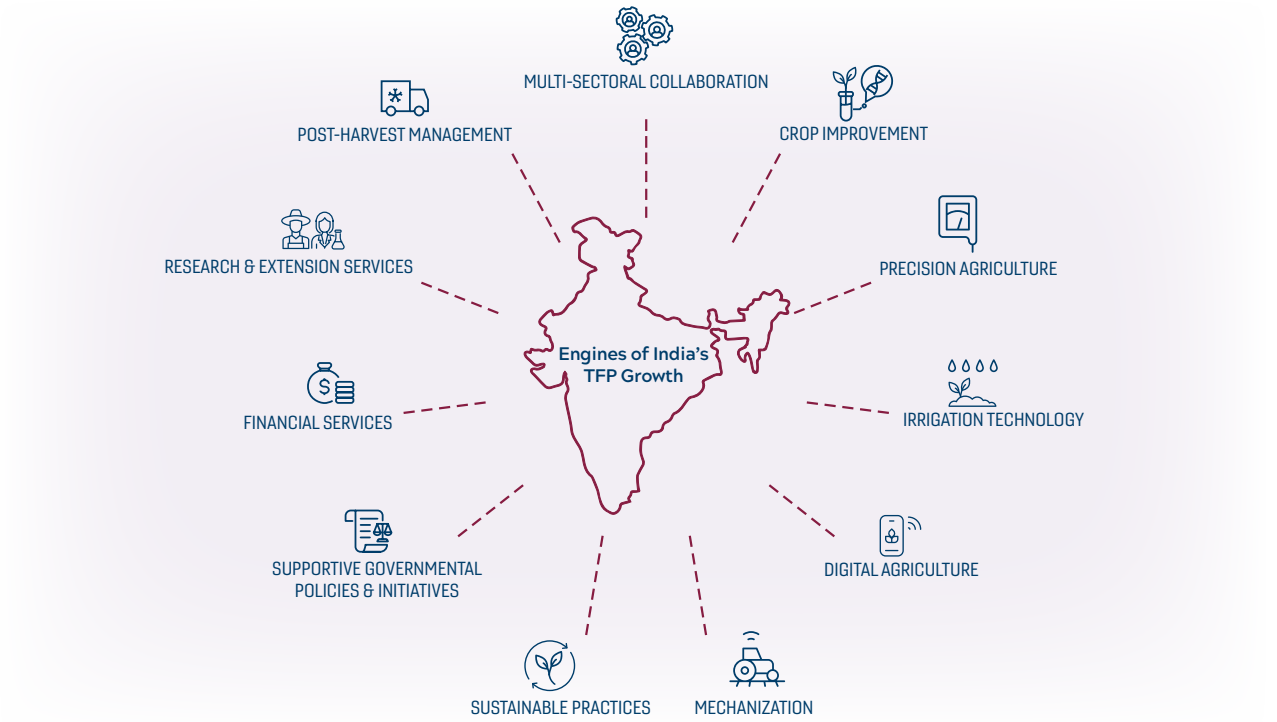


Source: USDA Economic Research Service (2024).

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 research and development, 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).

Figure 11. Engines of India's TFP Growth



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.

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.

Photo: Bayer Crop Science

Boosting Yields and Incomes in India

Bayer Crop Science

Agriculture is transforming and we need to bring the millions of smallholders along on the journey towards a more sustainable and increasingly regenerative future. Independent social impact measurement indicates that the Better Life Farming Alliance helps to increase smallholder farmer agricultural productivity, incomes, and quality of life. Better Life Farming Centers offer access to capacity building, innovative seeds, fertilizer, and crop protection solutions, micro financing, digital tools or other locally relevant services. At Bayer we reached 53 million smallholders through access to products, services and partnerships in 2023.

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.

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.

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). Investments beyond R&D alone will be needed to realize the target agricultural productivity growth rate.

Actions to Invest in Agricultural Innovation Systems

Policy

Strategic alliances and investment plans to close the agricultural R&D intensity gap (~$13 billion) 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.

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.

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.

