COLLEGE OF AGRICULTURE AND LIFE SCIENCES
VIRGINIA TECH

GAP REPORT®
GLOBAL AGRICULTURAL PRODUCTIVITY REPORT®

# every FARMER every TOOL

2023 GAP Report®

# ABSTRACT

Agricultural total factor productivity (TFP) growth has the potential to create returns to farmers–at all scales of production, society, the environment, and the economy. However, since 2011, average annual TFP growth has consistently fallen below the target growth rate required to sustainably meet global needs for agricultural outputs by 2050. Now, we must redouble our efforts to sustainably grow TFP. While research and development (R&D) is a key driver of TFP growth, there are many existing proven tools for sustainably improving TFP. In addition, the wider enabling environment, influences of behavior and decision-making, and external shocks and forces influence access to and sustained adoption of these proven tools. From research to stories from the field, the 2023 GAP Report® explores the opportunities and barriers to farmer access and adoption of proven, appropriate tools for sustainable agricultural productivity growth.

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# FOREWORD

The United States of America and, indeed, the entire food and agriculture sector is blessed to have a wealth of data and analytics at its disposal to address the many and growing challenges of our world. From our first-rate universities, think tanks, governments, and other sources emerges one seminal report that stands out in its global importance–the Global Agricultural Productivity (GAP) Report.

Agriculture has become so very diverse in its cropping, animals, geographies, technologies, inputs, markets, weather, and even politics. It could be easy to lose sight of the most critical goal on which societies around the world should be focused.

I assert that feeding almost 10 billion persons by 2050 is and must be our primary focus, a point from which we cannot stray. Indeed, the first two goals of the United Nations Sustainable Development Goals reflect this. However, the threats of climate change, war and strife, technology innovation (and rejection), economic fluctuation, and other mega-factors oftentimes obscure that which is most important. In fact, some countries around the world are foregoing agricultural productivity growth as they focus solely on their quest to solve other problems.

A good example of this is the problem of climate change, which is very important and must be front-and-center but often becomes the singular focus of policymakers. While understandable, our goal should and must be to address both climatic variability and agricultural productivity.

At the National Association of State Departments of Agriculture, we advocate for the power of "AND," which marries the GAP Report's Total Factor Productivity analysis, the efficiency with which we produce our crops, animals, and aquatics, with the additional focus on addressing problems facing the food and agriculture industry. The power of "AND" allows farmers to sustainably pursue our primary goal–the production of food to address hunger and nutrition needs of communities around the world.

NASDA encourages all involved with food and agriculture globally to embrace this report, share it, and certainly to adopt its recommendations such that our world will be fed adequately in 2050.

Ted McKinney
*CEO*
National Association of State Departments of Agriculture (NASDA)

CHAPTER 1

# EVERY FARMER, EVERY TOOL: THE NEED FOR A PARADIGM SHIFT

Globally we are consistently falling well below the target agricultural total factor productivity growth rate required to sustainably meet the world's needs from the agriculture sector. Achieving this target is critical not only for meeting demand of a growing population with evolving distributions of affluence, but also for achieving ambitious goals of poverty reduction, malnutrition elimination, and environmental resilience.

Despite decades of innovation and improvement in productivity-enhancing tools, many producers and other players in agri-food value chains do not have access to every proven and appropriate tool available. Moreover, pipelines of innovation face bottlenecks that also limit the number of producers that have access to emerging proven tools. The enabling environment, behavioral influences, and external shocks and stressors create both barriers and opportunities for every farmer to access every tool for sustainable productivity growth.

The 2023 GAP Report® presents the most recent data on global total factor productivity growth, including a spotlight on the Latin America region, and presents a novel framework for understanding the influences on access and adoption of proven productivity-enhancing tools. Partners of the GAP Initiative provide contextual evidence and examples of effective approaches to increasing productivity at all scales of production.

## 2023 GAP REPORT® KEY MESSAGES

1. Increasingly at the forefront of global policy dialogues, sustainable productivity growth is recognized as the single most effective solution to meeting demand for agricultural output and meeting environmental goals.
2. Total factor productivity (TFP) growth continues to be strong in China and South Asia, but is well below target growth across most of the globe. SubSaharan Africa and the United States show especially low TFP growth.
3. During 2011-2021, global TFP grew at an average of just 1.14 percent annually. To sustainably meet the agricultural needs of a growing global population by 2050, we must now aim for 1.91 percent average annual TFP growth.
4. If producers at all scales of production are able to access proven, appropriate, productivity-enhancing tools, including technologies and practices, we can make significant strides in closing the TFP growth gap. Increasing access to and adoption of proven-productivity enhancing tools will require strengthening the enabling environment, addressing influences of food system actor behaviors, and mitigating the effects of external shocks and forces.
5. Lack of TFP growth creates reliance on input intensification and land expansion to grow agricultural output. This may result in over-reliance on unsustainable production practices and continued decline in TFP growth.
6. Collaboration between the public, private, and civil sectors is critical for tackling barriers to every farmer having access to every proven tool for sustainable agricultural productivity growth.


## GAP REPORT LAUNCH 2023– A PRESCRIPTION FOR ACCESS

The Every Farmer, Every Tool: Increasing and Sustaining Access to Proven Innovations for Sustainable Agricultural Productivity Growth event, held at the National Press Club in Washington, DC on October 3, 2023, launched the 2023 GAP Report®. The event was co-hosted by Virginia Tech's GAP Initiative, The Coalition on Sustainable Productivity Growth for Food Security and Resource Conservation (SPG Coalition), and the United States Department of Agriculture (USDA). It featured experts from across sectors and regions to discuss what it will take for every farmer to be able to access every proven appropriate productivity-enhancing tool. The role of agricultural productivity growth for tackling climate change was addressed by the SPG Coalition and some members presented specific technologies and practices that take climate action while accelerating productivity growth.

New data from USDA reveals that the average agricultural total factor productivity (TFP) growth during 2011 to 2021 was well below the target annual growth rate needed to sustainably meet the demand for agricultural products by 2050. To make up this shortfall, we now need to achieve 1.91 percent annual TFP growth between now and 2050. If farmers around the world could better access and adopt scientifically proven and appropriate tools that sustainably improve agricultural productivity, we could improve our progress towards this goal.

### *So what will it take to get there?*

From the comments of keynote speaker, Brady Deaton, and the first panelists of the day–Ruramiso Mashumba (Global Farmer Network), Paul Spencer (Corteva), Tony Fernandes (State Department), Sergio Rivas (Tanager), Eugenia Saini (FONTAGRO), a comprehensive picture emerged.

1. A system of forces that creates a robust enabling environment, human capital development, research at all stages of development, and flows of information and technologies is required for reversing negative productivity growth trends.
2. Farmers of all socio-economic standings must be able to access advanced technologies that are appropriate for their production scale.
3. All proven tools that support increased productivity as well as environmental and social goals should be accessible and available to producers.
4. Education and training must accompany the introduction of advanced tools.
5. Models of access, distribution, and adaptation of tools need to specifically consider women and other marginalized producers, including their perspectives of efficacy and utilization.
6. Financing both innovation pipelines and the adoption of proven tools is critical for sustained productivity growth.

Among the numerous challenges that producers face, climate change is emerging as a leading threat to productivity and economic resilience, particularly in sub-Saharan Africa. Ruramiso Mashumba, farmer and regional lead for Africa at the Global Farmer Network, emphasized this point in her remarks. Weather patterns in Zimbabwe are more unpredictable than ever before, she said. These climatic changes have brought with it increasing pest pressure. However, producers do not have access to the tools required for recommended agricultural practices that mitigate climate impacts, such as conservation agriculture. State Department Deputy Assistant Secretary Tony Fernandes emphasized in particular the critical role that science-based policies play in creating access to climate adapted seed varieties.


USDA Under Secretary for Trade and Foreign Agricultural Affairs, Alexis Taylor, reiterated the need for science-based regulatory regimes that will facilitate the development and dissemination of proven climate-smart technologies and approaches to build more equitable and resilient food systems that support multi-country, cross-sectoral climate goals.

Elise Golan, Director for Sustainable Development at USDA, opened the event's second session of lightning talks by members of the SPG Coalition. She said, "it is very important that we lay the foundation about the importance of productivity growth for helping to mitigate and adapt to climate change." Projects, research, and initiatives featured included:

1. **Public-private partnerships for innovative research to increase sustainable agricultural productivity growth and mitigate climate change.**

   Foundation for Food and Agriculture Research, Saharah Moon Chapotin, Executive Director

2. **Water Quality Management in In-Pond Raceway Systems (IPRS) in Egypt.**

   Rosalind R. Leeck, Executive Director for Market Access and Strategy, and Northeast Asia Regional Director, U.S. Soybean Export Council

3. **Managing methane emissions in cows while increasing milk production by applying canola meal to rations.**

   Chris Davison, President & Chief Executive Officer of the Canola Council of Canada

4. **Public R&D, agricultural productivity, and GHG emissions. Environmental benefits of the world's first GE wheat.**

   Dan Blaustein-Rejto, Director Food & Agriculture, Breakthrough Institute

5. **Toolkit to support farmers to manage, measure and report on emissions.**

   He Waka Eke Noa: The Primary Sector Climate Action Partnership

   Adam van Opzeeland, First Secretary, Agriculture Trade, New Zealand Embassy Washington, DC

As the role food systems can take in climate action is increasingly in the spotlight of multilateral negotiations and global discussions, it is critical that the impact of sustainable agriculture productivity growth takes center stage as a leading strategy for achieving our societal, economic, and environmental goals.

CHAPTER 2

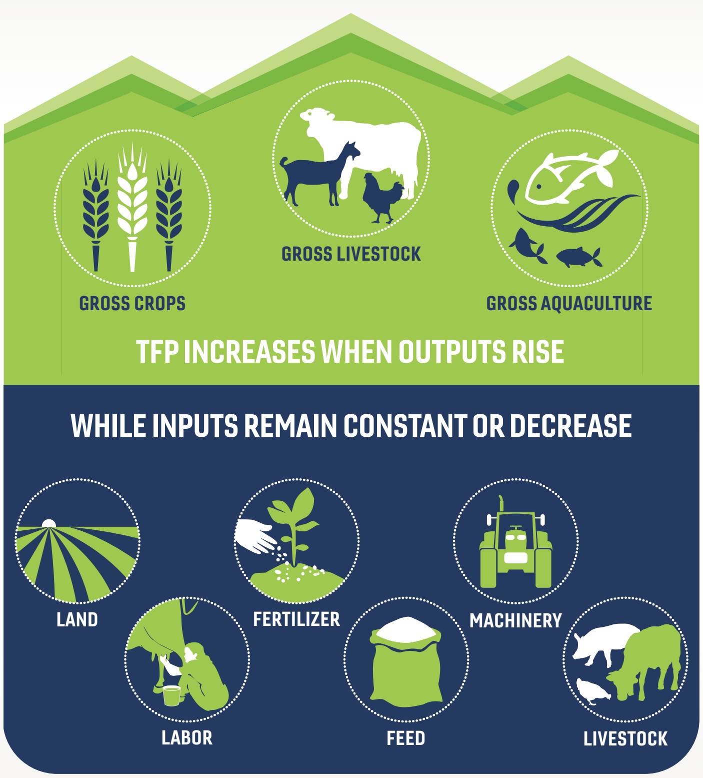
# TOTAL FACTOR PRODUCTIVITY: UNCOVERING THE BIGGER PICTURE OF AGRICULTURAL SYSTEMS

There is mounting pressure to find solutions to short- and long-term challenges facing local, regional, and global food systems. Major shocks, climatic variability, and rapidly changing demand for agricultural products have revealed fragile foundations and the need for a new *modus operandi* in the way food and other agricultural outputs are produced.

Agricultural productivity growth is and will continue to be at the core of strengthening sustainable agricultural systems. Indeed, improved efficiency of input and natural resource use has been increasingly emphasized as the single most effective solution to simultaneously achieving production and environmental goals (Searchinger et al., 2019).

Measured as total factor productivity (TFP), agricultural productivity growth is achieved when producers increase their output of crops, livestock, or aquaculture products, using the same amount or less land, labor, capital, fertilizer, feed, and livestock. In other words, TFP rises when producers utilize innovative agricultural technologies or labor and efficiency practices to increase output with the same amount or fewer resources (Figure 1).

**Figure 1:** Total Factor Productivity




Tracking changes in TFP growth reveals a bigger picture of how well agricultural production is able to contribute to pressing global issues such as poverty alleviation, food security and nutrition improvements, and environmental externality reduction (Rahman et al., 2022). For example, TFP growth can lead to increased competitiveness in the sector through lower production costs. A one percent increase in productivity growth is equivalent to a one percent decrease in the cost of producing, storing, and selling one unit of a particular product. Consumers also benefit from TFP growth since the per-unit price for producers moves through the value chain, influencing the prices consumers pay.

Changes in TFP also reveal how well our agricultural knowledge and innovation systems (AKIS) are reaching and supporting producers at all scales of production to improve productivity. An increase in TFP growth suggests that an increasing number of producers are adopting, at minimum, scientifically proven, contextually- and scale-appropriate tools–such as technologies, strategies, and practices–that improve the sustainable use of scarce resources, including non-renewables.

When the GAP Report® was first published in 2010, the "GAP Index" was established to track changes in TFP growth and to illustrate the future growth necessary–holding inputs constant–to sustainably fulfill global needs for agricultural products by 2050. The GAP Index target, which was a projected rate of 1.73 percent average annual TFP growth during 2010-2050 (solid green line, Figure 2), was based on the assumption that agricultural outputs would need to double between 2010 and 2050 to support a projected population of 10 billion people.

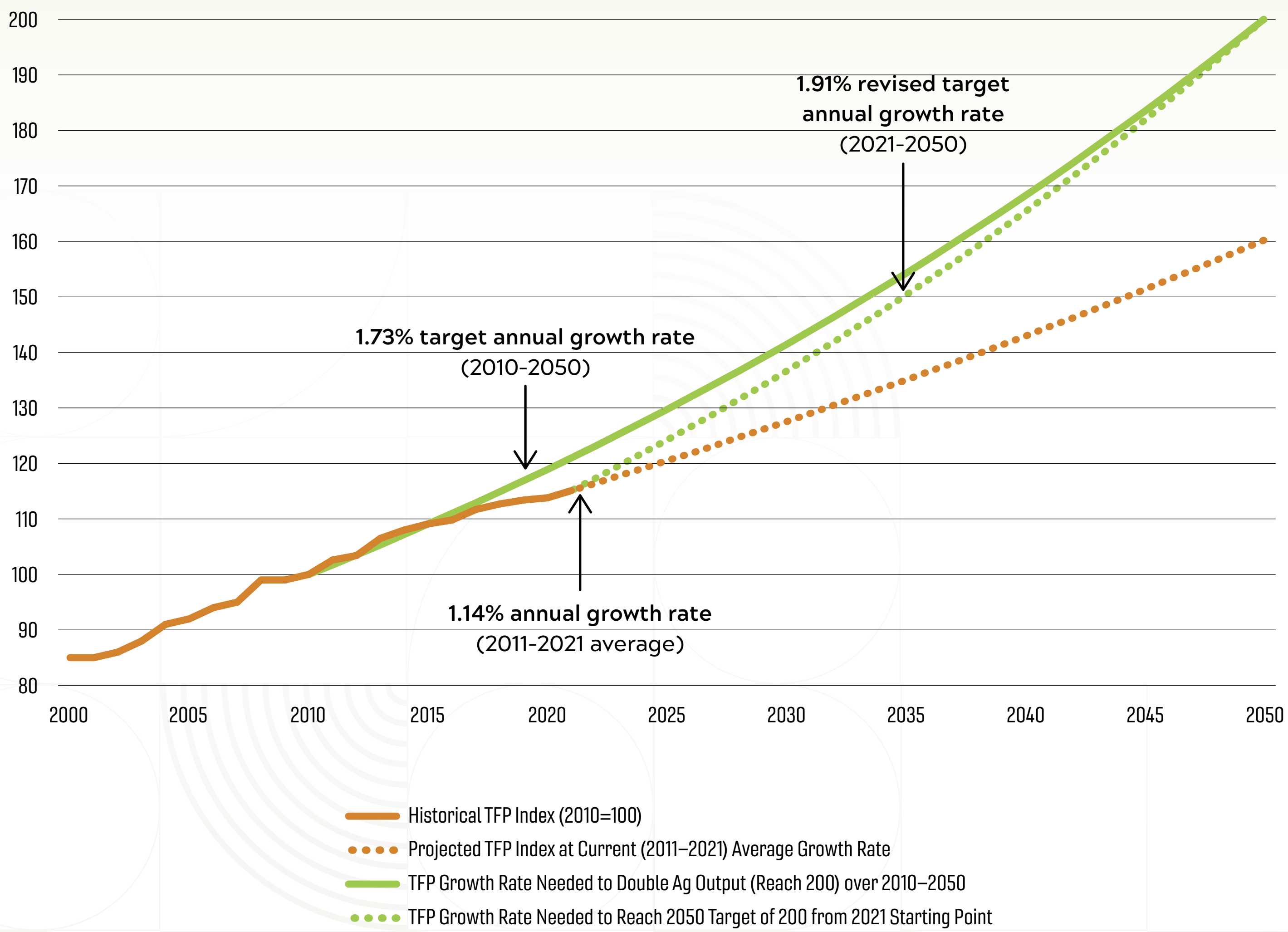
In 2022, the United Nations estimated that the global population could reach 9.7 billion by 2050 (United Nations, 2022). Although this estimate is slightly lower than earlier projections, we conclude that the assumption of needing to double agricultural production from 2010 to 2050 is still valid, especially because this assumption does not explicitly account for any negative impacts of climate change–which will continue to have important impacts on agricultural production and outputs.

At 1.14 percent, the global average annual TFP growth during 2011-2021 (orange line, Figure 2) fell well below the 1.73 percent annual growth GAP Index target. As a result of sluggish TFP growth during this period, it is now necessary to revise the GAP Index target upward to 1.91 percent average annual growth (dotted green line, Figure 2) to achieve sustainable production of global agricultural needs by 2050. If TFP growth continues to lag, the gap will continue to widen over time, making it increasingly difficult to close.

**Figure 2:**

## 2023 GLOBAL AGRICULTURAL PRODUCTIVITY INDEX

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




**Source:** USDA Economic Research Service (2023).

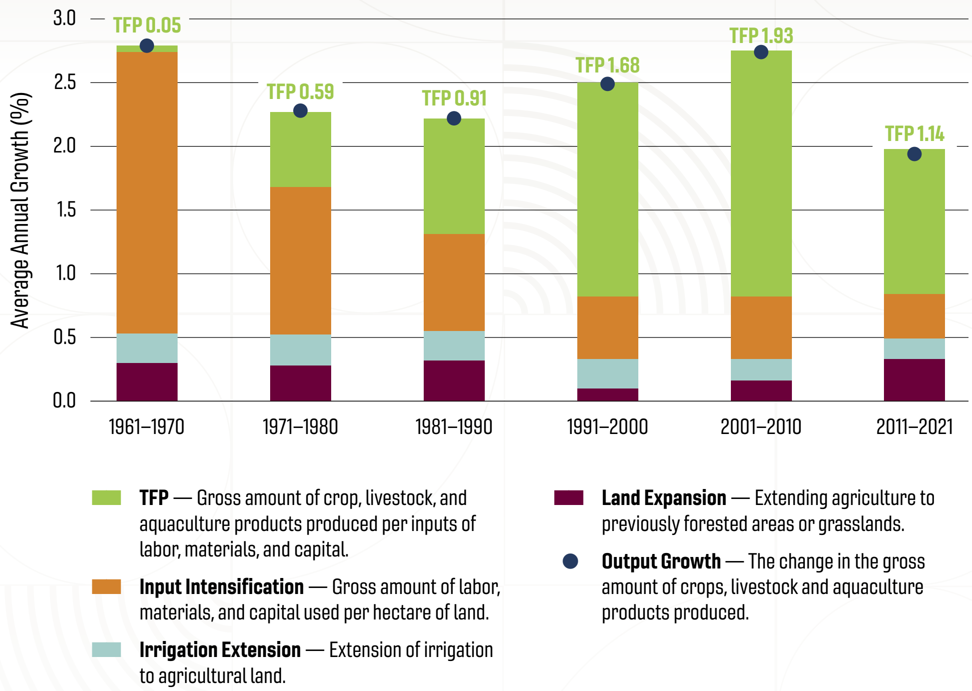
The implications of a widening TFP growth gap include the use of unsustainable agricultural practices, such as the conversion of wild and marginal lands to agricultural production. As a result of such practices, a portion of the gap will remain unfilled, leading to unacceptably high levels of malnutrition and rural poverty, accelerated loss of biodiversity, and detrimental system-wide inefficiencies. This gap will disproportionately impact already resource-poor communities.