Photo: SM Seghal Foundation

Crop Residue Management: Combating Stubble Burning for Environmental Sustainability

SM Seghal Foundation

The S M Sehgal Foundation's crop residue management project aims to combat stubble burning in Haryana and Punjab by promoting sustainable agricultural practices. By incorporating paddy residue in-situ, the project improves soil health, water retention, and nutrient availability. The foundation's initiatives include sensitizing farmers, establishing Village Development Committees and Women Leadership Schools, and promoting super-seeder machines. These efforts have led to improved crop yields, reduced air pollution, and enhanced food security. Over 30,000 acres have been covered without burning, significantly reducing CO2 emissions and protecting soil nutrients, benefiting over 4.94 million people across twelve states.

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. Factors such as 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.

Lack of market access can also exacerbate post-harvest losses, particularly for perishable goods that require cold chain logistics. These high-value, nutrient-dense products are essential for both producer incomes and consumer nutrition. Therefore, investing in market access infrastructure can incentivize productivity enhancements while supporting producer livelihoods and advancing food and nutrition security goals.

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 agricultural total factor productivity (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.

Photo: Corteva Agriscience

Empowering Women Smallholder Dairy Farmers in East Africa

Corteva Agriscience

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 empower women smallholder dairy farmers in Kenya and Ethiopia. Corteva's climate-optimized hybrid corn seeds are increasing silage yield and quality, while agronomists train farmers in sustainable practices. Recognized as an AIM for Climate Innovation Sprint, NPA has trained 7,000 farmers to date, increasing milk production by 46 percent, and reducing emissions by 26 percent. The program also empowers women, addresses nutritional challenges, and promotes sustainable agriculture.

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 (Cattaeno et al., 2020). 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.

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.

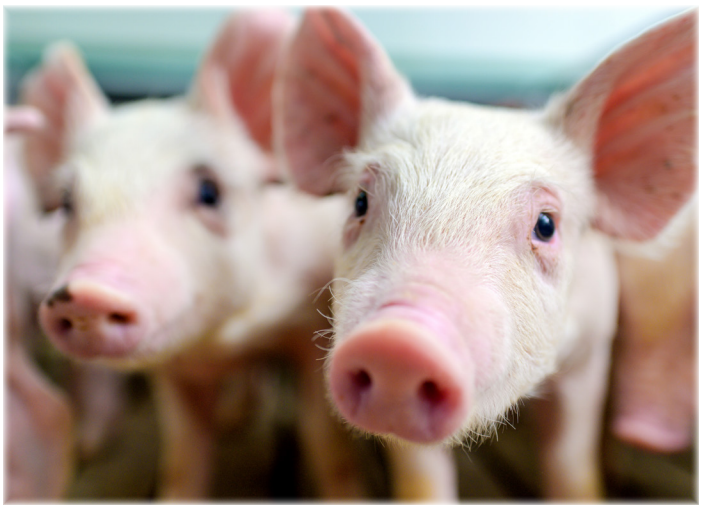
Define the linkages between food loss, food shortages, and food security to identify action points.

Photo: Tanager International

From Lab to Land: Making Science Work for Farmers

Tanager International

Smallholder farmers in Uttar Pradesh, India, are reluctant to adopt new technologies that could otherwise improve agricultural productivity. Tanager is testing and scaling practical innovations in mint cultivation by leveraging targeted small-plot research to adapt scientific principles in good agricultural practices to local conditions. A program to multiply the supply of quality planting materials has further improved agricultural productivity. The initiative has significantly improved productivity, reduced costs, and increased incomes for over 24,000 farmers while fostering a sustainable, scalable agricultural model.



Taking Action to Reduce and Upcycle Supply Chain Waste Through Innovative, Sustainable Solutions

Smithfield Foods

Reducing waste is one of the most fundamental ways to achieve efficient use of agricultural inputs and resources to increase productivity because producing something that isn't used is inefficient. Smithfield Foods is working toward the goal of zero-waste-to-landfill (ZWTL) status at company-owned U.S. facilities by 2025 by recycling used plastics, utilizing bakery byproducts in animal feed and implementing process improvements, diverting food waste from landfills. Smithfield also pursues strategies to help reduce post-consumer waste.

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 Report™ 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.

Driving Agricultural Productivity Through Entrepreneurs and Startups

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

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. However, scaling their innovations can be a challenge. The Daugherty Water for Food Global Institute at the University of Nebraska has developed several case studies on mapping agtech entrepreneurship ecosystems. Understanding and mapping the diverse regional ecosystems that support agtech entrepreneurship can help identify functional gaps in the ecosystem, facilitate and expedite commercialization, and aid startup founders and investors in leveraging existing resources. A supportive ecosystem for agtech entrepreneurs is essential to drive agricultural productivity growth and to meet the growing demand for nutritious food.

Photo: Daugherty Water for Food Global Institute

RESEARCH: HOW GLOBAL TRADE AND INNOVATION SHAPE THE FUTURE OF FARMING

LESSONS FROM GOLDEN RICE

Martha King and Sandro Steinbach*
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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 illustrates the promise and pitfalls of scaling such innovations, which are crucial for building a more resilient agricultural future.

Developed as 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 developing countries. 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.

Trade as a Driver of Innovation and R&D

International trade is vital for developing new agricultural practices and technologies that boost productivity. Golden Rice was a global collaborative effort involving multiple stakeholders like the International Rice Research Institute in the Philippines, European researchers, and private companies. Together they 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 developing countries.

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. 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, such as Canada and the United States, which boost 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.

Barriers to Adoption and Policy Implications

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 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 more adaptive regulatory policies that balance safety with the urgency of addressing global food security issues.

Phase 1: Early technology development

1984	1980s	1992	1996	1997	1999-2000
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.

Phase 2: Intellectual property rights and IP transfer			Phase 3: Field trials and regulatory approvals						
2001	2003	2004-2005	2008	2013	2018	2019	2021	2023	2024
Golden Rice technology licensed to Syngenta.	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.	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.

Even though strong scientific evidence supports the safety and benefits of Golden Rice, it 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. Public perception, influenced by how these technologies are presented and understood, also plays a vital role.

There is a clear need for more flexible and responsive regulatory frameworks to ensure that innovations like Golden Rice reach those who need them. 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. Golden Rice has faced numerous challenges in its journey from concept to widespread adoption. Regulatory barriers, particularly those surrounding GMOs, have been among the most critical factors in widespread adoption. Many countries have stringent approval processes that delay the release of new technologies, even when backed by strong scientific evidence. While intended to protect public health and the environment, this regulatory caution 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 slow the spread and hinder the potential TFP gains that could be realized if such technologies were more widely adopted. Socio-economic factors, such as the need for more infrastructure, education, and market access, also contribute to the slow diffusion of innovations in many developing regions. Farmers may hesitate to adopt new technologies if they lack the necessary support systems or if the economic incentives are unclear.

Policy Recommendations for Techology Transfer

There are three key policy recommendations that 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. Furthermore, facilitating the cross-border exchange of knowledge, technologies, and resources, trade can accelerate the development and dissemination of innovative agricultural solutions.

Second, regulatory frameworks need to be more adaptive and evidence 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 developed and 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. ■