Input intensification, such as the adoption of improved crop varieties, increased application of fertilizers and crop protection products, and use of mechanization, was the most important driver of increased agricultural output during the 1960s and 1970s (Figure 3). However, beginning in the 1980s, TFP growth became the leading contributor to agricultural output growth until the present day. During the 1990s, global TFP growth averaged 1.68 percent annually, which increased to 1.93 percent average annual TFP growth during the first decade of the 21st century. Unfortunately, during 2011-2021, average annual global TFP growth fell to 1.14 percent, ending two decades of robust growth and falling well below the global GAP Index target (Figure 2).

TFP growth declined sharply during 2011-2021, compared with 2001-2010, across all country income groups. Global TFP growth was a robust 1.93 percent annually during 2001-2010, but declined by an average 43 percent during the subsequent decade (Figure 4). The robust TFP growth of middle-income countries also declined sharply and was below the new target growth rate (1.91 percent annually) during 2011-2021. TFP growth in upper-middle-income countries declined by more than 50 percent between 2001-2010 and 2011-2021.

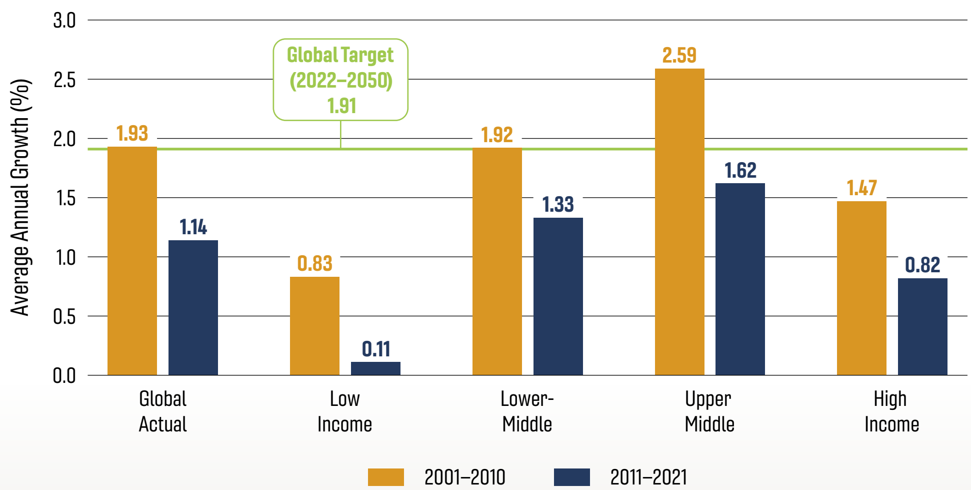
Low-income country TFP growth continues to lag, as reported in the 2022 GAP Report (Steensland, 2022). Low TFP growth suggests that both the pace of innovation and the adoption of agricultural innovations are declining. This trend is especially alarming, considering the agricultural production challenges of

**Figure 3:** Global Sources of Agricultural Output Growth, 1961–2021




**Source:** USDA Economic Research Service (2023).

**Figure 4:** TFP Growth by Country Income Group, 2001–2021




**Source:** USDA Economic Research Service (2023).

the coming years. This contraction in TFP growth may exacerbate already high levels of food insecurity and malnutrition and threaten the prospects for agriculture-led economic growth in many nations.

During 2011-2021, South Asia and China were the only world regions that experienced strong TFP growth (Figure 5). Strong TFP growth in South Asia (2.18 percent) was led by India and Pakistan (2.47 and 2.41 percent, respectively). Within the South Asia region, only Bangladesh (-1.16 percent annually) suffered from TFP contraction. Increasing productivity in South Asia has been linked mostly to technological change, including technology adoption, mechanization, labor reallocation, and adoption of information and communications technology (ICT) to disseminate information related to agriculture (Liu et al., 2020a).

TFP growth in China (1.97 percent) has been driven by mechanization (Liu et al., 2020b) and policies aimed at reversing unsustainable input intensification practices (OECD, 2018). Chinese government investments in agricultural research and development have no doubt played a role as well–China now spends more than twice as much on public agricultural research and development as the United States (Plastina and Townsend, 2023).

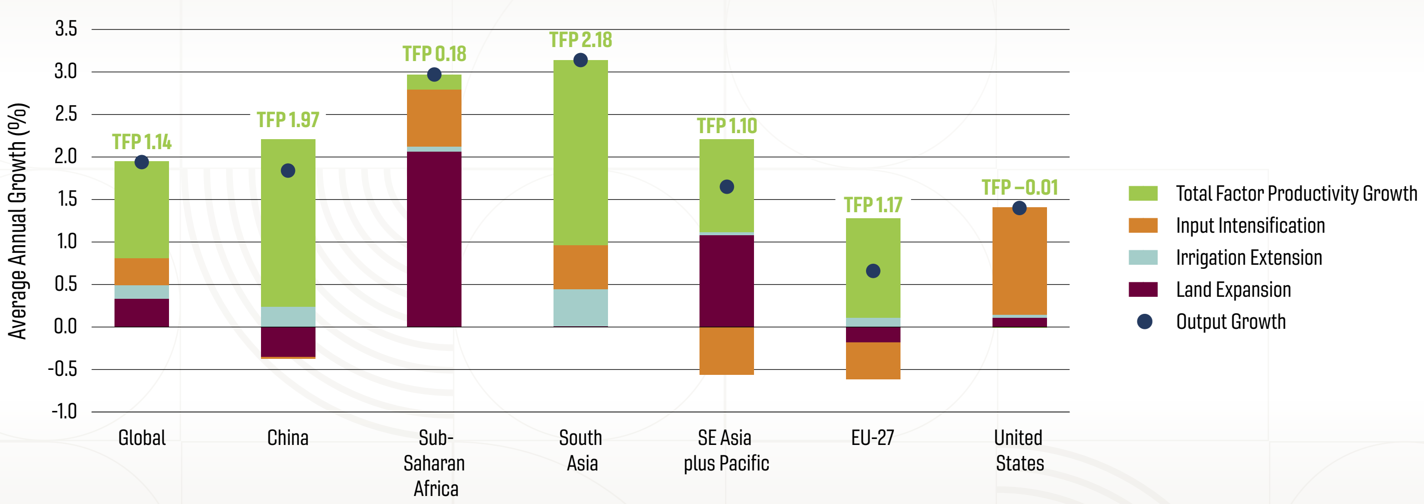
In the Southeast Asia and Pacific region TFP growth averaged 3.0 percent annually during 2001-2010, but fell sharply to only 1.1 percent annually during 2011-2021. Land conversion to agriculture, led by Indonesia and Laos, was the largest contributor to agricultural output growth in the region.

In sub-Saharan Africa (SSA), lagging TFP growth can be attributed to various factors, including lack of technological change, low expenditures on agricultural research and development, and climate change impacts, which appear to be most severe in warm regions (Ortiz-Bobea et al., 2021). With constrained access to productivity-enhancing tools such as mechanization, advanced seeds, fertilizer, and improved livestock breeds and feed, farmers are expanding agricultural land into wildlands at an alarming rate, with negative impacts on biodiversity (Koch et al., 2019).

In SSA, the conversion of lands to agricultural production (Figure 5) was the highest seen since the 1980s and average TFP growth (0.18 percent annually) was the lowest observed since the 1970s. Eight countries in SSA increased agricultural land area (cropland plus permanent pasture) by more than 3 percent annually during 2011-2021, and more than 100,000,000 hectares of land were converted to agricultural use across SSA during this period. Of the major SSA sub-regions, only the Sahel and Southern Africa experienced positive (0.88 and 0.72 percent annually) average TFP growth during 2011-2021. In sharp contrast, average TFP growth was -1.54 percent annually in East Africa.

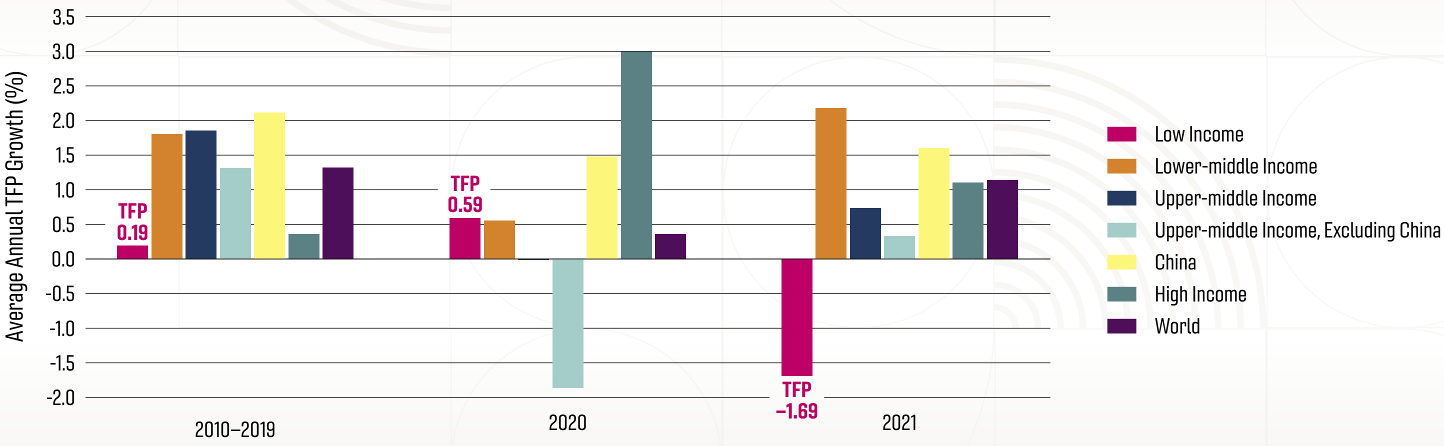
Average TFP growth in the United States has dropped markedly from 1.49 percent annually during the 1990s, 1.39 percent annually during 2001-2010, to negative during 2011-2021 (Figure 5). It is noteworthy that, according to USDA-ERS, in

**Figure 5:** Sources of Agricultural Output Growth By Region, 2011–2021




**Source:** USDA Economic Research Service (2023).

**Figure 6:** Short-Term TFP Growth




**Source:** USDA Economic Research Service (2023).

2019, U.S. public agriculture and food R&D expenditures in constant dollars reached its lowest level since 1970 (Nelson and Fuglie, 2022).

It may take several more years to understand the full impacts of the COVID-19 pandemic on agricultural productivity. For example, government actions in response to the pandemic inhibited the normal flow of agricultural production, marketing, and access to inputs, which increased the number of individuals suffering from food insecurity (FAO, 2021). With the updated global TFP data now available from USDA-ERS, we have the opportunity to examine the short-term (up to 18 months) impacts of the COVID-19 pandemic on TFP growth.

Most country-income groups experienced lower TFP growth in 2020 compared to 2010-2019, except for low-income and high-income countries, which experienced higher TFP growth (Figure 6). This contributed to a very low global average TFP growth of 0.5 percent in 2020. In the GAP Report, we usually do not report on annual variations in TFP, so as to emphasize longer-term trends in TFP growth, which are largely driven by technological change. Nevertheless, the large decrease in TFP growth in 2021 in low-income countries (-1.69 percent annual loss) should be of concern, especially because it comes on the heels of a decade of no growth in agricultural TFP.

Global growth in the production of agricultural products continues to exceed population growth, as it has every year since 1994 (except for 2009). Average annual global population growth during 2011-2021 was 1.11 percent (Ritchie et al., 2023). During the same period, the annual output of agricultural products grew by 1.94 percent annually.

However, global demand for agricultural outputs is still not being met as a result of system failures such as distribution inefficiencies, food loss and waste, and socio-economic inequalities. As a result, undernourishment continues to be an acute problem, with more than 800 million people still facing chronic hunger globally. In 2021, the FAO estimated that the prevalence of undernourishment jumped from 8.4 to 9.9 percent of the global population in just one year (FAO et al., 2021). Inciting events, such as the COVID-19 pandemic and the Russian invasion of Ukraine, which restricted the movement of food and resources in both the short- and long-term, have and will continue to exacerbate this number.

**In light of our current food environment, we face a dual imperative–to sustainably improve agricultural productivity at all scales of production in local, regional, and global food systems while simultaneously ensuring that TFP growth creates returns for the producer, society, the environment, and the economy. There are already numerous technologies, practices, and strategies that have proven successful in achieving this dual goal. Ensuring that every farmer has access to every proven and appropriate productivity-enhancing tool could significantly contribute to closing the productivity gap.**

CHAPTER 3

# REGIONAL SPOTLIGHT: UNVEILING AGRICULTURAL PRODUCTIVITY TRENDS IN LATIN AMERICA AND THE CARIBBEAN

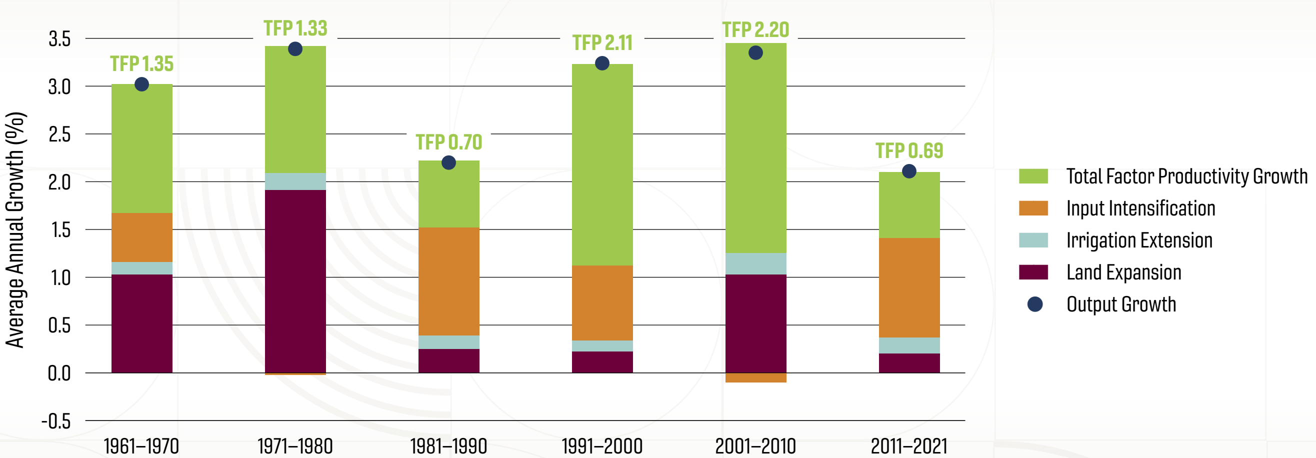
Latin America and the Caribbean (LAC) is one of the largest net food exporters globally, and, in the decade up until 2015, was an outperforming region in terms of poverty and malnutrition reduction (FAO, 2023). Major climatic and economic disruptions have presented LAC agri-food systems with challenges, such as rising input prices, constrained ability to participate in global markets, and crop devastation resulting from droughts (Piñeiro et al., 2020; Wilson Center, 2022). This has resulted in an increasing number of people who are unable to afford a nutritious diet and growing sustainability concerns. However, increased investment in scientific research and innovation, especially in precision agriculture, more robust policy frameworks for sustainable and productive food systems, and inter-sectoral cooperation, can reposition the LAC region at the forefront of regional and global agricultural needs for improved livelihoods and environmental sustainability (FAO, 2023; CGIAR, 2023).

## SOURCES OF LAC AGRICULTURAL OUTPUT GROWTH SINCE 1960

During the 1960s and 1970s, land newly converted to agricultural production was the major driver of agricultural output growth in the LAC region; however, average TFP growth was the second largest contributor during this period (Figure 7). Land expansion and TFP growth tapered off during the following decade, and intensification of input use was the largest contributor to output growth. During the 1990s and 2000s, TFP growth was robust in the LAC region, led by technological change that contributed the most to output growth. However, during 2011-2021, average TFP growth in the region decreased to only 0.69 percent annually, an almost 70 percent decline compared to the previous decade (2001-2010). Currently, in LAC, producers are once again relying primarily on input intensification to increase output, applying more inputs, such as labor, fertilizer, and capital, per hectare of land (Figure 7). Agricultural output growth in LAC also decreased significantly during 2011-2021 compared to 2001-2010, to its lowest decadal value since before 1961.

LAC regions with strong TFP growth during 2001-2010 suffered serious growth declines during 2011-2021, including Central America, where average TFP growth declined from 1.6 percent annually during 2001-2010 to 1.0 percent annually

**Figure 7:** Sources of Agricultural Output Growth in LAC, 1961–2021




**Source:** USDA Economic Research Service (2023).

during 2011-2021. Similar declines occurred in Andean countries (Bolivia, Columbia, Ecuador, Peru), where average TFP growth fell from 2.0 percent annually to 0.79 percent. Brazil experienced a strong 3.8 percent annual average TFP growth during 2001-2010, but this growth fell sharply to 1.53 percent annually during 2011-2021 (Figure 8).

Input intensification also grew sharply from 2001-2010 to 2011-2021 in Central America, Andean countries, and Southern Cone countries (Argentina, Chile, Paraguay, Uruguay). For example, during 2011-2021, fertilizer consumption increased by almost 4.0 percent annually across Central American countries. Input intensification (an average of 2.46 percent annual increase) was especially important in Mexico as a means of increasing output. During 2011-2021, for example, fertilizer and livestock feed use by Mexican producers increased annually by an average 2.2 and 3.4 percent, respectively.

In sharp contrast to Brazil and Mexico, Haiti suffered from shrinking TFP and a 2.5 percent loss of agricultural output during 2011-2021. Serious and ongoing civil and political unrest, resulting in the abandonment of agricultural land, extreme weather events such as droughts and floods, and little to no infrastructure for irrigation or transportation have contributed to a troubling state of the Haitian agricultural sector, detrimentally affecting its predominantly agrarian population.

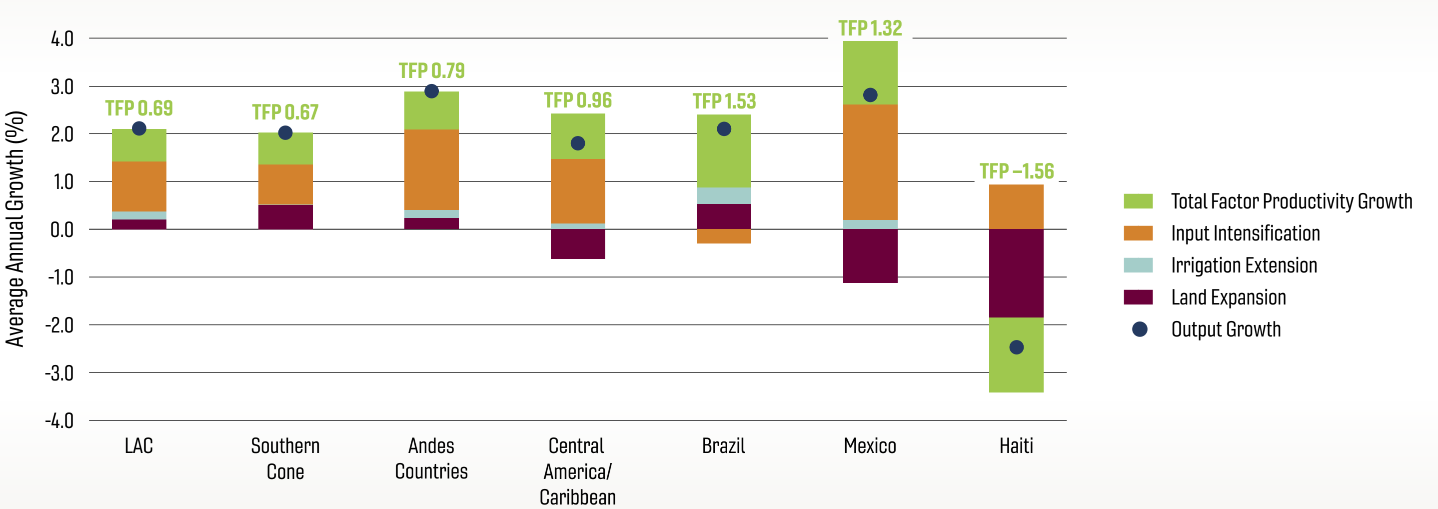
The LAC region, and indeed the world, benefitted from strong TFP growth during the decades of the 1990s and 2000s. The sharp decrease in TFP growth from 2011-2021 emphasizes the need for commitment to strengthen the enabling environment for productivity-enhancing tools, reduce barriers to adopting those tools, and find opportunities to reduce the impact of external shocks and forces to make innovations available to producers at all scales of agriculture.

## LAC'S ENABLING ENVIRONMENT INVESTMENTS

New policy initiatives and investments in LAC are focused on improving agricultural productivity to address the rising costs of a nutritious diet and stagnating poverty reduction, while protecting the region's vast natural capital and biodiversity.

Take, for example, **Panama**'s recent *State Agrifood Policy Act*, which aims to increase access to healthy and nutritious food at affordable prices. The law establishes four areas of structural reforms: agrotechnology use and production value chains; agri-food education; public sector legal framework and management model; and a welfare model for rural families. It aims to create conditions for the technological transformation of agriculture and establishes guidelines related to productivity, competitiveness, food sovereignty,

**Figure 8:** Sources of Agricultural Output Growth in LAC, Regions and Selected Countries, 2011–2021




**Source:** USDA Economic Research Service (2023).

and legal security (IICA, 2023a). Its launch catalyzed a portfolio of investment projects, valued at $1.2 billion over the next ten years, focused on technological transformation of agriculture, especially emphasizing the inclusion of youth, rural women, and family farmers. "Protected Horticulture" is one such project, which will aim to improve family horticultural operations using controlled environment agriculture, such as greenhouses and indoor farming operations, through technological innovations that reduce applications of pesticides.

One of the Act's priorities is taking into account the voices of commercial producers, consumers, importers, traders, family farmers, and indigenous peoples in developing its projects (IICA, 2023b). This inclusion of Panamanian voices, including incorporating the input of family farmers in the "Protected Horticulture" project, is vital for developing policy that is relevant, tailored, and sustainable over the long-term.

In **Panama** and other tropical nations, there has been under-development of adequate technologies for crop production, which has resulted in the importation of foreign tools (Collado et al., 2018)–but the introduction of innovative tools alone does not equal agricultural productivity growth. Amid the backdrop of the *State Agrifood Policy Act*, the development of locally-sourced crop protection tools aimed at increasing food security, coupled with robust business models that are inclusive of the specific needs of farming communities, is hoped to increase sustained adoption and success of these tools.

Horticultural production is a growing and increasingly competitive market, especially for Central America and the Caribbean (OECD & FAO, 2019). In the **Dominican Republic** (DR), the Ministry of Higher Education, Science, and Technology is collaborating with the Specialized Institute of Higher Studies Loyola and faculty from Virginia Tech to research water use for avocado farming and identify potential applications of remote sensing technologies for the estimation of water needs. The country produces 5.7 million tons of avocados every year; however, since 2019, multiple reports have described increased avocado plantings within natural reservation areas, established by low-income farmers with little to no access to farming land. One of the primary public concerns is the detrimental effects that deforestation and the planting of fruit crops could have on the aquifers and water sources of the country, ultimately impacting agricultural production overall.

Researchers from the collaborating teams assessed four irrigation treatments to better understand if the crops were over-irrigated, using drones to measure plant health from different physical ranges. Data from the study indicated that avocado farmers in the DR are significantly over-irrigating their avocados. Improving farmer knowledge of irrigation needs and access to advanced management tools will yield benefits for farmers and the nation. In order to increase the adoption of productivity-enhancing tools, it's vital to make known to producers the returns for improving management practices, such as water cost savings in avocado production, by sharing the results of the research.

Enabling environments can more effectively facilitate the transfer of agricultural R&D and productivity-enhancing tools when the sector is more efficiently organized.

In **Argentina**, for example, the establishment of farm organizational structures called "planting pools" has played a significant role in increasing agricultural productivity throughout the country. Planting pools are formal contracts between producers, investors, and other agricultural supply chain actors that are responsible for production processes, such as inputs, labor, and financing. Investors enter into rental contracts with landowners across regions to engage in production activities. These agreements are often overseen by professional agricultural consultants who manage production. Planting pools have been successful at attracting new financial capital into agriculture, incorporating improved production practices and technologies on the farm, and using mechanisms such as insurance to better organize agri-management.

The establishment of planting pools could lead to improved production practices and the use of more advanced technology among farmers. Data from an early agricultural census shows that those involved in planting pools are more likely to perform soil analysis and monitor pests, ultimately improving production in the long term (Lence, 2010). Increasing farmers' access to non-traditional contracts and financing opportunities has the potential to de-risk business, which is especially meaningful for small-scale farmers who may not be as capable of taking early major financial steps on their own.

There is no single solution to alleviating the complex and ever-evolving impacts of an unpredictable climate, rising global population, and resource scarcity–or for introducing more effective tools to farmers. Nevertheless, context-relevant policy development, evidence-based research, and the expansion of agricultural financing are valuable pathways toward developing an enabling environment that not only fosters access to but also the long-term use of productivity-enhancing tools in Latin America.

# AGRICULTURAL TFP GROWTH IN ARGENTINA: INVESTMENTS IN RESEARCH AND INNOVATION

*Stephen Morgan, Economic Research Service, U.S. Department of Agriculture, Washington, DC*
*Keith Fuglie, Economic Research Service, U.S. Department of Agriculture, Washington, DC*
*Eugenia Saini, IICA-FONTAGRO, Washington, DC*

## INTRODUCTION

Argentina is a competitive global exporter of both crops and animal products, with agricultural exports totaling over $53 billion in 2022 (Trade Data Monitor, 2023). To support agricultural competitiveness, Argentina has maintained one of the most prominent public agricultural research systems in Latin America and the Caribbean alongside Brazil and Mexico (Echeverria, 2021). However, agricultural productivity growth in Argentina has been uneven over time and across commodities. This article analyzes changes in Argentina's agricultural productivity since the 1960s, emphasizing contributions of public investment in agricultural research and development. This article also highlights other developments including private sector innovations in biotechnology, land and capital use, and the policy environment, which may contribute to agricultural productivity growth.

## ARGENTINA AS A COMPETITIVE AGRICULTURAL PRODUCER

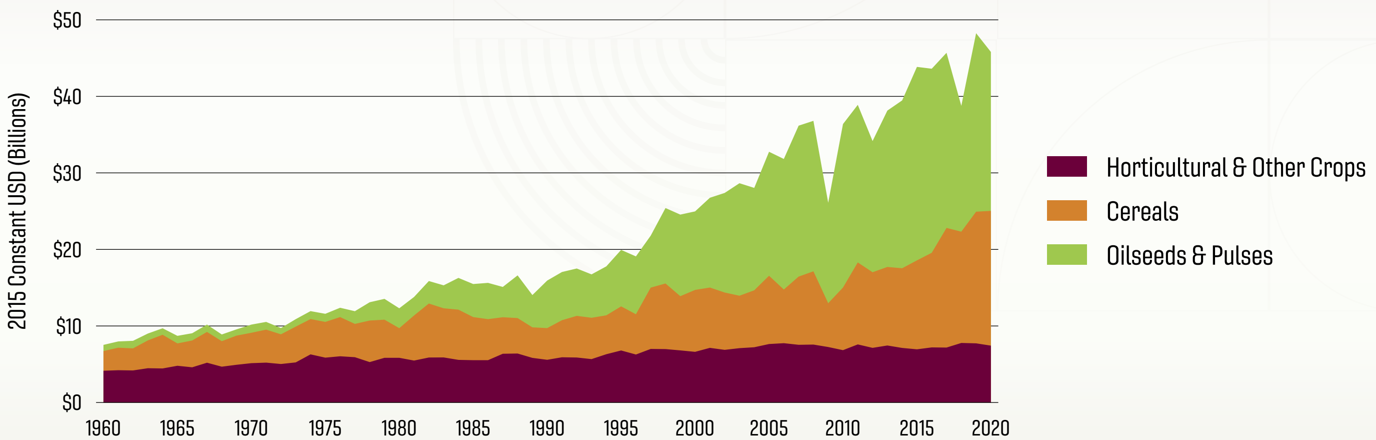
The export value of Argentina's crops has more than tripled since 2002. In 2021, Argentina was the largest exporter of soybean oil and meal, the second largest exporter of corn, and the fourth largest exporter of soybeans by value (Padilla et al., 2023). Argentina is also a major global producer of beef (Ufer et al., 2023). Other main commodities for export include wheat, sunflower, and milk.

Argentina has experienced significant growth in both crop and livestock production since 1960. Between 1960 and 2020, the value of the country's crop production rose from around $7.5 billion to over $45 billion (Figure 9) and output growth was an average of 3 percent per year. Oilseed production has represented an increasing share of Argentina's crop output. In 1960, oilseeds represented approximately 10 percent of crop output compared to 45 percent in 2020. Cereal output also increased over time, but at a lower rate than oilseeds, while horticultural and other crop outputs remained relatively stable.

Livestock production in Argentina grew at a slower rate than crop production at 1.3 percent annually from 1960 to 2020 (Figure 10). Output growth associated with non-ruminant animal products has increased over the past four decades, while ruminant-related output has remained stable.

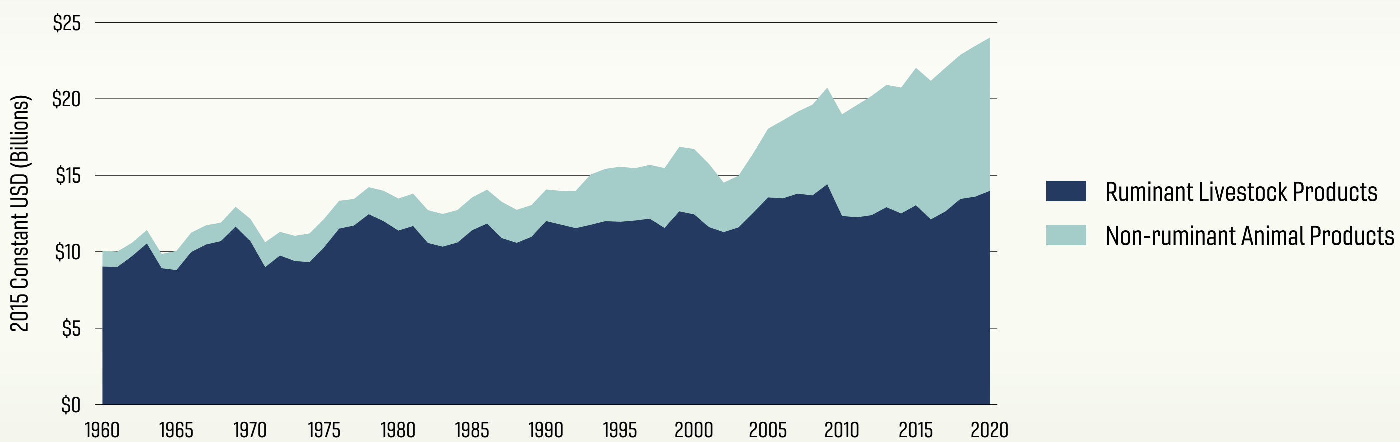
Growth in non-ruminant output is important because it implies an increased need for animal feed composed of both grain and oilseeds. However, it is important to note that while Argentina traditionally relied on grass-fed production systems for cattle, there has been increased use of feedlots–an intensive production system that aims to grow or fatten cattle quickly–and increased use of animal feed in ruminant production as well (Lence, 2010).

**Figure 9:** Composition and Change in Crop Output in Argentina




**Source:** Production quantities and prices are from FAOSTAT (2023).

**Figure 10:** Composition and Change in Livestock Output in Argentina




**Source:** Production quantities and prices are from FAOSTAT (2023).

## PRODUCTIVITY GROWTH

Agricultural output growth in Argentina has resulted primarily from gains in agricultural productivity rather than adding more resources to production. Building on an analysis by Saini & Lema (2015), recent data on total factor productivity (TFP) growth in Argentina reveals that agricultural productivity in Argentina grew at an average annual rate of 1.49 percent from 1961 to 2020. During this period, agricultural output grew at an average annual rate of 1.99 percent. This means that TFP accounted for 75 percent of output growth, while increases in land, labor, and capital inputs accounted for only 25 percent.

Productivity growth in Argentina has been uneven over time. During the period between 1961 and 1990, TFP growth was 2.32 percent per year, leading to positive output growth even as input use was shrinking. This suggests that during this period, new agricultural technologies, including improved varieties of grains, supported increased production with fewer resources. However, in more recent decades, agricultural output growth has been driven by more intensive use of inputs in agricultural production. From 1991 to 2020, TFP growth was 0.54 percent per year and only accounted for 25 percent of output growth. The increased use of land, labor, and capital accounted for 75 percent of the growth in agricultural output. This was especially true for the crop sector, where growth in input use was 2.8 percent annually. Technological change may have contributed to increased input use, as the application of no-till–growing crops without disturbing the soil through tillage–allowed cropland to be farmed more intensively and brought previously marginal pasture and uncultivated areas into production. At the same time, new genetically modified (GM) crop varieties that could tolerate herbicides were adopted. This increased the application of chemical herbicides. Though, the insect resistance GM trait may have reduced reliance on some insecticides.

## THE IMPACT OF PUBLIC AND PRIVATE RESEARCH ON THE TRAJECTORY OF ARGENTINE AGRICULTURE

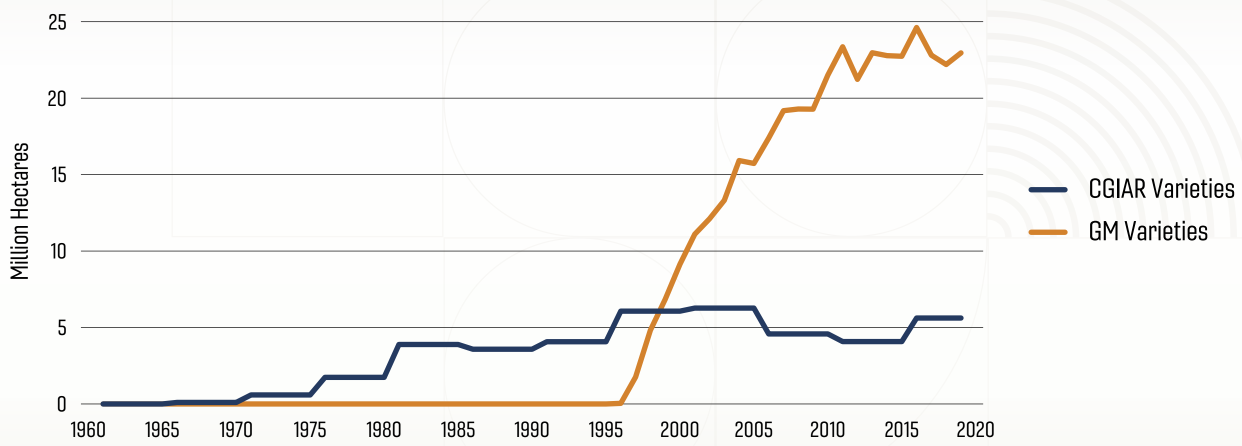
Public research and development activities not only create new technologies but also help to adapt existing technologies to local agroecological conditions to improve productivity. In Argentina, the National Institute of Agricultural Technology (INTA) is the major vehicle for conducting public agricultural research and development as well as extension activities. In 2006, INTA represented nearly 60 percent of public agricultural research spending in Argentina, with most other funding being provided by higher education institutions (Stads, 2008). Additionally, INTA extension and training encourage the adoption of productivity-enhancing technologies by producers.

Focusing on INTA funding from 1961 to 2020, regression estimates find a positive relationship between public agricultural research expenditure and agricultural TFP growth in Argentina. We estimate that over the long term, public investment in agricultural research and development has had an internal rate of return of 37 percent per year. This translates into a benefit-cost ratio of 17:1; in other words, assuming a 5 percent real discount rate, each one peso investment by public institutions like INTA generated approximately 17 pesos in economic value over a 50-year time period.

In addition to public institutions like INTA, other sources of new technologies for Argentina include the private sector and CGIAR (formerly the Consultative Group for International Agricultural Research), a system of international agricultural research centers that conduct basic research focused on low-income countries.

Private investment in new GM crops plays a significant role in Argentine agriculture. The first GM varieties of soybeans were introduced in Argentina in 1996, and within five years, had spread to more than 90 percent of production–a

**Figure 11:** Diffusion of CGIAR and Genetically Modified Crop Varieties in Argentina




**Notes:** CGIAR crop varieties include varieties of wheat, maize and beans with at least some CGIAR germplasm in their pedigrees. GM crop varieties include varieties of soybean, maize and cotton varieties with genetically modified traits.

**Source:** CGIAR crop variety adoption area from Fuglie & Echeverria (2023); GM crop variety adoption area from ISAAA (annual reports).

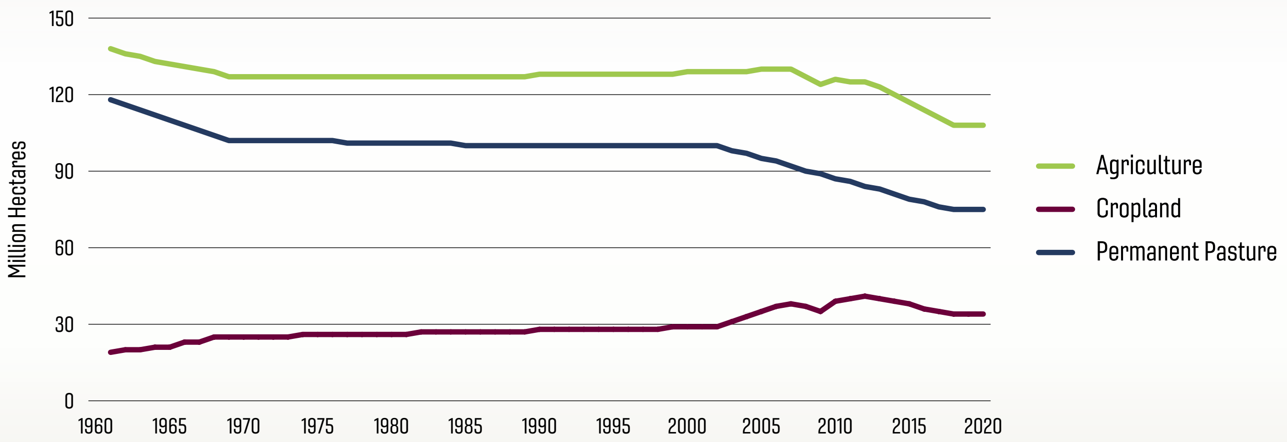
faster diffusion rate than was observed in the United States (Qaim & Traxler, 2005). One factor contributing to the rapid expansion of GM soybean use in Argentina was the availability of the technology under weaker intellectual property institutions that led to lower markups for GM seeds (OECD, 2019). Reduced costs and broader availability were associated with higher welfare gains accruing to soybean producers in Argentina when compared with producers implementing the technology globally (Qaim and Traxler, 2005).