POWERING PRODUCTIVITY THROUGH HIGH-IMPACT BUNDLES

CROSSING THE VALLEY OF DEATH

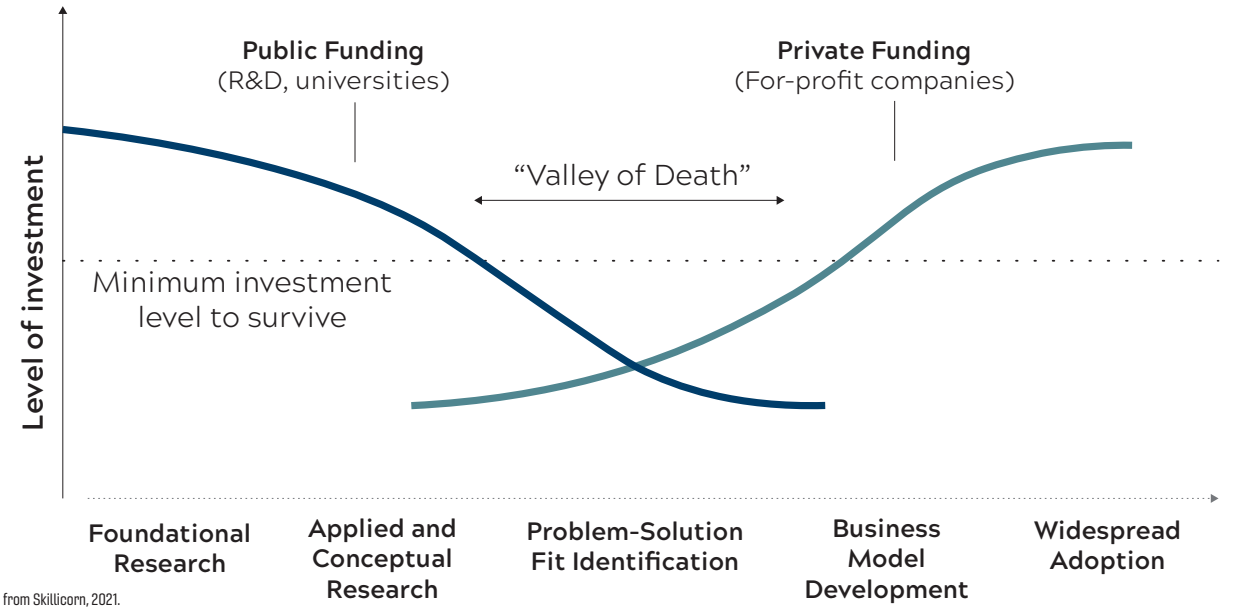
In the 2023 GAP Report™, *Every Farmer, Every Tool,* we emphasized the central importance for producers, at all scales of production, to be able to access and adopt proven and appropriate productivity-enhancing tools to close the total factor productivity (TFP) growth gap of the past decade. Productivity 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) (Frank et al., 1996, Ellwood et al., 2022).

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 (Vallas and Kleinman, 2008; Ellwood et al., 2022). 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, 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 and Sørheim, 2012). Evidence from various country contexts and agricultural systems highlights several factors impeding widespread adoption of proven and emerging tools (see box below).

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 integrated demand and supply side interventions to achieve impactful market penetration, cost efficiencies, and user acceptance.

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.