Figure 11 plots the share of the harvested land area planted for CGIAR and GM crop varieties between 1960-2020. Improved varieties of crops made available through collaborations with CGIAR centers were introduced around 1970 and represented around 20 percent of the harvested area (~3.9 million hectares) by 1981. Adoption of improved varieties of wheat significantly contributed to increased yields and value of production in Argentina. The CGIAR-related crop germplasm may have increased the value of Argentina's crop production by as much as $2.7 billion/year (Fuglie & Echeverria, 2023). In Argentina, semi-dwarf wheat varieties were adopted in approximately 95 percent of the wheat production area by 1983 (Anderson et al., 1988). GM varieties were first introduced for soybeans in 1996 and later for corn and cotton. They were widely adopted, representing 36 percent of the total harvested area of all crops by 2000 and 62 percent by 2020. Regression analysis suggests that each 1 percent share of cropland in GM crop varieties raised agricultural TFP by 0.1 percent–for Argentina's $29.1 billion agricultural sector (2016-20 average, in 2015 US dollars), this amounts to $1.8 billion/year in increased value-added.

## OTHER KEY DEVELOPMENTS AFFECTING ARGENTINE AGRICULTURAL GROWTH

Intensification of land and capital inputs, including machinery and equipment, helped increase yields in Argentina (Sturzenegger & Salazni, 2007). From 1995 to 2020, the agricultural capital stock in Argentina more than doubled, increasing from $38

**Figure 12:** Agricultural Land Area in Argentina, 1961–2020




**Source:** FAOSTAT (2023).

to $78 billion (USDA-ERS, 2022). These trends are associated with increased production of oilseed and grain crops, which are relatively more capital-intensive compared with other horticultural crops.

Agricultural land use patterns in Argentina also changed over time, reflecting the growing importance of crops over livestock and the conversion of pastures to cropland (Figure 12). Total cropland in Argentina grew from 19 million hectares in 1961 to a peak of 41 million hectares in 2012, before declining to 34 million hectares by 2020. Area in permanent pastures and rangeland declined from 118 million hectares to 75 million hectares from 1961 to 2020. This decline partially reflects the conversion of grasslands to cropland, especially as new practices, such as no-till, made it profitable to cultivate areas previously deemed too marginal to sustain crop production (Trigo et al., 2009).

No-till agriculture involves planting crops without turning the soil and leaving pre-existing crop residue in the field (Manuel-Navarrete & Gallopín, 2012). Benefits of no-till include gains in short- and long-term productivity, improved soil health and erosion control, and improved water management due to increased soil organic matter (Peiretti & Dumanksi, 2014). Producers benefit from cost savings in land preparation due to reduced input costs associated with tilling (Trigo et al., 2009). However, no-till does result in some increased costs, particularly in the form of increased herbicide use to manage weeds (Manuel-Navarette & Gallopín, 2012).

No-till agriculture trials were first implemented in Argentina in the 1970s, and the adoption of the practice was rapid beginning in the 1990s. By 2011, over 23 million hectares, or 79 percent of grain production in Argentina, was under no-till (Peiretti & Dumanski, 2014). The use of no-till farming practices expanded cultivation by allowing marginal lands, which were previously used for livestock grazing, to be converted to intensive cropping systems.

The establishment of new farm organizational structures also played a significant role in increasing output in Argentina. One example is the development of planting pools, which can describe a wide variety of formal contracts between producers, investors, and other actors in the agricultural supply chain (Lence, 2010). A common example is where investors enter into rental contracts with landowners across regions to engage them in production activities (Sturzenegger & Salazni, 2007). These arrangements are often overseen by professional agricultural consultants who manage production and who have contributed to increased production in the Pampas, the main crop-producing region of the country (Urcola et al., 2015). Planting pools have been successful at attracting new financial capital into agriculture, incorporating improved production practices and technologies on the farm, and using mechanisms such as insurance to manage agri-management tools better (Lence, 2010).

## POLICY ENVIRONMENT FOR ARGENTINE AGRICULTURE

Agricultural output and productivity growth in Argentina has occurred in the context of a complex and evolving policy environment. Prior to the 1990s, macroeconomic and trade policies were historically biased against Argentinean agriculture (Sturzenegger and Salazni, 2007). These policies included export taxes on competitive products, requirements of licenses to export products, and overvalued exchange rates, which made Argentinean agricultural products relatively more expensive for foreign consumers.

However, during the 1990s, Argentina undertook significant structural reforms and deregulated broad sectors of the economy. One major change was fixing the exchange rate to the US dollar. Deregulation for agriculture involved a variety of measures, such as eliminating export taxes and quantitative restrictions and lowering tariffs on agricultural inputs, including fertilizers, pesticides, herbicides, and machinery (Sturzenegger and Salazni, 2007).

In the early 2000s, Argentina experienced an economic crisis that resulted in a depreciation of the exchange rate and the return of export restrictions and taxes. Further instability extended into the 2010s with high levels of inflation, overvalued exchange rates, and other quantitative restrictions (Costa, 2019). These developments negatively affected agricultural prices in Argentina, driving domestic prices even lower than international prices for the major commodity groups (OECD, 2019).

## CONCLUSION

Argentina has experienced high returns from public agricultural research and development, which significantly contributed to TFP growth in the region. From 1961 to 2020, agricultural TFP grew at an annual rate of 1.49 percent, and public research and development expenditures were important factors of this growth.

These results are important for a variety of reasons. First, Argentina provides evidence of the high returns elicited from public agricultural research and development expenditures. These findings are consistent with those of other countries in the region, including Brazil, Uruguay, and Mexico (Rada & Buccola, 2012; Bervejillo et al., 2012; Fernandez-Cornejo & Shumway, 1997). Second, the returns to public investment in agricultural research and development in Argentina accrue even with significant private sector investment in agricultural technologies, including GM seed varieties and other investments through CGIAR. This suggests that public and private investments are complementary and may serve to provide farmers and ranchers with a broader set of tools to improve on-farm productivity. Third, policy and economic instability, especially surrounding exchange rates and export taxes, have presented significant challenges to agricultural growth in Argentina and may continue to affect agricultural productivity (Durand-Morat, 2019). However, public efforts to support research and extension efforts, such as those of INTA, can support sustained agricultural productivity growth even during periods when the policy environment is unfavorable for agriculture.

# NEW IRRIGATION MANAGEMENT STRATEGIES FOR AVOCADOS IN THE CARIBBEAN

*Emmanuel Torres, Eastern Shore Agricultural Research and Extension Center, Virginia Tech, Painter, VA*
*Gabriel Gonzalez, NGA Precision Agricola, Chillán, Chile*
*Arturo Bisono, Campo Moderno, Santo Domingo, Dominican Republic*
*Willy Maurer, Loyola Specialized Institute of Higher Education, San Cristobal, Dominican Republic*
*Jorge Mancebo, Loyola Specialized Institute of Higher Education, San Cristobal, Dominican Republic*
*Felix Rondon, Loyola Specialized Institute of Higher Education, San Cristobal, Dominican Republic*

Although small in size, the Dominican Republic (DR) has an abundance of avocado orchards, with nearly 55,000 acres of avocado trees mostly targeted for export to the United States and Europe.

According to the Dominican Ministry of Agriculture, the country produces 634,000 tons of avocados every year, ranking the country among the top 5 largest producers in the world, behind Mexico, Peru, Colombia, and Indonesia. The United States is the main market for the Dominican avocado, with $37.5 million worth of avocados exported in 2021 (approximately 48% of the total exported).

Nonetheless, the large market cap of the avocado industry has created its own challenges for the Dominican people. Since 2019, multiple reports have cast light on the increasing presence of avocado production within natural reservation areas. These small developments are commonly planted and managed by low-income farmers with little to no access to farming land.

One of the primary public concerns is the detrimental effects that deforestation and the establishment of fruit crops could have on aquifers and water sources. While major farming companies have access to technical knowledge and technologies that allow them to manage plantations efficiently, small and medium farmers have limited access to or awareness of such resources.

Even a basic knowledge of crop irrigation requirements has many benefits, such as the improvement of water use efficiency (liters of water consumed per kg of avocado produced), the optimization of fertilizer usage by decreasing potential leaching and assuring enough moisture for the fertilizer to be available, and the promotion of a sustainable balance between avocado farming and environmental conservation. Although it requires adjustments for each individual farmer, the ability to estimate average crop water consumption is a first step toward a deeper understanding of actual water usage and the improvement of water use policies of the country.

Soil moisture sensors are a useful tool that can be used to estimate plant water needs based on measurements of soil water content and complement knowledge of irrigation requirements. However, this technology can be too expensive for smallholder farmers and, even then, may not provide complete information if the sensors can only estimate the volume of water near the area where they are installed. Variations in soil properties, crop species and stage of growth, and atmospheric conditions will also influence plant water use.

In 2019, the Ministry of Higher Education, Science, and Technology of the Dominican Republic, in collaboration with the Specialized Institute of Higher Studies Loyola and faculty from Virginia Tech, embarked on a multi-year project with the objective of both identifying water requirements for avocados and finding potential applications of remote sensing technologies for estimation of spatial and temporal variations in water needs.

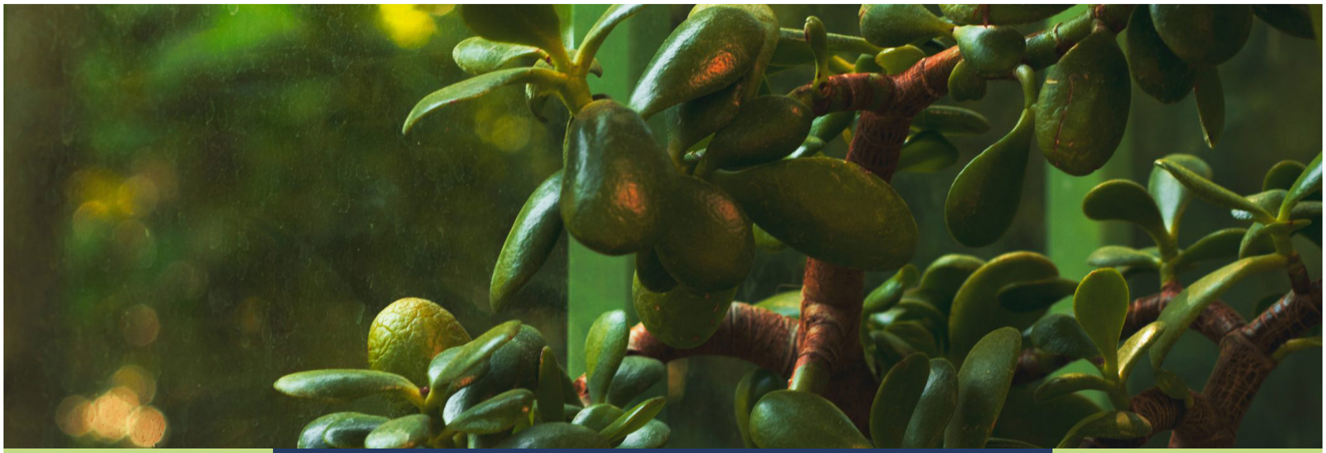
The project, “Determination of crop evapotranspiration through the integration of energy balance data for the optimization of avocado irrigation in the Dominican Republic,” was first established in an organic avocado farm in the southwest region of the country. Data was collected from 2.5-year-old ‘Hass’ avocado trees, where researchers established four irrigation treatments based on the current commercial irrigation practices of the DR. Treatments consisted of 100 percent of the normal irrigation regimen, 125 percent of the irrigation regimen as a representation of an over-irrigated crop, and 75 percent and 50 percent to represent a sub-irrigated crop. The hypothesis was that if plants were over-irrigated, plant performance would not be affected with less irrigation applied. Researchers established the four treatments in a Randomized Complete Block Design with four replications in a 1.5-acre study area within the farm.

The water balance of the soil was measured using soil moisture sensors established in two directions–one in the same direction as the planting bed and the other in the direction towards the adjacent planting bed. Sensors were established at three different depths and distances from the trunk of the tree. In each of the directions, sensors were established 20 inches from the trunk at 12 inches of depth, 40 inches from the trunk at 24 inches of depth, and 60 inches from the trunk at 48 inches of depth, respectively. Additionally, two sensors were established at 60 inches from the tree at 12 inches. There were 16 sensors per tree.

To assess plant performance, researchers measured the number of leaves per unit area, known as the Leaf Area Index, as an estimation of plant biomass. This index measures the spread of leaves over a certain area of land (measured in square meters per square meter). For example, one unit of this index is equivalent to the leaf area of 10,000 square meters in a hectare.

Additionally, the researchers captured aerial photos of the crops using a drone flying 100 feet in the air. These photos were captured with a special camera that can recognize wavelengths of light beyond what a human can see. This technique can gather unique information, such as the measurement of plant health via plant reflectance of infrared and near-infrared light.

From the images, researchers calculated multiple Vegetation Indexes to estimate plant performance. A Vegetation Index is calculated by converting data from different color bands in a picture. This assessment makes green plant life stand out, distinguishing it from other aspects of the picture. Converting data in this way can help determine how much plant cover there is, how healthy the plants are, and how big the plant leaves are.



**AFTER THE ANALYSIS OF THE COLLECTED INFORMATION, RESEARCHERS IDENTIFIED FIVE KEY FINDINGS:**

1. **A single three-year-old avocado tree in the southeast of the DR requires an average of 41 L/day of water.** This number represents water needed for transpiration and water that will be retained and later lost by the soil around the tree (evaporation). This estimation is in accordance with measurements from Lahav and Whiley in 2002, which stated that three-year-old avocado trees needed 30 to 50 liters per day in Mediterranean climates.

2. **Avocado farmers in the DR are over-irrigating.** Data showed no significant difference in Leaf Area Index and multiple Vegetation Indexes among the irrigation treatments. This shows that the avocado trees studied performed equally well with only half the current average water application. Therefore, avocado farmers are using on average 9,000 liters per hectare more water than necessary. These findings are an initial effort to measure water use efficiency for Dominican avocados that could be replicated in other locations of the country.

3. **Vegetation Indexes, which are used to assess various aspects of plant health, growth, and environmental conditions by analyzing the reflectance of light from plant canopies, are excellent tools for estimating plant performance and water status.** These indexes offer valuable insights for a wide range of applications in agriculture, forestry, ecology, and environmental monitoring. Moreover, Vegetation Indexes are commonly employed to estimate plant water status. One frequently used index for this purpose is the Normalized Difference Vegetation Index (NDVI), which compares the reflectance of near-infrared and red light. NDVI is often utilized to evaluate overall plant health, including the presence of water stress. In simpler terms, NDVI values typically range from -1.0 to 1.0. Negative values often indicate the presence of clouds or water, while values close to zero and positive suggest bare soil. Higher positive NDVI values can reflect varying levels of plant growth, ranging from a bit of greenery (0.1 - 0.5) to abundant, healthy vegetation (0.6 and higher). Vegetation Indexes hold significant value for farmers because they provide precise and timely insights into the health and condition of their crops.

4. **More research is needed to develop a useful water management program for the country.** For example, the recommendations developed for avocado production from this project are only applicable to soils of clay textures, such as the one at the study site. Additionally, the information is only relevant for trees similar in age to the ones used for the study. Ultimately, the outcomes from this project, which originated from the efforts of multiple national and international institutions, demonstrate the importance of agricultural research and collaboration between organizations to create sustainable solutions to conservation challenges across the globe.

5. **Research into the water usage of specific crops can have a significant influence on policy decisions related to water management, agricultural practices, and environmental sustainability.** Research that accurately quantifies crop water requirements can provide policymakers with essential information for designing water allocation policies. These policies may prioritize water distribution to crops based on their water efficiency and economic value. Crops that are water-intensive might face stricter regulations or incentives to encourage more efficient irrigation practices. Similarly, understanding the crop's water needs can lead to the development of irrigation regulations that align with sustainable water usage. For instance, policymakers might mandate the use of more water-efficient irrigation techniques, such as drip irrigation, application of remote sensing, or low-cost soil moisture sensors for monitoring in areas where water resources are scarce. Research findings could also lead to the establishment of incentive programs aimed at encouraging farmers to adopt practices that promote water and fertilizer efficiency. These incentives could include financial support for purchasing modern irrigation equipment, conducting soil moisture monitoring and soil nutrient analysis, or adopting advanced farming technologies.

Nationwide policies should continue to prioritize funds for research to enhance water use efficiency in agriculture. Research-informed policies can aid in developing national drought management strategies, and contribute to the long-term sustainability of water resources, fertilizer, agricultural productivity, and food security.

Moreover, results should always be directed to the final user, the farmer, through agricultural extension services, workshops, and training programs, as educating farmers about efficient irrigation practices and the water needs of specific crops will directly lead to the grassroots adoption of more sustainable farming methods.

## ACKNOWLEDGMENT

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CASE STUDY

## PANAMA'S *STATE AGRIFOOD POLICY ACT*: PRIORITIZING FOOD SECURITY AND PRODUCTIVITY

**Margaret Ziegler, US Representative, Instituto Interamericano de Cooperación para la Agricultura (IICA)**

Panama's agrifood sector has faced challenges in recent years due to insufficient investment in agricultural productivity, dependence on food imports, low levels of value addition, and high levels of subsidies for agricultural production.

To address these challenges, Panama proudly established new policies in January 2023 to foster agricultural productivity and food security. Panama's *State Agrifood Policy Act* (PADE) guarantees the human right to food and supports farmers and the production sector with new policies and more targeted investments. The law was ratified by President Laurentino Cortizo Cohen during the 62nd Tourism and Agricultural Fair of San Sebastián de Ocú in the Panamanian province of Herrera.

PADE is the result of a two-year discussion process with Panama's public and private sectors. It creates the conditions for the country's people to access healthy and nutritious food at affordable prices. In addition, the law favors the competitiveness of agriculture, focusing on the economic, social, and environmental sustainability of food production and the well-being of rural people. The law establishes four areas of structural reforms: reform of agrotechnology use and production value chains; agrifood education reform; legal framework reform; and reform of rural welfare for families.

The PADE law launched a portfolio of investment projects valued at $1.2 billion over ten years, with projects focused on the technological transformation of agriculture. Each of the public agricultural institutions will execute these public investment projects under the coordination of the Ministry of Agricultural Development (MIDA), the governing body of Panama's agricultural sector. Among these institutions are the University of Panama, the National Institute of Agriculture, the National Secretariat of Science and Technology (SENACYT), state banks (BDA and BANCONAL), the Institute of Agricultural Insurance (ISA), and the Institute of Agricultural Research of Panama (IDIAP), among others. These public investments are expected to leverage additional private investments of an estimated $20 billion over ten years. This represents a 40 percent increase in investment for 18 priority agricultural products and, ultimately, increased opportunities for improving farmer access to the tools they need to grow a bountiful harvest in the context in which they work.

One of the investment projects, for example, is the "Protected Horticulture" project, which improves family horticultural operations in controlled environments such as greenhouses, as well as through technological innovations that can reduce labor in extreme heat and reduce applications of pesticides. Another project aims to scale up the use of iron-biofortified bean seeds and the development of early warning systems to alert potato disease onset. In addition to the focus on family farming using advanced agrotechnologies, the PADE prioritizes initiatives that aim to reduce agriculture's environmental impact, decrease greenhouse gasses, and conserve water. The law also enforces the establishment of agriculture export hubs to streamline trade and export of agrifood products, especially enhancing the ability of family farmers to participate in more trade and export opportunities.

Components of the PADE include new investments in agrotechnology that will attract and retain younger generations to work in agriculture, forestry, and fishing. Ultimately, its establishment fosters an enabling environment for sustainable and productive agriculture and affirms agriculture's role as an engine of Panama's economic and social development. Strengthening the enabling environment will catalyze Panama's potential to ensure its farmers have the tools they need to grow the food that communities need.

OPINION

# ADVANCING AGRICULTURAL PRODUCTIVITY AND SUSTAINABILITY—TOGETHER

**Andres Rodriguez, Agricultural Attaché, Embassy of Chile to the United States**

Sustainability and food security are two of the main strategic pillars of the Ministry of Agriculture of Chile. If we want to ensure food security, we must be more efficient and productive–in other words, produce more with less. If this goal is not already challenging enough, obstacles such as climate change, drought, and soil erosion pervade.

Chile is committed not only to food security but also to sustainability, and there's no other way than to take our creativity to its maximum expression–and let collaborative work take a key role.

One of the main collaborative initiatives between Chilean and U.S. scientific institutions is the NASA DEVELOP program. This year, we celebrate ten years of working together on this successful program. The first project with Chile was snowmelt modeling from the Andean snowpack for more effective water allocation and planning in the Atacama Region of Chile. In the most recent project, in partnership with CIREN (Natural Resources Information Center, under the Chilean Ministry of Agriculture), we worked on calculating specific crop coefficients in the Maipo River Valley using available Earth observations from space, allowing us to evaluate crop evapotranspiration and irrigation requirements without ground instruments. This would enable the potential to improve irrigation efficiency and reduce water consumption. These are great examples of how we can use water more productively.

Another important initiative is the "Systems Approach," a strategy to decrease greenhouse gas emissions in agriculture. After two decades of negotiations, Chile is in the last mile of the authorization process of the Systems Approach for table grape exports to the North American market.

This agreement will allow importers in the U.S. to receive table grapes without methyl bromide fumigation from low pest-prevalence areas in regions of Chile, such as Atacama, Coquimbo, and Valparaíso, that meet the demanding requirements established.

In those eligible areas, the application of methyl bromide will be replaced with different approaches that the Systems Approach considers, such as registration of growers who demonstrate their compliance, traps in orchards, field monitoring, and U.S.-Chile certificate of origin joint inspection to ensure the export of a safer, higher quality, greener product.

This initiative will not only help to reduce the environmental footprint of horticultural production and trade, but will also help to reduce post-harvest loss–a key contributor to improving agricultural productivity.

Let us embrace the spirit of collaboration and innovation as we work together towards food security and safeguarding our planet for future generations, working hand-in-hand to advance productivity and sustainability.

CHAPTER 4

# EVERY FARMER, EVERY TOOL: A FRAMEWORK FOR SUCCESS

Since the 1970s, agricultural innovation of technologies, practices, and strategies have contributed to more productive agricultural systems that are increasingly able to provide returns to producers, society, the environment, and the economy. However, the previous decade's (2011-2021) sluggish TFP growth suggests that, particularly in low-income countries, the adoption rate of proven productivity-enhancing tools is not sufficient to contribute to sustainable productivity growth. To reach the new annual target TFP growth rate of 1.91 percent and to reduce the need to increase agricultural output through unsustainable practices, we must seek to lessen the barriers that farmers at all scales of production face in accessing and adopting proven, appropriate productivity-enhancing tools.

## PROVEN & EMERGING TOOLS FOR SUSTAINABLE TFP GROWTH

There are well-established tools–including technologies, practices, and strategies–that have demonstrated success in improving farm efficiency and sustainable productivity by optimizing resource utilization and minimizing environmental and economic costs. Ongoing R&D improves existing tools and identifies and validates new ones to sustainably improve productivity, farmer livelihoods, environmental and human health, and economic growth.

### 1. Improved Genetics

Improved crop and livestock genetics help to maximize yield and nutritional quality while increasing tolerance to various environmental stresses and minimizing input requirements.

a. Traditional and marker-assisted breeding
b. Transgenic technology
c. Gene editing
d. Assisted reproductive technologies
e. Selective breeding

### 2. Precision Agriculture

Data, technology, and automation are leveraged to make production management more precise and resource-efficient (Monteiro et al., 2021).

a. Low-flow (e.g., drip) irrigation
b. Information and communication technologies–geographic information systems (GIS), satellites, artificial intelligence and machine learning, and sensors
c. Drones and autonomous vehicles
d. Variable rate technology
e. Precision seeding and feeding

### 3. Soil Health Management

Healthy soil is integral to sustainable productivity. Soil health management practices reduce erosion, maximize water infiltration, improve nutrient cycling, reduce the need for inputs, and improve land resilience (USDA, 2023).

a. Regenerative practices–reduced or no-till, cover crops, rotational grazing, and crop rotation

b. Integrated nutrient management–fertilizers, crop residues, animal manures, and compost

c. Soil cover and living root presence

d. Water management

### 4. Integrated Production Systems

Local integration of production systems (cropping and livestock, aquaculture) increases agricultural output while strengthening ecosystem services and reducing the environmental impacts of resource use (Lemaire et al., 2014).

a. Integration of crop and livestock systems

b. Ecosystem integration, such as agroforestry

c. Controlled environment agriculture, such as aquaculture or hydroponics

### 5. Pest & Disease Management

Pests and disease are a major threat to producer productivity and input costs. Efficient and effective control of these threats while also maintaining ecosystem services is critical to sustainable productivity growth (USDA , n.d.).

a. Precision spraying and chemical control

b. Biological control–pest predators, semiochemicals, habitat provision for natural enemies

c. Integrated pest management–the combination of a variety of practices, including cultural practices (e.g., crop rotation, tillage, water management, crop protection)

d. Disease management–biosecurity measures, vaccination and parasite control, herd health management

### 6. Mechanization & Automation

Machinery and agricultural engineering maximizes labor productivity, improves output quality, minimizes loss, and maximizes resource utilization efficiency.

a. Drones, autonomous vehicles/robots, and sensors

b. Tractors, harvesters, and precision planters

c. Implements enabling reduced or minimum tillage

### 7. Knowledge-sharing Platforms

Training on new and existing productivity-enhancing tools is necessary for optimizing the use of the tools, minimizing costs, and maximizing uptake. Knowledge sharing on how to incorporate new technologies into indigenous farming practices is critical for attaining productivity growth (Muthee et al., 2019).

a. Farmer field schools and technical and vocational education and training institutes

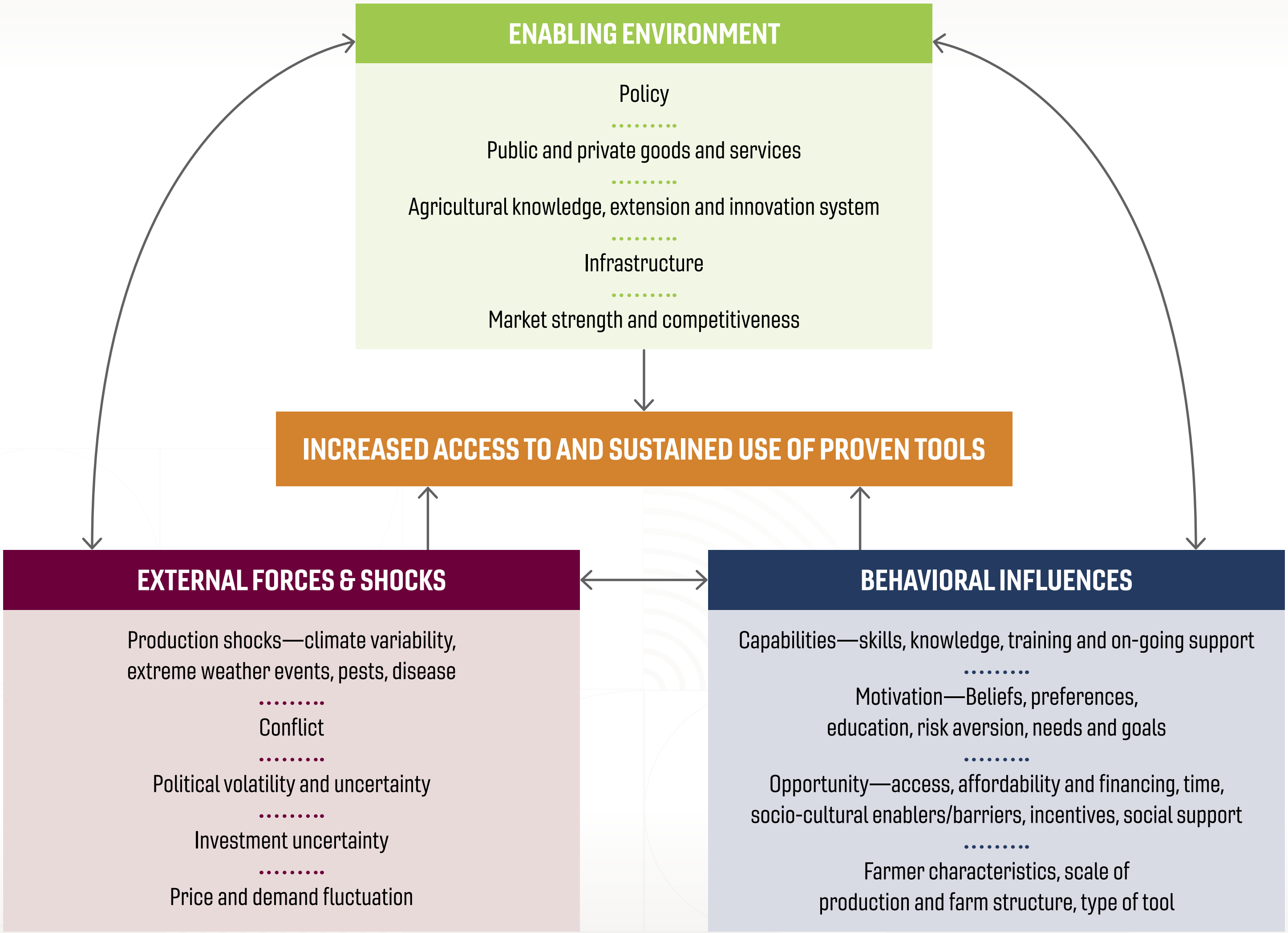
b. Extension and advisory services

c. Digital platforms and apps

## INCREASING ACCESS AND ADOPTION OF PRODUCTIVITY-ENHANCING TOOLS

Producer access to and sustained adoption of productivity-enhancing tools is impacted by the wider enabling environment, behavioral influences, and external forces and shocks (Figure 13). Within each of these milieus, barriers and opportunities for tool uptake are reinforced by socio-economic contexts, production scale, and the agro-ecological environment. This framework can be used to identify policies and investments that will ensure every farmer has access to and can sustainably adopt every proven, appropriate productivity-enhancing tool.

**Figure 13:** Framework for Access and Adoption of Productivity-Enhancing Tools




### Enabling Environment

Agricultural productivity growth is impacted by the multifaceted setting of the agricultural sector, food systems, and the wider economy. This enabling environment for tool access and adoption includes (1) policy (agricultural, macroeconomic, non-farm sectors), (2) public and private provision of goods and services, (3) the agricultural knowledge, extension, and innovation system, (4) infrastructure, and (5) market strength and competitiveness.

The enabling environment affects access to and adoption of sustainable productivity-enhancing tools by influencing the resources available for research and development the flow and dissemination of tools, incentives for technological adoption, magnitude and variability of returns on investment, uncertainty and risk, and long-term availability. Examples from across the world demonstrate how these elements work alone and in concert to foster enabling conditions or barriers to accessing and sustaining the adoption of proven, appropriate productivity-enhancing tools (Table 1). The enabling environment is largely dependent on political will, perceived economic growth opportunity, and available evidence to inform the efficacy of policy and practice, illustrated in the examples in Table 1.

**Table 1:** Examples of Enabling Environment Impacts on Tool Adoption

| POLICY | PUBLIC & PRIVATE GOODS & SERVICES | AGRICULTURAL KNOWLEDGE, EXTENSION & INNOVATION SYSTEMS | INFRASTRUCTURE | MARKET STRENGTH & COMPETITIVENESS |
|---|---|---|---|---|
| Agricultural input subsidies and coupled payments have a negative relationship with TFP growth in the Organisation for Economic Co-operation and Development (OECD) countries (DeBoe, 2020).<br>•••••<br>African countries remain reluctant to adopt GM technology due to unfavorable policies shaped by public opinion and unclear trade frameworks (Gbadegesin et al., 2022).<br>•••••<br>Stronger intellectual property policy leads to higher levels of innovation (Diaz-Bonilla et al., 2014).<br>•••••<br>Increased market openness and trade have created technology spill-ins in LAC (OECD, 2012).<br>•••••<br>A strong macroeconomic environment creates stability for good functioning markets and investment (OECD, 2020). | Service-sharing platforms like Hello Tractor improve access to mechanization in sub-Saharan Africa.<br>•••••<br>Insurance and affordable finance reduce the risk of technological adoption and sustain use in times of shock (World Bank, 2022).<br>•••••<br>Access to credit consistently has a positive impact on agricultural innovation adoption (Yokamo, 2020).<br>•••••<br>Provision of education, governance, water, sanitation, health, law enforcement, energy, and ICTs impacts producers' ability to integrate tools into their production systems (Diaz-Bonilla et al., 2014). | The European Union supports agricultural knowledge and innovation systems (AKIS) to support developing and scaling innovations through co-creation and knowledge sharing between advisors, farmers, foresters, researchers, educators, and policy- and decision-makers. AKIS supports rural access to innovation (EIP-AGRI, 2022).<br>•••••<br>Return on investments in forage R&D could be improved by strengthening AKIS through institutional reform and relationship improvement to create access and encourage forage adoption in Colombia (Encisco et al., 2022).<br>•••••<br>Evidence in Ghana shows that vigorous extension services are needed to increase uptake of new technologies such as legume inoculants (Mohammed & Abdulai, 2022). | Rural roads increase access to productivity-enhancing inputs and markets, and reduce producer and consumer transaction costs in Nepal (Shrestha, 2020).<br>•••••<br>In India, households that access roads diversify production, adopt modern agricultural technologies, and increase hired labor use (Shamdasani, 2021).<br>•••••<br>New digital infrastructure in China has demonstrated a positive impact on agricultural efficiency (Ren et al., 2023). | Vietnam's improvement in market competitiveness has increased producer willingness to adopt innovation (Gray & Jones, 2022).<br>•••••<br>Policies that enable competition, innovation, sustainable use of resources, and trade that facilitates the flows of goods, capital, and knowledge, contribute to the adoption of new technologies in OECD countries (DeBoe, 2020).<br>•••••<br>In Sweden, producer perception of competitiveness intensity positively impacts market orientation and lean production orientation, which leads to improved farm performance (Nybom et al., 2021). |

As illustrated in Figure 9, the enabling environment is influenced by external forces and shocks and behavioral influences and vice versa. For example, extreme weather events or conflict and civil unrest can influence policy priorities, available resources, macroeconomic conditions, and physical infrastructure. Conversely, deregulations in the financial sector and increasing demand for agricultural products, including biofuels, exchange rate fluctuations, and global economic growth, contributed to the 2007-2008 food price crisis that created widespread shocks to food systems and food security around the world (Hochman et al., 2014; Brobakk & Almas, 2011).

Research shows that in low-, middle-, and high-income countries alike, producer and food system actor decision-making and behavior related to technological and innovation adoption are highly influenced by the enabling environment. Policies, access to agricultural knowledge, training, goods and services, infrastructure, and market incentives all influence behavior change, particularly by affecting the risk (perceived or actual) of tool adoption. Producer risk aversion and lobbying in the agricultural sector may in turn impact the enabling environment.

TAKE HOME MESSAGE

The enabling environment needs to be customized to create access to and adoption of productivity-enhancing tools based in part on national drivers of market growth. Factor-driven, efficiency-driven, and innovation-driven economies will require different types of policies, institutions, infrastructure, and strategies, depending on their proximity to the global technological and production frontier (Aghion and Durlauf, 2009; Diaz-Bonilla et al., 2014). Incorporating resilience-enhancing strategies also needs to be at the forefront of planning processes to ensure that gains in productivity are not lost in the face of exogenous shocks. These strategies will vary based on the agroecological and socio-economic conditions of each country.

## Behavioral Influences

Even if productivity-enhancing tools are made more accessible by a robust enabling environment, adopting these tools on a sustained basis may require considerable behavior change by producers and other food system actors. Especially in low-income countries, technology and innovation adoption can be associated with modernization and development, which may be at odds with socio-cultural value systems and indigenous production knowledge and priorities (Curry et al., 2021). Action and investment strategies should be tailored to affect factors of behavior change, such as the capabilities, opportunities, and motivators for producers and food system actors to adopt and sustain the appropriate use of productivity-enhancing tools.

Capability, opportunity, and motivation are three factors that have demonstrated an impact on changing behaviors (COM-B) (Michie et al., 2011), including agricultural technology and innovation adoption. **Capability** refers to the psychological (e.g., knowledge, skills) or physical factors (e.g., required equipment, physical strength) that would lead to a producer adopting a productivity-enhancing tool on a sustained basis. **Opportunities** include physical places to acquire the technology, required inputs to apply the technology, affordability and financing, social support of the behavior change (including farmer organizations), and economic and environmental resources (e.g., savings, a water source for irrigation). **Motivation** refers to the internal processes that influence decision-making and behavior change. This includes personal beliefs and perceptions (e.g., risk aversion, technology acceptance), outcome expectations, and self-efficacy (the belief that one has the power to change behavior).

The impact of interventions targeting productivity-enhancing technology and innovation are mediated by COM-B elements as well as characteristics of the producer or other food system actors, the scale of production, and the type of tool. Table 2 gives examples of how behavioral factors affect sustained adoption of various productivity-enhancing tools.

**Table 2:** Examples of Behavioral Influences on Tool Adoption

| CAPABILITIES | OPPORTUNITIES | MOTIVATION |
|---|---|---|
| In Ireland, dairy farmers find grassland management practices, such as grass measurement, to be high-effort tasks that are physically taxing, especially among older farmers. Increased skill and knowledge facilitated grass measurement uptake (Regan et al., 2021). | Among Rwandan banana farmers, time and financial resources to own and use a mobile phone, and network availability, negatively impact the adoption of digital extension. However, social opportunity, such as gender norms and cultural view of mobile phone use, was ranked highly (McCampbell et al., 2023). | Trust in the intervening organization impacts adoption rates. In the Netherlands and Germany, government enforcement of microbial applications has a negative impact on adoption, while extension agents and farmer organization training and support have a positive relationship (Tensi et al., 2022). |
| Knowledge about Western Corn Rootworm control measures among Austrian producers influences the motivation and adoption of the measures (Kropf et al., 2020). | The time cost associated with an irrigation technology set-up in South Africa, despite low financial cost from government subsidies, limits adoption. Digital technologies need to be offered in complementary packages, not discrete applications (de Witt et al., 2021). | In China, risk-averse producers are less likely to adopt new technology and invest less in technology. Farmers with longer-term contracts are more likely to adopt technology (Mao et al., 2017). |
| Farmers in Ecuador who received text messages on Integrated Pest Management practices have higher knowledge and are more likely to implement the practices than those who did not receive text messages (Larochelle et al., 2017). | Smallholders in Africa, Latin America, and Asia face a $170 billion funding gap as financial providers deem loans too risky or they do not offer products tailored to smallholder producers, especially women (Savoy 2022). | Motivation to adopt climate adaptation practices in western Nepal is positively affected by a producer's assessment of the effectiveness of recommended adaptation practices but negatively affected by their perception of the threat of climate change (Lamichhane et al., 2022). |
| Education, extension, and training have positive impacts on the adoption of nitrogen management technologies in South Asia (Begho et al., 2022). | Lack of access to quality land, exclusion from decision making, and lack of access to finance constrain women's ability to access and adopt productivity-enhancing rice technologies in East Africa (Achandi et al., 2018). | Misinformation on biotechnology in Kenya has led to resistance to the adoption of improved crop varieties, despite the reversal of nationwide bans in 2022 and a need to tackle historic droughts (Ombogo, 2023). |

## A FARMER'S PERSPECTIVE

**Virginia Grain Producer, Virginia Tech, Class of '95**

**QUESTION: What should we know from the farmer's perspective about the practicalities of adopting productivity-enhancing tools on the farm?**

**ANSWER:** Improving agricultural productivity is crucial at all scales; however, there are concerns with the feasibility of continually increasing agricultural productivity. Technology is one of the primary methods of increasing production and productivity levels at all scales. However, technology can be difficult to access depending on the scale of the farm. Smaller farms with less liquidity have issues with keeping up with modern technology and often find it difficult to continually add new technologies to their production. New, top-of-the-line equipment that could be crucial to increasing productivity is often expensive and difficult to maintain. For farmers to be willing to invest in new technology, it has to be worth investing in, reliable, and useful over several years.