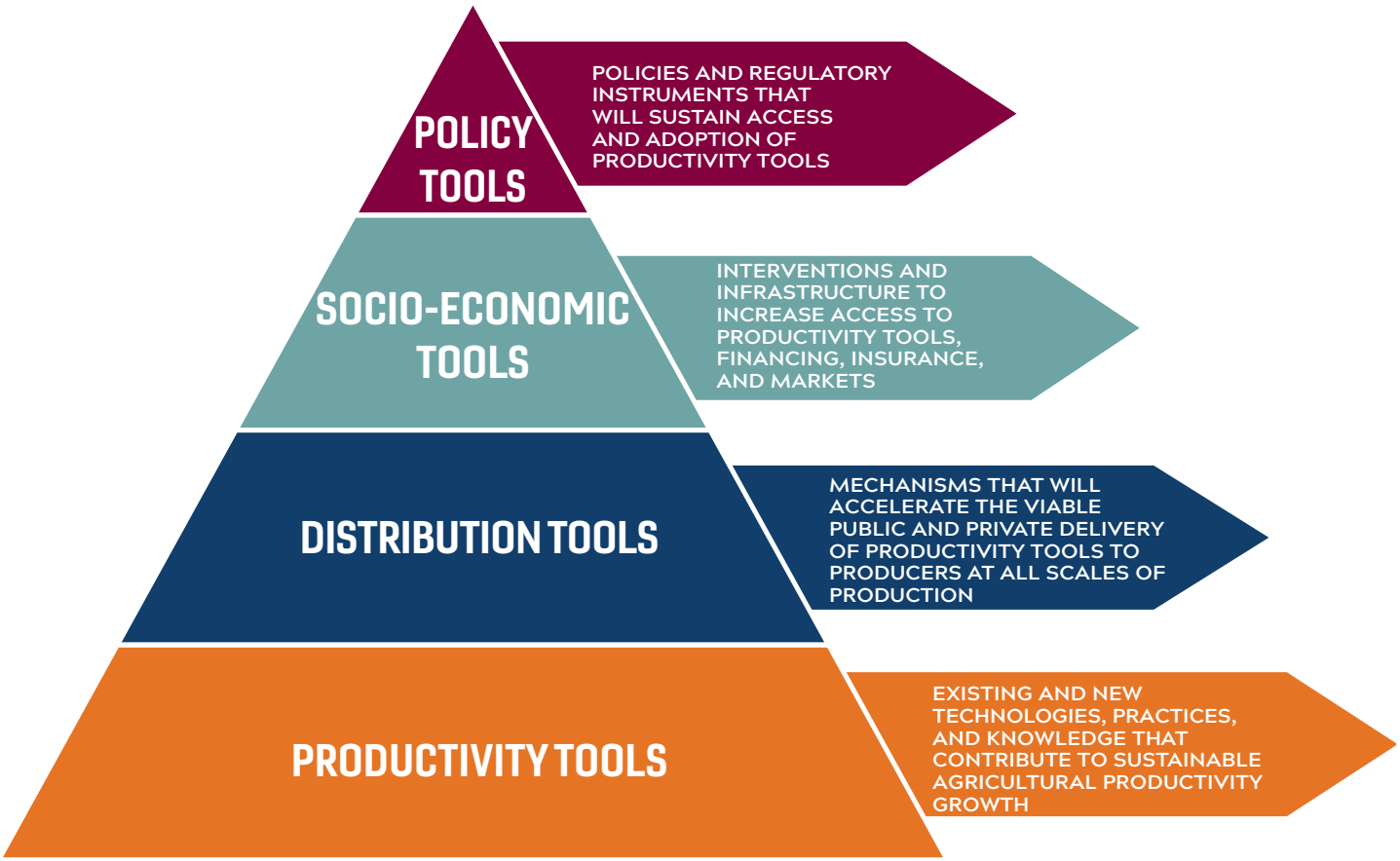
Agricultural productivity tools face a complex interplay of technical, biophysical, political, financial, market, and sociocultural factors and are unlikely to scale without being accompanied by companion interventions, mechanisms, policies, and institutions (Barrett et al., 2020). Leveraging a 'bundling' 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.

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, Total Factor Productivity (TFP) Growth Bundles should include productivity, distribution, socio-economic, and policy tools to build efficient and sturdy bridges across the Valley of Death. 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 the five priorities for advancing productivity growth outlined in this report (Figure 13).

Figure 13. Recipe for TFP Growth Bundles



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).

OFF THE SHELF & 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 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.

Innovation actor leadership. According to research by Ellwood et al. (2022), innovation actors such as, scientists, engineers, analysts, business managers, 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.

Technology-push and market-pull. Technology-push innovation strategies create market demand by offering creative and disruptive solutions to user needs.

Contrastingly, 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).

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.

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.

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

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.

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.

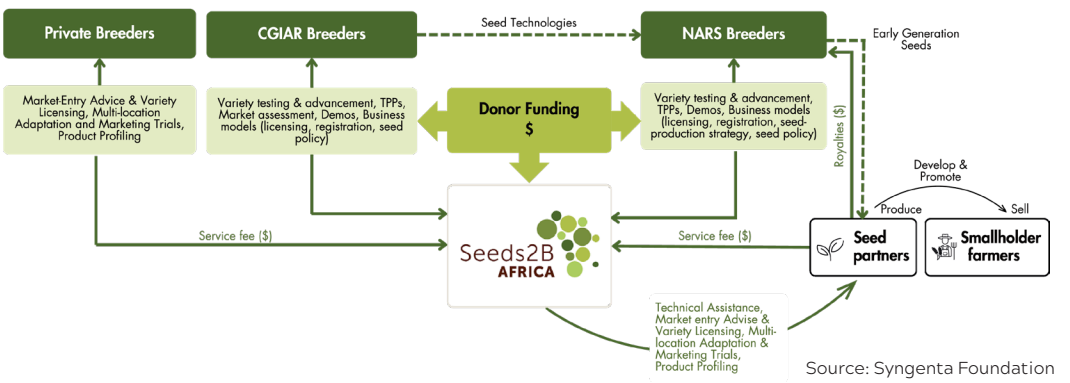
Strategies for a coordinated approach. A successful deployment strategy involves the integration of various stakeholders' efforts to ensure a cohesive and unified approach. This coordination not only enhances the efficiency of the implementation process but also amplifies the overall impact on TFP growth. 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