To continue improving agricultural productivity levels for the smaller scale farmer, technology investments need to be supported across many areas. Overall, there are concerns with new farm technology, and ensuring increasing agricultural productivity will require repeatable, controlled, and consistent technology that is available and affordable at all scales of production.

**QUESTION: What would be the most helpful to support you in adopting productivity enhancing tools and technologies?**

**ANSWER:** University led research is a crucial asset for farmers. Technologies discovered through university research tend to be accessible and affordable to farmers. For crop producers, commodity-based research within breeding programs is a key tool for improving productivity. Public breeding programs provide access to improved crop varieties at an adoptable price point. As climate change continues to have impacts on weather patterns, it is crucial that research be conducted to create more resilient crop varieties. More funding needs to be allocated towards agricultural research within universities and public programs. Attempts should also be made to increase collaboration between farmers and public research efforts.

### TAKE HOME MESSAGE

Behavioral influences such as capability, opportunities, and motivators will play a critical role in driving sustainable agricultural productivity growth by impacting producer and food system actors' adoption of existing and emerging productivity-enhancing tools. Adoption-oriented interventions, tool development, and ongoing support must be designed in light of the complexity of experiences, beliefs, gender, values, and perceptions of individuals and communities involved in agriculture.

## External Forces & Shocks

The uncertainty and risk that producers and other food system actors face in bringing food from farms to the table are well known. The impact of exogenous events on production, such as losing an entire crop to a new disease or pest, motivates the improvement of agricultural knowledge and innovation systems. External shocks and other types of forces also have a direct role in the accessibility and sustained adoption of productivity-enhancing tools. The past several years have demonstrated that climatic variability, extreme weather events, conflict, political uncertainty and volatility, changes in investment, and price and demand fluctuation can cause smallholder producers to fall back down the innovation curve, losing important gains in agricultural productivity.

Fertilizer use, for example, has dropped off significantly in sub-Saharan Africa as a result of the crisis in Ukraine and resulting increases in fertilizer prices (Pinto, 2022). Even in high-income countries such as Canada, the Netherlands, the U.S., Denmark, and the UK, where producers are less economically vulnerable, external forces such as political uncertainty (e.g. unanticipated regulations) act as a deterrent to investing in smart farming technologies (Eastwood & Renwick, 2020).

Behavior and decision-making are largely informed by the perceived threat of external shocks and forces. Especially within smallholder production systems that have significant potential for sustainable agricultural productivity growth, economic vulnerability increases the impact of external shocks (e.g., production, health) on technological adoption. This may discourage producers from investing in agricultural innovations, such as modern irrigation technology in China (Tan et al., 2021) or improved seeds in Ethiopia (Gebremariam & Tesfaye, 2018). It could also lead to producers returning to less productive practices and tools due to a lack of affordability or availability.

External shocks and forces also mediate access and adoption by affecting the enabling environment. For example, changes in political regimes transitioning to military rule not only destroy agricultural systems from violence and conflict but also create dysfunctional policy environments and negatively impact trade. Sudan and Niger, for example, are likely to see further declines in agricultural productivity, food insecurity, and household resilience as a result of political volatility coupled with extreme weather events (IFRC, 2023).

**TAKE HOME MESSAGE**

Policy and investment action to improve agricultural productivity must consider how external shocks and forces may impact the continuity of agricultural innovation uptake to ensure that sustainable productivity gains are not lost and to continue to accelerate returns to the producer, society, the environment, and the economy.

# POLICY AND INVESTMENT PRIORITIES

Within the context of the enabling environment, behavioral influences, and external forces and shocks on the accessibility and sustained adoption of proven productivity-enhancing tools, The GAP Report® offers six data-driven policy and investment priorities to inform actionable next steps for policymakers, investors, researchers, implementers, and other interested agricultural productivity enthusiasts.

| | |
|---|---|
| Invest in public agricultural R&D and extension services | Public sector agricultural R&D and extension services generate innovation and information that facilitate environmentally sustainable agricultural output growth, improve human health, and support a vibrant agricultural economy. |
| Embrace science- and information-based technologies and practices | Science- and information-based technologies and techniques enable producers of all scales to manage environmental and economic risks by improving their sustainability, resilience, and competitiveness. |
| Improve the infrastructure and market access for agricultural inputs and outputs | Efficient transportation, communications, and financial infrastructures, and affordable and equitable access to markets for agricultural inputs, services, and outputs, support sustainable economic growth, diminish waste and loss, and reduce costs for producers and consumers. |
| Cultivate partners for sustainable agriculture and improved nutrition | Public-private-producer partnerships supporting agricultural development, gender equity, and nutritious food systems leverage public and private investments in economic development, natural resource management, and human health. |
| Expand and improve regional and global trade | Forward-looking trade agreements, including transparent policies and consistently enforced regulations, facilitate the efficient and cost-effective movement of agricultural inputs, services, and products to those who need them. |
| Reduce post-harvest loss and food waste | Reducing post-harvest losses and food waste increases the availability and affordability of nutritious food, eases the environmental impact of food and agricultural production, and preserves the value of the land, labor, water, and other inputs used in the production process. |

BAYER CROP SCIENCE

## Better Life Farming—Unlocking Smallholder Farmers' Potential

Better Life Farming (BLF) was launched in 2016 in Uttar Pradesh, India, with 20 farmers in 20 villages and three global partners: Bayer, International Finance Corporation (IFC), and Netafim. By June 2023, BLF had reached over 1 million smallholder farmers through more than 2,500 BLF Centers in India, Indonesia, Bangladesh, Mexico, Honduras, and Tanzania. More than 30 local partners have joined the alliance, offering their products and expertise directly to farmers via BLF Centers (Explore the 3D interactive BLF Center Tour).

BLF Centers are agri-shops located in rural villages. Farming solutions from the partner network are made accessible to smallholders through a "last mile delivery model." The centers also provide access to agronomic education, customized agronomic solutions, financing (including financial literacy training), market access, and fair prices as well as partnerships. Bayer calls this holistic service scope the BLF ecosystem. BLF Centers are owned by agri-entrepreneurs, many of whom are women or those who also run model farms, from the community they are located in. Each BLF Center services around 500 farmers from five to ten villages.

A recent impact study conducted in May 2023 among 684 BLF farmers revealed that most farmers who have worked with BLF in India for more than a year reported positive social benefits. 76 percent of farmers reported that their income increased because of BLF, 77 percent reported that they experienced a better way of farming, and 74 percent perceived an improved quality of life.

The BLF ecosystem provides training to farmers on sustainable practices and productivity. For example, farmers learn how to correctly use fertilizers and crop protection methods,


The Better Life Farming Model in India (due to different local partners, models may vary across countries).

thereby reducing input volumes and optimizing environmental footprint. Well-coordinated market linkages minimize storage times for fruit and vegetable production and, thus, potential food losses. Good water management practices may reduce the consumption of water by up to 70 percent, for example, in rice.

BLF is based on a business model to ensure long-term sustainability. The model allows partner companies to mitigate any potential high risks, open new sustainable profit generation opportunities in underserved agricultural markets, and give farmers long-term access to proven agricultural productivity-enhancing tools.


Photo: Bayer Crop Science

Meet our Better Life Farmer and Agri-Entrepreneurs our Better Life Farmer and Agri-Entrepreneurs

Photo: Bayer Crop Science

BAYER CROP SCIENCE

## How a Small Change in Cattle Feed Is Transforming Ranchers' Lives in Mexico and Central America

For low-income farming families in Central America and Southeast Mexico, raising cattle and selling dairy is a vital livelihood strategy. The typical small dairy rancher has about 25-30 head of cattle grazing on a similar number of hectares. They sell their daily milk production to local milk processors and artisanal cheese producers.

It's difficult, however, to raise dairy cows in the local climate. During the five-month dry season, problems arise when grass growth is insufficient to feed the herd–and climate change is exacerbating the problem. With droughts, cows can lose up to 25% of their weight, produce 50% less milk, and become more likely to fall sick and less likely to breed.

Bayer shared an economic growth opportunity with dairy ranchers and dairy processors in these regions that could address the challenge: for ranchers to plant corn on a part of their grazing land, then undergo training to perform corn silage, a proven preservation technique in harsh climates that allows feed to be preserved over long periods of time. The initiative, called DKsilos, would also provide access to a technological package, machinery, technical advice, and milk collection outlets. Bayer trained dairy ranchers, for example, on how to grow corn and when to harvest to produce silage. Silage is produced through chopping of corn plants, for which Bayer provided the necessary machinery and tools.

Small-scale cattle ranchers quickly received economic benefits from Bayer's new business model. On average, farmers profited about $5,000 USD more per year when implementing DKsilos thanks to lower feeding costs and higher milk productivity. The dairy processors, in turn, benefitted from access to locally sourced milk year-round instead of transporting milk or milk powder from distant suppliers.

"In times of drought, silage helps a lot to feed the animals," said one female cattle rancher in an impact study involving small-scale cattle ranchers in Mexico and Honduras. "DKsilos has allowed us to be more prepared and not worry as much."

Most participating ranchers who have worked with DKsilos report positive social benefits. In a study conducted by 60 Decibels in May 2023 among 400 cattle ranchers, 68% of participants reported that their income increased because of DKsilos, 75% reported that they experienced a better method of farming, and 67% perceived an improved quality of life.

The DKsilos program has been operating for seven years, reaching over 40,000 farmers throughout Southeast Mexico, Guatemala, Honduras, Nicaragua, Costa Rica, Panama, and the Dominican Republic. In the future, the program will expand to more countries and digital products will continue to be tested to help improve production, productivity, and sustainability.


The DKsilos Model

Photo: Corteva Agriscience

CORTEVA AGRISCIENCE

# Sustainable Innovations for Smallholder Farmers

Through a program called Ag Equity Initiatives, Corteva is leveraging its own technologies and scientists to bring sustainable innovations to smallholder farmers globally who are facing some of the greatest pest, disease, and climate challenges. In collaboration with USAID, CGIAR, Bill & Melinda Gates Foundation, and other key stakeholders, Corteva is co-developing new seed varieties that will provide vital nutrition to food insecure regions around the world. Corteva is also working to advance regulatory frameworks that will enable farmers to access these sustainable innovations.

## Maize Lethal Necrosis Impacts Food Security in Eastern Sub-Saharan Africa

Maize lethal necrosis (MLN) is a viral disease that severely reduces grain yield for smallholder farmers. Along with collaborators from CIMMYT, KALRO, USDA, and STAK, with funding from the Bill & Melinda Gates Foundation, Corteva is using genome editing to develop a MLN-tolerant, locally adapted germplasm that will be released to seed companies in Kenya for the benefit of local farmers and regional food insecure communities. Through the use of genome editing, Corteva is able to cut the development time for MLN-tolerant hybrids in half.

## Parasitic Striga Targets Critical Sorghum in Sub-Saharan Africa

Striga is a parasitic weed that targets the roots of sorghum plants, dramatically impacting yields for this major food staple in West Africa. Corteva and its collaborators from Kenyatta University, ISAAA AfriCenter, and AATF, with funding from USAID, are applying gene editing techniques to create a Striga-resistant ‘smart’ sorghum that hinders the host connection by preventing Striga germination and parasitism. By measurably reducing Striga infection, farmers will observe increases in productivity and be better equipped to meet the food consumption needs of millions of people in this arid region.

## Solving Pearl Millet Post-Harvest Issues in Africa and India

Nutrient-rich pearl millet has a high lipid content and freshly ground flour becomes rancid within 5-7 days of milling, making it unusable for households and commercial production. In collaboration with The International Maize and Wheat Improvement Center (CIMMYT) and the Bill & Melinda Gates Foundation, Corteva Agriscience is leveraging its gene editing expertise to solve pearl millet’s post-harvest rancidity issues. This addresses a critical food security challenge especially for women smallholder farmers in sub-Saharan Africa and India who are largely responsible for millet post-harvest labor, turning the seed into flour for baking and other uses (UN News, 2022). Utilizing CRISPR gene editing tools and deep genome knowledge, the improved pearl millet grain will have a shelf life of up to six months, improving harvestable yield, reducing labor challenges, and increasing smallholder incomes through warehouse and distribution opportunities.

## Improving Teff Productivity for Human and Livestock Consumption in Ethiopia

Providing up to two-thirds of the daily protein and dietary fiber consumed by millions, Teff is a food staple for people and livestock throughout Ethiopia. This nutrient-rich grain is also gluten-free, making it an important option for people with celiac disease or gluten intolerance. However, lodging–or the displacement of the plant from the upright position–makes the teff plant more susceptible to diseases and pests, increasing contaminant levels, reducing grain quality, and lowering protein content. Corteva is leveraging gene editing expertise to develop semi-dwarf versions of the teff plant, making it more resistant to lodging and other climate-related issues. Improved teff plants could reduce yield losses by up to 25 percent.

Corteva is collaborating with others and leveraging our leading germplasm library combined with new breeding technologies to target critical crops that provide vital nutrition to the most food-insecure regions of the world. Our Ag Equity Initiatives align with our purpose and values to enrich the lives of those who produce and those who consume for generations to come.

Photo: Corteva Agriscience

CORTEVA AGRISCIENCE

## Strengthening Smallholder Markets in Argentina

Through Prospera Argentina, Corteva Agriscience is collaborating with provincial governments, Global Communities, and other key stakeholders to improve the productivity and incomes of smallholder farmers in Argentina. Together, the collaboration is strengthening the market system for smallholder farmers in the provinces of Salta and Corrientes, helping Corteva to grow its business and meet the needs of its customers.

Salta and Corrientes represent Argentina's diverse growing climates, with arid Salta surrounded by mountains and tropical Corrientes bordered by the Rio Parana. Here, smallholder farmers primarily grow corn for livestock feed. Although growing conditions in these regions are favorable for corn, farmers often lack access to climate-optimized seed, sustainably advantaged crop protection products, and agronomic training. They also face challenges with harvesting, warehousing, and access to finance.

Corteva is working closely with key stakeholders and farmers to better understand farmer challenges and assess gaps in the existing market system. Through a multi-pronged approach, the program is increasing farmer access to key tools for growing agricultural productivity, such as financing, mechanization, and agronomic training, as well as developing market linkages that enable smallholder farmers to transport and sell excess grain. In collaboration with Global Communities, Prospera Argentina is connecting smallholder farmers to a market system for key inputs and services.

Corteva agronomists provide training to farmers on climate-optimized Pioneer® and Brevant® corn seed hybrids, proper fertilizer use, sustainable application of crop protection products, and sustainable agricultural practices. Using demonstration plots and group discussions, agronomists share best practices on the impact of seed hybrids on yield, timing of fertilizer, and crop protection application, as well as optimal harvest methods for livestock feed, storing, and commodity market sales.

Together, this collaboration is supporting smallholder farmers in the Salta and Corrientes provinces to produce more corn and increase their incomes, all while strengthening the market system for all involved.

Photo: Daugherty Water for Food Institute, University of Nebraska

DAUGHERTY WATER FOR FOOD GLOBAL INSTITUTE

## Challenging Assumptions in Farmer-Led Irrigation: The Value of Informal Equipment Rental Markets

Farmer-led irrigation focuses on small-scale, local, and contextual irrigation solutions to improve livelihoods and food security, and often involves the private sector. Farmer-led irrigation is not a new concept in the global development community, but one in which there are varying ideas on implementation. Well-intentioned policies to support farmer-led irrigation development may fall short by neglecting to understand the needs of farmers and the support systems that must be in place to create long-term viability.

Government and donor-funded subsidies, pay-as-you-go schemes, and grants are often used to make the purchase of irrigation equipment more feasible for farmers in sub-Saharan Africa. The assumption behind these policies is that the most desirable outcome for farmers is to own their own pumps. However, it may not always make sense for smallholder farmers to own their own irrigation equipment–often, these are expensive and depreciating assets which are not used often and require ongoing maintenance and storage.

Instead, farmers may opt to hire local entrepreneurs in an informal market to provide irrigation services for their farms. New research from the Daugherty Water for Food Global Institute (DWFI) at the University of Nebraska unearths how irrigation-as-a-service can provide value to both farmers and service providers, while unlocking new business opportunities for entrepreneurs.

Irrigation-as-a-service is practiced through informal markets, including friendly transactions in which neighboring farmers lend and rent irrigation equipment among one another. Because these transactions are not tracked, the impact of lending and renting small-scale irrigation equipment is often unrecognized.

Conducting local field interviews and examining the informal markets that already exist organically can challenge assumptions on how best to provide irrigation access to local farmers. In a report published in February 2023, DWFI explored the current state of irrigation-as-a-service for smallholder farmers in Rwanda with the goal of finding scalable, farmer-led solutions to increase irrigated agriculture. The business models the team examined include farmer-to-farmer lending, entrepreneur-to-farmer rentals, and water tanker trucks.

Mary, for example, a farmer in Rwanda, rents irrigation equipment from Claire, her neighbor who owns a pump but doesn't irrigate every day. Mary pays Claire a set fee three times a week, buys her own fuel, and is in charge of any repairs that come up when she is using the pump. The arrangement results in benefits for both parties. Claire can quickly pay off her pump, receive rental income, and invest in more equipment if desired. By irrigating, Mary can farm during additional seasons and grow high-value crops–all of which result in increased income. Additionally, this irrigation-as-a-service arrangement can bypass barriers to accessing credit, reduce farm labor, and build technical capacity for smallholder farmers.

"Even though I could purchase my own pumps," said another farmer who hires a local entrepreneur to irrigate his crops, "I prefer to hire someone to irrigate for me."

Estimating how much land is being irrigated using pump rentals, as in the case of Mary and Claire, is difficult due to the informal and inconsistent nature of the market. However, DWFI estimates, using a proven methodology, that lending and renting of pumps has increased the actual irrigated area by 8-35 percent in Bugesera district and 3-21 percent in Nyagatare district of Rwanda.

The Government of Rwanda's support for small-scale irrigation is currently focused on the sale of subsidized irrigation equipment through fewer than two dozen approved retailers. To support scaling up informal markets, DWFI recommends that Rwanda diversify its funding for smallholder irrigation to support more irrigation-as-a-service entrepreneurs with startup grants, adjust policies to promote new businesses, and encourage farmers to lend their equipment.

Photo: John Deere

JOHN DEERE

## From Farm to Phone: The Future of Connected Farms

By 2050, the world's population is expected to grow from 8 billion to nearly 10 billion people, increasing global food demand by 50%. As farmers work hard to sustainably feed our growing world, they must do so amid steep challenges, from unpredictable weather and labor shortages to constant market volatility. Technology is an increasingly valuable tool to help farmers address these challenges, and the key to technology is connectivity.

Advanced connectivity–from mobile internet and Long-term Evolution (LTE) to fixed broadband–has been prioritized in urban areas globally, despite that rural areas are home to most of the farms nourishing our world. Farmers need fast, reliable connectivity to take advantage of the technologies they use now and those that will emerge in the years to come.

Today, 500,000 John Deere agricultural machines harness cellular connectivity to push data to the cloud, providing farmers access to vital agricultural information on mobile devices. While these machines serve an important purpose for farmers today, the ability to unlock that data in real-time through more advanced connectivity is what is coming next. Satellite connectivity has emerged as a frontrunner to enable machines to send and receive data in real-time because of the vast coverage it can provide.