Source: Syngenta Foundation

The main reason why adoption of new seed technologies remains low is because the handover between research and private seed commercialization is disconnected. 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 market-appropriate 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.

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.

Photo: AATF

Bundling for Farmer Productivity and Food and Nutrition Security in Africa

AATF

Maize and cowpea play an important role in food and nutrition security and farmer livelihoods in Africa. However, productivity of both crops has been historically low due to pests, drought, and poor agronomy by farmers. To address these productivity challenges, both conventional and genetic engineering approaches have been used to develop improved varieties that have increased yields by up to 60 percent. AATF has been working to enhance the capacity of farmers to successfully adopt these new varieties complemented with good agronomic practices (GAPs), ICT tools, and targeted awareness creation to significantly reduce the existing yield gaps between research stations and farmers' fields for both crops in Africa.

Photo: Virginia Tech

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 over the past decade, achieving the revised target of 2 percent 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. Bridging the 'Valley of Death'–the gap between technological innovation and widespread adoption–remains one of the most pressing challenges. In this context, 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.

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.

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.

Public-Private Partnerships to Deploy Biofortified Wheat in Pakistan

HarvestPlus

HarvestPlus and its partners have achieved a major milestone in the transforming seed and food systems by developing and growing zinc enriched wheat varieties in Pakistan. HarvestPlus facilitates the rapid adoption of nutritious crop varieties to improve livelihoods and advance agricultural productivity and resilience. As a result of collaborative efforts, the adoption of the zinc-biofortified wheat variety Akbar 2019 marks a significant milestone in Pakistan's agricultural development and has been cultivated

Photo: HarvestPlus

on 42 percent of the wheat cropping area in 2023-24. The production of this variety and the improved yields it achieves shall benefit over 97 million people in one year in Pakistan because it will increase access to affordable nutrition and contribute to improved livelihoods, especially benefitting smallholders and women.

Photo: 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.

Photo: IFDC

Enhancing Smallholder Farming Through Integrated Agricultural Support

International Fertilizer Development Center

HortiNigeria, a program managed by the International Fertilizer Development Center (IFDC), seeks to increase agricultural productivity and sustainable fertilizer use in Nigeria. By focusing on a holistic approach, the program has successfully integrated a suite of services, technologies, and interventions that work synergistically to improve soil health, increase yields, and ensure the sustained use of agricultural innovations by smallholder farmers in Kaduna and Kano states.

Photo: The Mosaic Company

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

The Mosaic Company

A new era of understanding soil microbiome and functional relationship with crop production has emerged. 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. With over fifteen years of proven research on 2,300 plus global field research trials, two products, BioPath® and PowerCoat™ are exceeding expectations. The use of these two products with the same fertilizer recommendations of source, rate, time, and placement is increasing corn yields by 3.8 to 7.3 bushels per acre. This bundling of technologies is helps sustain farmers' operation and improve nutrient use efficiency.

Photo: ACDI/VOCA

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

ACDI/VOCA

ACDI/VOCA leverages private sector engagement to support women and youth to increase their agricultural productivity. Initiatives like Feed the Future Honduras Food Security, Agriculture, and Resilient Market Systems (FARMS), USAID Zambia Enterprise Development and Growth Enhanced (EDGE), and USAID Ghana Market Systems and Resilience (MSR) implement inclusive models, such as agroparks and outgrower schemes to ensure access to essential resources for women and youth. Partnerships, such as with INALMA in Honduras, illustrate the effectiveness of private sector collaboration by providing infrastructure and market access to smallholder farmers. This collaboration can also support the implementation of innovative models to address resource constraints, empowering women and youth to boost productivity to close yield and gender gaps.