Due to this emergence of satellite communications technology, John Deere is actively working to enhance its existing satellite connectivity technology to enable farmers around the world to take advantage of technology and to further connect 1.5 million machines by 2026. To help achieve this goal, John Deere announced a request for proposals (RFP) in September 2022, seeking a satellite communications partner or partners to help bring connectivity and technology needed to farmers around the globe. Together, the plan is to provide a solution available in the market in 2024.

In the near term, farmers can expect satellite connectivity to help them do more with less and improve their operations. Satellite connectivity can affect their work in these ways:

- **Autonomy:** Autonomy solves one of agriculture's biggest issues: limited availability of skilled labor. With autonomy, farmers and their workers can step away from machines to focus on other value-added tasks, such as planning for the next day's activities or strategizing with advisors. But starting, stopping, and keeping those machines in action requires strong connectivity. For instance, starting a machine can be as simple as swiping right to left–but only if the mobile device and tractor are connected. Farmers are taking advantage of autonomy typically during tillage, but John Deere's goal is to offer this technology at each step of the production cycle by 2030, including when planting seeds, nurturing crops, and harvesting plants. Satellite connectivity will allow farmers to better manage their teams and operate with more precision.
- **Machine-to-machine communication:** The average size of a farm in the United States is 445 acres, but many are larger. Farmers often have many machines operating in a field at one time, whether planting, spraying, or harvesting crops. More machines running at once is good for productivity, but enabling those machines to communicate with one another while doing the work is even more efficient. Satellite connectivity will allow every field across every farm to communicate, such as highlighting where seeds have been placed so efforts aren't duplicated. Visibility into data the moment it's created enhances efficiency and productivity.
- **Maintenance:** Machine downtime can be the difference between getting seeds planted or not. If a machine is down, farmers may not feel the impact of costs until months later during harvest. When there are machine issues, it can take hours or even days for a maintenance team to arrive. Today, many farmers have the ability to receive alerts on their phones when their machines might need service. When the machine is connected, farmers and their advisors can also remotely drop in to view the screen in the cab, opening up opportunities to optimize the job being performed at any given time. With access to real-time satellite connectivity, more farmers will have the ability to share diagnostics with off-site technical support staff to fix many operational issues remotely.

Adoption and optimal use of agricultural technology is essential to supporting farmers in completing their everyday tasks, meeting rapidly growing global food demands, and sustainably growing agricultural productivity. To take advantage of the latest technologies, farmers need reliable access to connectivity.


Photo: Farm Foundation

FARM FOUNDATION

## Supporting Emerging Voices of the Agricultural Industry

*Kayla Braggs*

According to the USDA Economic Research Service, the output of American farms contributed $164.7 billion, or 7 percent, to the U.S. Gross Domestic Product in 2021. With the global population projected to reach 9.5 to 10 billion people by 2050, farmers and ranchers around the world are responsible for producing more food and fiber on less land, using less water.

In 1933, the Farm Foundation was established to serve agricultural and rural communities. While these communities serve as the primary production centers for American agriculture, they face a unique set of challenges such as access to affordable energy, clean water, and healthy food choices. The Farm Foundation develops partnerships to catalyze the delivery of practical, comprehensive, and objective information to public and private sector leaders.

The Farm Foundation facilitates programs that explore the relationship between productivity, innovation, and environmental sustainability to improve production within the agri-food industry. These programs help establish connections between governmental agencies, private companies, and independent farmers to foster innovative production. One of these programs is the Young Farmer Accelerator Program, which helps young farmers build a strong network of agribusiness contacts. Another is the Agriculture Scholars Program, which targets students studying agricultural economics with an interest in future policy work, and one is the Young Agri-Food Leader Program, which actively engages emerging leaders in food and agribusiness with interactive learning and networking experiences. All programs focus on exposing participants to exclusive learning opportunities, career growth and development, and an opportunity to gain a deeper understanding of the food and agricultural value chain.

Innovation is the key to finding solutions to the dynamic issues agricultural professionals face, including depleting natural resources, inequities in land availability, and negative impacts caused by climate change, as well as the increasing food demand. While the development and adoption of new technologies has driven agricultural productivity growth during the past two decades, there is still uneven progress for producers across the sector. The Farm Foundation works to develop informational material around land ownership and utilization, conservation, and international policies affecting production, marketing, and income in the efforts to close the productivity gap between producers around the world.

INTERNATIONAL POTATO CENTER

# Spearheading Anemia Zero with Biofortified Potatoes in Peru

Anemia, a prevalent health issue in Peru, particularly among women and children, has prompted the implementation of a groundbreaking initiative called Anemia Zero. At the forefront of this campaign is the International Potato Center (CIP), playing a pivotal role in producing and distributing advanced clones of biofortified potatoes. These specialized potatoes, enriched with iron, offer a sustainable and accessible solution to combating anemia in the country.

## Anemia in Peru

Anemia is a significant public health concern in Peru, where it affects more than 40% of the population; particularly vulnerable are children and pregnant women. Iron deficiency, one of the primary causes of anemia, has severe consequences, such as impaired cognitive development, weakened immune systems, and reduced work productivity. Recognizing the urgency to address this crisis comprehensively, the Anemia Zero campaign was launched, focusing on improving nutritional status, especially in low-income communities of the Andes that have limited access to diverse diets.

## Biofortified Potatoes

Biofortification is a proven nutritional strategy to ensure foods are as nutritious as possible. As a critical partner in the Anemia Zero campaign, CIP has played a crucial role in spearheading the development of these potatoes. Using conventional breeding techniques, CIP has been able to increase the iron content in the tubers of these biofortified potatoes. This innovation allows individuals for whom potatoes are a staple, as in Andean diets, to obtain a significant portion of their daily iron requirements by simply including these potatoes in their diet, offering an effective and affordable solution to combating anemia. Biofortified advanced clones can provide up to 50% of the iron requirements for women living in areas of high potato consumption.

CIP has been instrumental in successfully implementing the Anemia Zero initiative. As a global research-for-development organization focused on potato science and other root and tuber crops for the benefit of smallholder farmers and their communities, CIP is contributing its expertise in breeding and genetics to develop high-quality biofortified potato varieties with increased iron content.

Working closely with local farmers in select communities, CIP has provided training and technical assistance to ensure the successful cultivation of these biofortified potatoes. Through its extensive network of partners, CIP has facilitated the dissemination of advanced clones of iron-rich potatoes, reaching farmers in various regions of the North of Peru.

Furthermore, CIP has collaborated with government extension agencies, health clinics, social protection programs, research institutions, local organizations, and communities to promote the adoption and acceptance of biofortified potatoes as a sustainable solution to anemia. The organization has conducted awareness campaigns and nutritional educational programs to highlight the nutritional benefits of these potatoes and empower communities to make informed dietary choices.

This initiative has been piloted with 140 farmers in Northern Peru. Registered in 2023, the advanced clones will be released in 2024. CIP's collaboration with various stakeholders is helping drive the acceptance of these nutritious potatoes. Although adoption and acceptance are still in their infancy, the iron-rich potato is crucial to achieving the country's anemia eradication goal.

Photo: HarvestPlus

HARVESTPLUS

# Increasing Access to Nutrient-Enriching Technology to Bring Resilience to Food Systems

Amid climate change and other global challenges, farmers face significant shocks, compromising their food security and livelihoods. Floods, droughts, and greater exposure to crop diseases are direct nutritional and economic threats to millions of smallholder farmers and contribute to a deficit of plant and human nutrition. As temperatures rise, crops are expected to lose 8-10% percent of yield and 3-17 percent of their protein and nutrient contents.

Plant breeders at CGIAR centers and National Agricultural Research and Extension Systems have successfully achieved exceptional yields and nutrition gains with nutrient-enriched varieties of food crops that are more stable under a variety of challenging environmental conditions. This process of biofortification uses conventional breeding and agronomic techniques to develop nutrient-enriched crops that are proven to improve health. Improving smallholder farmers' access to nutrient-dense, biofortified varieties of staple crops is vital for safeguarding nutritious diets, protecting livelihoods, and building resilient food systems.

In Pakistan, where 98 percent of the population relies on wheat as a daily staple, and malnutrition is estimated to cost the country USD 7.6 billion annually, devastating floods in 2022 destroyed millions of hectares of fertile land and displaced 33 million people. Biofortified zinc wheat is helping offset climate-induced losses as its production has risen rapidly to approximately 5.5 million metric tonnes (MT) in 2023.

Zinc wheat provides up to 50 percent more zinc than traditional varieties and up to 10 percent higher yield, bolstering the agricultural system's resilience and improving productivity–all while accelerating the reduction of widespread, yet preventable, zinc deficiency.

To determine plant breeding priorities and ensure biofortified crops integrate the preferences and needs of farmers, extensive socio-economic research is conducted by HarvestPlus and its partners to assess farmers' willingness to pay for improved crop varieties, their perception of the health benefits, and the sensory and baking properties of the products.

Attracted to zinc wheat's nutritional advantage, its good taste when used for traditional foods like chapati, and its competitive productivity, over 2.1 million farmers are now growing the crop (up from only 218,000 five years prior), enriching the diets of nearly 11 million vulnerable people.

Globally, more than 100 million people in farming households are eating hundreds of varieties of nutrient-enriched crops–billions more could, and should, benefit. HarvestPlus and partners use a variety of approaches to improve access to biofortified varieties, including establishing market linkages between farmers and value chain actors and raising awareness through social and digital media.

In Zimbabwe, for example, HarvestPlus is connecting thousands of smallholder farmers to lucrative markets through digital technologies, now readily available to farmers even in rural parts of the country. Using mobile apps and SMS-blasts, farmers can easily access information about interested market buyers and processors and seed availability. They can receive virtual training, real-time extension services, and location-specific weather forecasts. The digital marketplace allows farmers to grow iron beans, vitamin A maize, and vitamin A orange sweet potatoes based on demand, and for processors to increase their capacity based on a guaranteed supply.

In Nigeria, where population growth, micronutrient malnutrition, and climate impacts converge, nearly 2.1 million farmers have adopted vitamin A-enriched cassava. The biofortified variety provides an average fresh root yield of 20.5 metric tons per hectare (MT/Ha), two-fold above the average yield (10.2 MT/Ha) of other improved but non-biofortified varieties. A primary objective of HarvestPlus upon introducing nutrient-enriched varieties into the food system–especially in highly entrepreneurial contexts like Nigeria–is to partner with local organizations to train and empower women on the processing and utilization of biofortified crops. With enhanced business skills, women could become nutrition and agricultural ambassadors within their communities and kickstart small-and medium-sized enterprises that produce nutritious food products for markets.

As climate change intensifies, nutrient-enriched crops offer the potential to sustainably improve the resilience and livelihoods of smallholder farming households, making food systems more nutritious and inclusive, and capable of addressing hidden hunger.

Photo: Heifer International

HEIFER INTERNATIONAL

## Guatemala: Increasing Incomes, Breaking with Traditions

One-third of Guatemalans are employed in the agricultural sector. Many producers are Indigenous peoples concentrated in remote, rural communities that lack access to basic services. As a result, farmers and producers earn unsustainably low incomes that fuel an endless cycle of poverty.

While price volatility has always been a major challenge for producers of cardamom and other cash crop spices in Guatemala, in recent years, producers have also faced climate change and extreme weather events, crop failures, high inflation, and the COVID-19 pandemic, all of which significantly impacted productivity and disrupted basic needs. Most small-scale producers cannot access the innovations and information they need to ensure a productive, profitable, and sustainable future.

To sustainably increase producers' incomes, Heifer International has engaged in an evidence-based programming strategy delivered alongside traditional extension services and training to support spice producers to improve their yields, diversify their crops when appropriate, and find opportunities to market and sell their products at the best possible time under the most optimal conditions.

Heifer's Green Business Belt (GBB) project works with 37 communities and 36 farmer-owned agribusinesses across Alta Verapaz in north-central Guatemala. The project aims to support Guatemalan spice producers to develop profitable spice and agroforestry enterprises while improving forest management across 16,000 acres of biodiverse land. Through the project's activities, enterprises focused on spice value chains will become stronger and more inclusive as Heifer partners with private and public sector entities to promote market systems and value chains that increase producers' incomes.

Working in communities with low access to markets or credit, Heifer's technical teams and local partners support producers, cooperatives, and community organizations that are committed to the project, have land to grow crops, and are willing to implement techniques to improve their spice production. Through training tailored to the local context, producers learn about agroforestry systems and good agricultural practices while addressing specific problems like crop management, so they can improve their production in an environmentally sound way. Furthermore, Heifer's Values-Based Holistic Community Development training helps stakeholders strengthen social capital within their communities, enabling them to improve how they work together to run their businesses and collectively capitalize on their newly gained entrepreneurial skills.

Technicians also ensure the project's stakeholders sustain their success by building capacity in financial activities such as savings, credits, market analysis, and value chain analysis to manage and grow their businesses. As a result of the comprehensive training, producers, cooperatives, and community organizations have increased their incomes, in addition to improved crop management, increased access to new markets, and increased the utilization of market information and tools to enhance decision-making and business planning.

Marta Botzoc Teyul is one of Adira Cooperative's leaders. The cooperative, located in the municipalities of Raxruhá and Chisec in Alta Verapaz, Guatemala, has 926 active members who are working to increase their income with Heifer's support. Teyul and other members are focused on achieving this by improving the quality and quantity of their products, as well as diversifying the kinds of spices they grow in the lush rainforest.

"[Access to information] is extremely important because we understand how the market dynamics work, in prices, volumes, and qualities," Teyul said. "Knowing the market, we will make better decisions in terms of product commercialization, qualities required by the market, and above all, crop management."

Stronger administrative support can also create unexpected opportunities for producers. For instance, the cooperative is in the process of applying for commercial organic certifications that will further increase demand–and, therefore, the price–of their spices.

Florinda Aracely Tzib Maaz is a community promoter who has been working to improve conditions for women producers in her community.

"Because we are women, many times they do not believe that we are capable of maintaining our land," Maaz said. "Most of the women in our community have been the ones who have worked their land, [doing] the cleanings and [applying] the organic fertilizers."

Through her work, she's learned the power of aggregation as well as knowing what a fair price is for her crops so that she can walk away from a bad deal.

"If we have nowhere to sell and we give it to the intermediaries, they earn a lot more than the price we give them with our product," Maaz added. "That is why we are organizing ourselves to gather our harvest and sell it together so that we can get better payment for our product."

Based on a 2022 Heifer survey, 62% of the households of the GBB have closed the gap between a Living Income Benchmark and actual income. While some farmers surveyed benefited from a short-term bump in cardamom prices, the training they received on production cycles and market analysis ensures they can be successful long-term. With access to data and pricing information, farmers can determine how price fluctuations will impact their overall income. This knowledge enables farmers to more easily identify opportunity costs of income fluctuations and adapt their planning for a more stable and sustainable future.

Photo: IICA

IICA

# Delivering Safe Tools for Farmers Through Institutional and Regulatory Innovation

In Latin America and the Caribbean, farmers are interested in adopting new crop varieties and livestock derived from biotechnology and genome editing that can withstand climate change pressure, as well as improve the taste, nutritional quality, and use of vital inputs. However, the science-based regulatory systems necessary for the adoption and use of these technologies are limited in several countries.

To assist in building institutional and regulatory capacity, the Inter-American Institute for Cooperation on Agriculture (IICA) is using a coordinated approach to help its 34 member states of the Americas design and implement science-based regulatory systems to benefit farmers, consumers, and the environment, and to boost trade. As a neutral institute that contributes to strengthening the technical capacity of ministries of agriculture, IICA conducts training workshops, shares science-based information, and creates a process for cooperation and feedback to build trust. IICA has worked since 2006 with its member countries on institutional support, capacity building, and communication around biotechnology and biosafety issues.

In Honduras, IICA helped build the capacity of the Ministry of Agriculture to establish a clear and transparent regulatory framework. Farmers are now adopting biotech-developed crops that require fewer pesticide applications, require less labor to harvest, and result in higher net profits. For every dollar invested in the cultivation of biotech maize in Honduras, for example, farmers are now receiving $14.70 in profits.

Guatemala is beginning confined testing of some biotechnology products as well. With the support of IICA, both Honduras and Guatemala have developed science-based policies to regulate the adoption and use of genome editing in agriculture, which enables plant breeders to achieve traits desired by farmers, such as drought tolerance, or desired by consumers, such as higher nutritional content.

IICA is also supporting innovation for institutional cooperation in trade. An example can be found in Central America, within the framework of the Guatemala-Honduras-El Salvador Customs Union Agreement. This agreement began in 2015 when Guatemala and Honduras created the customs union to advance trade in goods and services; El Salvador joined the agreement in 2018. Since Honduras had adopted biotech maize (genetically modified to resist pests) and Guatemala had not, IICA supported the two governments by conducting a risk analysis of potential transboundary movements.

IICA also carried out joint work between Honduras and Guatemala to create the "Technical Rule on Biosafety of Living Modified Organisms for Agricultural Use" that was submitted to national public consultations in the two countries and to the World Trade Organization. This process helped Guatemala create a new biotechnology regulatory framework that now allows its agricultural research centers to conduct tests and confined field trials of new crops that can eventually be used by its farmers.

With more than 80 regulators from 17 countries of the Americas, IICA has organized several seminars to provide clarity for developers to create safe and useful products such as rice resistant to bacterial blight, mustard green that is gene-edited to reduce bitter taste, and gene-edited bananas with reduced browning. IICA also facilitates hands-on laboratory training in gene-editing in partnership with the Bioversity-CIAT Alliance in Colombia and the Technological Institute of Costa Rica (TEC).

Thanks in part to this institutional support and training offered by IICA, a growing number of Latin American countries have regulatory frameworks in place, allowing the research, development, and production of biotech products that are accepted by more farmers and consumers. Making these technologies accessible to farmers can boost agricultural productivity and improve lives and livelihoods.


Photo: Mosaic

THE MOSAIC COMPANY

## Soil Monitoring Technology and Real-time Data Improve Outcomes for Farmers and the Environment

The Mosaic Company, in partnership with The Nature Conservancy (TNC) and the University of Florida Institute of Food and Agricultural Sciences (UF IFAS) Extension, has invested in a program in Southwest Florida that advises farmers and ranchers about best management practices for nutrient and irrigation applications.

Florida's agricultural industry, which produces more than 300 agricultural crops and contributes billions of dollars annually to the state's economic base, must share the state's limited water resources with other industries and a rapidly growing population. Headquartered in Florida, Mosaic invests in global partnerships that address water conservation and nutrient stewardship–helping maximize the impact of water and fertilizer inputs to support sustainable food production.

With funding from Mosaic, the TNC and UF IFAS Extension project introduced a soil probe program using in-field soil moisture probe technology to support a farmer's decision-making processes around water and fertilizer applications. In real time, the technology, which is tailored for the specific crop the farmer is growing, provides knowledge of soil salinity and moisture. This data is especially helpful in the humid subtropical climate of Florida, which has distinct dry and rainy seasons, characterized by sporadic rain, or warm, humid conditions with frequent showers and thunderstorms.

In practice, the dashboard may communicate to a farmer that the crops are within an acceptable moisture range and the farmers can wait to irrigate, particularly with heavy rains in the forecast. Optimizing irrigation helps enable nutrient management in the soil because farmers are minimizing the extent to which they may overapply water that pushes nutrients away from the rootzone, resulting in benefits for the environment and the farmer. After a brief training by TNC or extension agents to orient the farmer to the dashboards and the data they house, the farmer is ready to use the insights to inform decisions about when and how to apply water and fertilizer to their fields. Farmers, extension agents, and TNC all have access to the digital dashboards and the data the probes store; the groups collaborate regularly during the demonstration period to ensure the technology is working as expected.