Photo: TNC

Public-Private Collaboration to Combat Land Conversion in Brazil

The Nature Conservancy

The Nature Conservancy (TNC) is pioneering a groundbreaking initiative to combat deforestation and land conversion driven by beef production. The Pará Cattle Integrity Program encourages ranchers to increase the productivity of their already-cleared land rather than expand into intact forest. By partnering with the Brazilian beef industry and catalyzing innovative state policies on cattle traceability, TNC aims to prevent 5 million hectares of habitat loss in the Amazon and Cerrado by 2030. The program, backed by public-private collaboration, has already seen the state of Pará implement a first-in-class policy mandating statewide individual cattle traceability.

Photo: Heifer International

Tractors, Tech and Transformation

Heifer International

Heifer International is collaborating with African startup, Hello Tractor, a smartphone application and online marketplace that enables smallholder farmers to request affordable tractor services to till, plant and harvest their fields forty times faster and 2.5 times cheaper than using hand tools. The Mechanization for Africa Project collaboration connects smallholder farmers and tractor owners in remote, rural areas of Nigeria, Uganda, and Kenya, allowing them to book a tractor by the hour using the Hello Tractor mobile app. To date, the initiative has provided services to 21,048 smallholder farmers in need of mechanization services; created 368 direct jobs and resulted in a 227 percent boost in participating farmers' income.

Photo: 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 $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 $636,148 in annual sales over 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.

Photo: IICA

Bundling Nature-Based Solutions to Strengthen Caribbean Climate Resilience

Inter-American Institute for Cooperation in Agriculture

The Inter-American Institute for Cooperation on Agriculture (IICA) and partners in the Caribbean, with funding from the Caribbean Biodiversity Fund (CBF), developed bundles of tools, socio-economic interventions, and dissemination pipelines using vetiver grass as an ecosystem-based adaptation solution for climate action and sustainable livelihoods. This approach was effective in promoting community-led nature-based solutions, through vetiver nursery establishment, vetiver-based handicrafts and green businesses training, and application of technology such as GIS and drone imagery to measure and track progress in landscape restoration. The strong involvement of communities in every phase of the project was central to successful environmental and socioeconomic outcomes.

Photo: CIP

Mulching Over Tilling Revolutionizes Potato Farming

International Potato Center (CIP)

The International Potato Center's (CIP) "Potato Zero Tillage through Rice Straw Mulch" (PZTM) initiative is revolutionizing potato farming across India, Bangladesh, Cambodia, and Peru. The regenerative agriculture technique preserves soil health, enhances yields, and combats land degradation and water scarcity by planting potatoes in untilled soil and covering them with rice straw. The project emphasizes empowering smallholder farmers, particularly women, through training and collaboration with local organizations. PZTM fosters sustainable agriculture while addressing global challenges like climate change and food insecurity, aligning with the United Nations' Sustainable Development Goals for poverty reduction, gender equality, and environmental sustainability.

Photo: NASDA

Targeting Trade Barriers in Indonesia with Communication and Innovation

National Association of State Departments of Agriculture

In 2023, the National Association of State Departments of Agriculture (NASDA) led a trade mission to Indonesia, where NASDA members and U.S. Dairy Export Council President & CEO Krysta Harden participated in government and industry meetings. Harden and New Mexico Agriculture Secretary Jeff Witte established a technical collaboration project with Indonesia to provide education and support for Indonesia's small-scale dairy farmers and trainings and pathways for U.S. dairy producers to maintain exports to Indonesia given trade barriers. By targeting trade barriers and fostering open dialogue in Indonesia, NASDA is bundling actionable solutions for prioritizing a sustainable, productive U.S. dairy industry and a safe, nutritious food supply for Indonesians. NASDA intentionally matches states with emerging markets to ensure agriculture has no barrier to innovation.

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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.

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