Many of the participating farmers were initially recruited to use the probes through UF IFAS "Field Days," or on-farm events where industry partners and farmers gather to network and share best practices and the latest research-based recommendations related to precision agriculture, nutrient and water management, and other topics. To date, several hundred farmers throughout Florida have implemented the probes with overall increased access to water and fertilizer information.

The goal of this program is for farmers to learn how to use the probes and implement best practices for nutrient stewardship and irrigation management. After a growing season of using the soil moisture probes, farmers can then decide whether to invest in their own probes and accompanying dashboards for their operation. TNC and other nutrient stewardship program partners are scaling the training to other regions to improve resource use by even more growers.

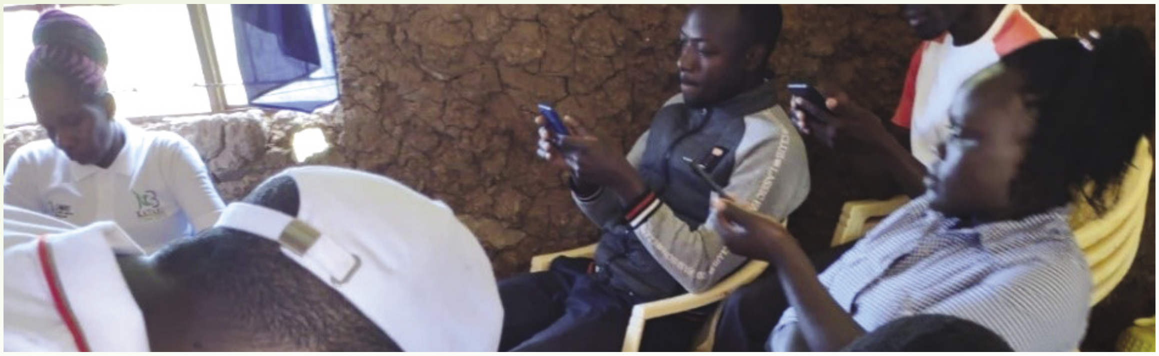


Photo: Purdue University

PURDUE UNIVERSITY

## Engaging Hard-to-Reach Farmers through Scientific Animations without Borders

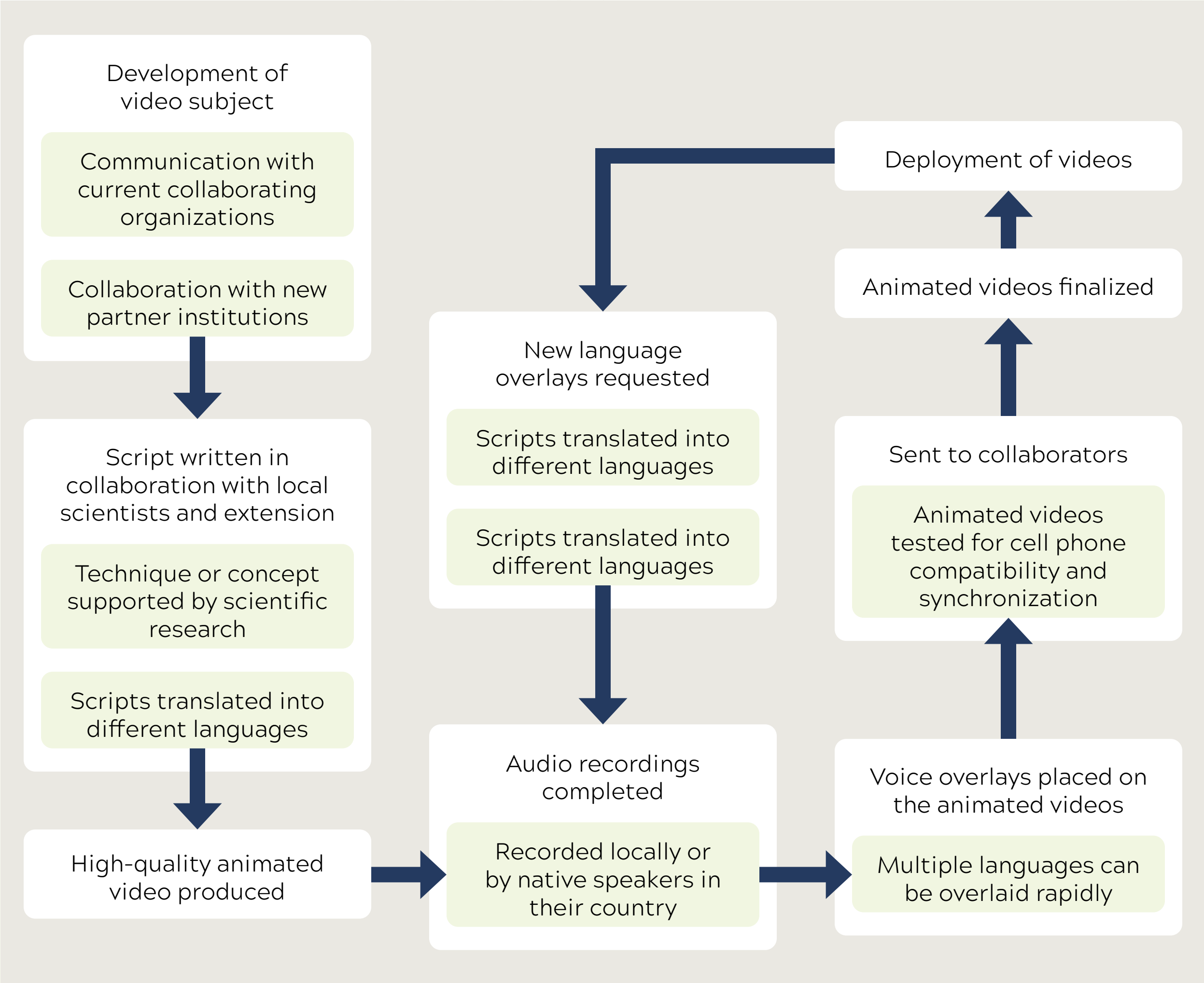
*Julia Bello-Bravo and Gary Burniske*

A major challenge for agricultural extensionists is providing technical assistance to smallholder farmers who live in remote, hard-to-reach areas. In addition, some farmers may only speak local languages. Women farmers and minority ethnic groups in particular have limited access to education and extension services. Smallholder farms (< 2ha) account for 80% of farms in lower- and lower-middle-income countries and produce 35% of the world's food (Lowder et al., 2021). Total Factor Productivity (TFP)–or the comparison of total outputs relative to the total inputs used in production of the output–can be effectively increased on smallholder farms by introducing technology to overcome barriers of distance, literacy, and marginalized languages.

Scientific Animations Without Borders (SAWBO™) is a tool for communicating technology and best practices in agriculture, particularly to hard-to-reach farmers (Bello et al., 2020). It is a university-developed initiative focused on the development of educational content for people around the planet, no matter where they are or what language they speak. SAWBO™ transforms extension information on relevant topics into 2D, 2.5D, and 3D animations, which are then voice-overlaid into a diversity of languages. SAWBO™ videos can be downloaded for free and used by any institution for their own local educational programs in the field. Animations are available in a variety of file formats, including for mobile phones.

SAWBO™ was originally developed by researchers at the University of Illinois, and through their collaboration with "information deployers" (scientists in developing nations who do extension work, extension agents in developing nations, NGO employees/volunteers, and Peace Corps volunteers) created a methodology to use animations to reach populations with low-literacy with important extension practices. Since then, Michigan State and Purdue University have contributed towards the refinement and wide-scale deployment of SAWBO™ in partnership with multiple institutions in Africa, Asia, and Latin America.

In 2012, SAWBO™ was first piloted in the Maradi region of Niger and focused on the local acceptability of a mobile phone-based platform of three different SAWBO™ animations: hermetic storage, biological pest control, and water treatment. The results of the pilot project determined that the videos were effective in transmitting messages on integrated pest management practices and cholera prevention while also illuminating challenges in sharing them with others with limited access to smartphones. Animations were developed to be less data-heavy and viewable on simple mobile phones. Next, researchers expanded the piloting into Nigeria with a focus on pest management in cowpea. These SAWBO™ videos were designed to combine pest control methods from scientific research with indigenous knowledge. The videos were then disseminated to farmers with low literacy and followed up with field surveys. The findings acknowledged SAWBO's potential for technology transfer. It also identified challenges in utilizing indigenous knowledge that may not be readily transferable because it is embedded in local traditions that are not followed in other geographical areas. Further research utilizing SAWBO™ animations for integrated pest management revealed that complex topics can be animated and utilized widely, and not just in a local context. The animated characters from one location were deemed to be acceptable in others where the character's physical traits were different. For example, animations with Latin American farmers were found acceptable in African countries. The effectiveness of SAWBO™ in addressing the gaps and solutions related to gendered agricultural learning is proven through a case study in Mozambique using animations (Bello et al., 2020). Women, who make up about 90% of those employed in the agricultural sector, have lower literacy rates and less access to training and technical advice by extension agents (USAID). SAWBO overcame these gaps in delivering animated technical messages for practices that lead to improved productivity and sustainability.




Flow chart for the development of SAWBO™ animations through an international collaborative approach (Bello et al., 2011)

Photo: SSA

SASAKAWA AFRICA ASSOCIATION

# Digital Solutions for Effective Extension and Advisory Service Delivery Among Farmers in Ethiopia

Access to technology and innovation is vital to improving productivity, in which farmer training and extension systems play a pivotal role. To address the gap in the extension worker-to-farmer ratio in Africa, the Sasakawa Africa Association (SAA) promotes e-extension through a number of tools, including a Digital Classroom System (DCS), radio programs, mobile phone-based services, and the Amplio Talking Book (ATB).

In 2020, SAA partnered with Amplio (https://www.amplio.org/) to pilot ATB, or "Sasakawa Radio" as farmers called it. The device is used to provide extension and advisory services to farmers, especially those who have low-literacy. The battery-charged ATB is an on-demand audio-enabled device that can operate as a standalone radio. The device can receive feedback and tracks usage statistics, enabling experts to identify opportunities to expand or modify program content in near real time. To fit the rural context, the ATB does not require access to the internet or electricity. The information is also given in local languages.

The pilot project was implemented in the Ana Sora district of the Oromia region and Angacha district of the Southern Nations, Nationalities, and People's (SNNP) region of Ethiopia. A total of 1,260 smallholder farmers (30% women) were organized into 42 groups with ATBs that contained 16 different pre-recorded messages on regenerative agriculture, nutrition-sensitive agriculture, and market-oriented agriculture.

Farmers listened to the messages, on topics such as soil fertility management, in groups.

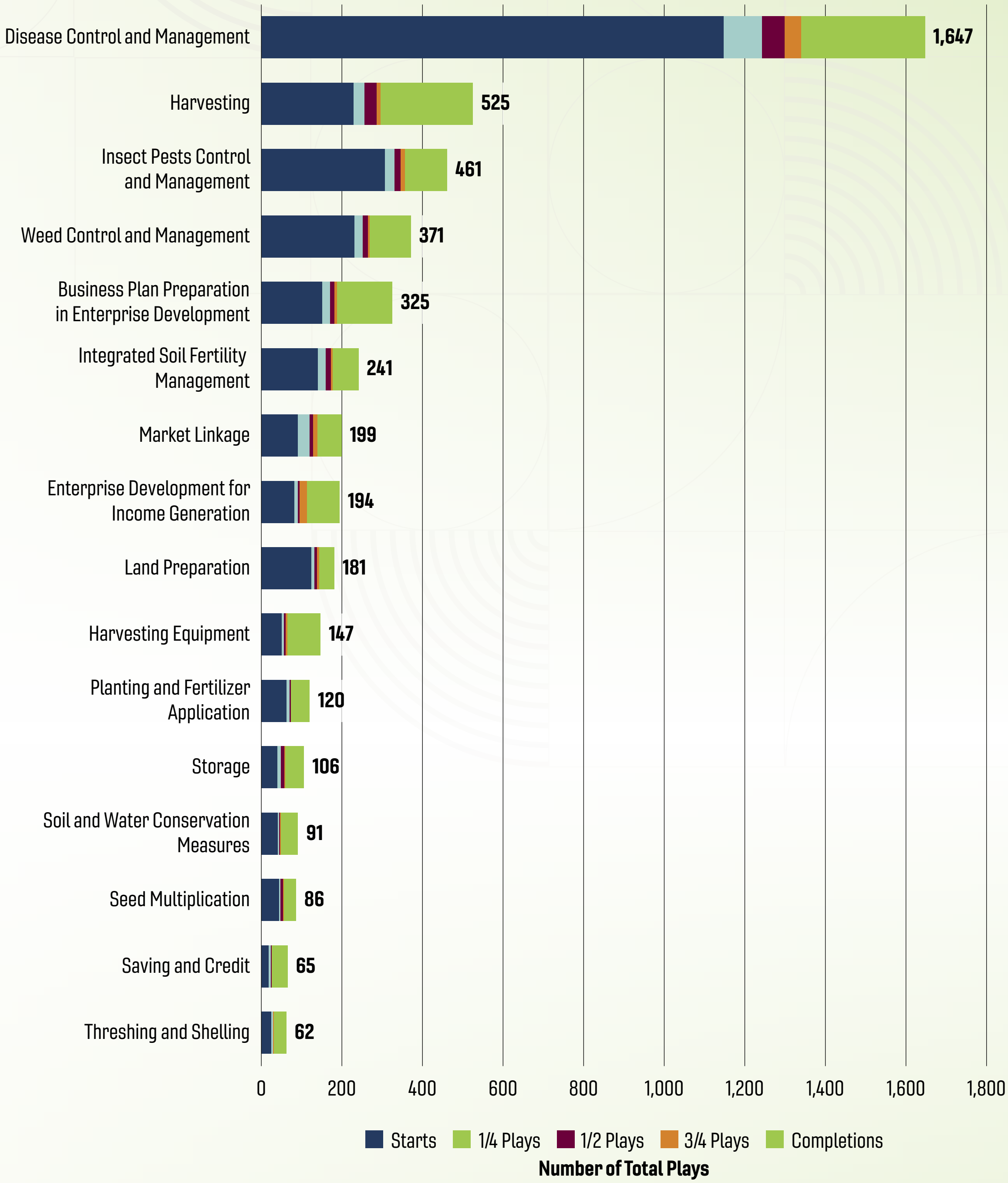
Field monitoring revealed that 231 (68 women) farmers, including 69 (21 women) youth, listened to the messages on the ATB. Usage statistics collected from 28 ATBs showed that messages on regenerative agriculture were played for 79 hours (22 entireties/completions), with Integrated Pest Management (IPM) being the most listened to at about 54 hours. The usage statistics collected from 26 ATBs showed that the nutrition-sensitive agriculture messages were played for 32 hours. Fifteen messages were listened to until completion 389 times, of which harvesting operations followed by harvesting equipment were the most attended messages.

In a survey carried out in Ana Sora and Angacha districts in Ethiopia, 87% of the 60 farmers interviewed preferred ATB over other e-extension technologies promoted by SAA because the radio is accessible anytime, anywhere.

After experiencing the technology's utility, one farmer said, "If we get Sasakawa Radios (Talking Books), we might need less frequent visits from extension agents."

As of August 2022, 1,954 adult farmers (571 women) and 544 youth (157 women) farmers received training in regenerative agriculture and nutrition-sensitive agriculture through ATBs, leading to increased knowledge of extension information.

**Frequency of Good Agronomic Practice (GAP) Messages Listening Completion Recorded on One Talking Book**




**Source:** SAA, 2022

Photo: S M Sehgal Foundation

S M SEHGAL FOUNDATION

# Complementary Productivity-Enhancing Solutions Provide Pathway to Sustainable Agriculture Among Indian Farmers

*Pooja O. Murada, Priya Choudhary, Pawan Kumar*

The S M Sehgal Foundation (Sehgal Foundation) is currently present in 12 states of India promoting the Agriculture Development Program (ADP), which aims to improve smallholder livelihoods through the adoption and adaptation of innovative technologies. Sehgal Foundation's goal is to increase crop productivity through the improvement of soil fertility, increased adoption of irrigation, and encouraged use of small-scale machinery.

Increasing knowledge of proven practices and tools to implement sustainable farming practices can lead to improved crop yields, increased profitability, and better stewardship of the environment. Practices such as soil testing to make informed decisions about the use of essential micronutrients, technologies such as mini sprinklers for enhancing water use efficiency, and mini reapers for labor efficiency have demonstrated impact in Uttar Pradesh, India.

Through the ADP, the Sehgal Foundation deploys its Package of Practice (PoP) approach, which involves promoting multiple science-based farming techniques and technologies that farmers use alongside traditional production methods. By implementing a comprehensive PoP, farmers enhance their crop yields through improved efficiency from field preparation to harvesting.

The PoP approach also increases information on and access to productivity-enhancing tools by providing small and marginalized farmers with farm equipment at subsidized rates and training on how to use the equipment. Farmers bear a portion of the machinery's costs to foster a sense of ownership. Ajay Kumar, a farmer from Undi village, Mathura, Uttar Pradesh, for example, is the recipient of a multi-crop reaper.

"I heard about the benefits of a multi-crop reaper machine and I went ahead to contribute a portion for getting the machine at a subsidized price," Kumar said. "Within five days I got back my invested amount of INR 22,000 (264 USD), and by April 12, 2022, I had harvested 23 hectares of wheat. For this, I charged INR 1,400 (43 USD) per hectare, and my gross earning was INR 81,200 (975 USD)."

Mini sprinkler irrigation equipment is another type of technology available for subsidized purchase through the PoP approach. Farmer Harun, from the village of Buraka, used the equipment to irrigate his crop.

"The mini sprinkler irrigation method has had a prominent effect and has not only changed the farming landscape of the village," he said, "but is also conserving water as it uses only 40 to 50 percent of water compared to the flood irrigation method."

By 2023, the Sehgal Foundation has conducted 1,504 farmer engagement activities, drip irrigated 644 acres of land, and conducted a total of 14,219 demonstrations on various crops through the ADP program. Among farmers implementing the PoP approach in India, there has been a 10-18 percent increase in output, an 88 percent reduced labor input due to the use of machines such as zero tillage and potato planters, an INR 5,000/ha (USD 60) reduction in production costs, and 59 percent and 22 percent increased water savings through sprinklers and laser levelers, respectively.

Implementation of complementary productivity-enhancing solutions has clear potential to improve sustainable productivity growth in smallholder agriculture in India. The PoP approach could be replicated in other regions to gain similar wins in productivity.

Photo: Smithfield Foods

SMITHFIELD FOODS

## Increasing Productivity While Reducing GHG Emissions

As the world's population continues to grow, farmers and food companies are facing a steep challenge: to produce more food with fewer resources while minimizing their impact on the planet. With the global population expected to significantly expand by 2050, it will take a concerted effort to improve efficiency and reduce environmental impacts while still continuing to produce enough food to meet the increasing global need.

Smithfield Foods has been working for more than two decades to address this significant challenge. As one of the world's leading vertically integrated protein companies, Smithfield manages, supports, or works directly with every part of its supply chain, from the farmers who raise hogs and grow the grain that feeds its animals to the drivers who deliver products to store shelves. The company's vertically integrated business model has resulted in extensive research and investments that address some of the greatest sustainability challenges and opportunities facing the protein industry. The results of this research are shared with the company's 3,000 contract farms and 600 company-owned farms globally, allowing them to efficiently manage farm operations and minimize environmental impact.

Smithfield has committed to reducing greenhouse gas (GHG) emissions across its entire U.S. value chain by 30% and achieving carbon-negative status in all company-owned U.S. operations by 2030. Smithfield was the first in its industry to establish a carbon reduction goal covering scope 1, 2 and 3 emissions.

In developing sustainability programs to achieve these goals, Smithfield has become increasingly focused on capturing methane, a potent GHG, from the hog manure on its 400 company-owned farms and 2,100 contract farms in the U.S. Manure is the primary contributor to Smithfield's GHG emissions and represents its greatest opportunity for GHG reduction. Given Smithfield's comprehensive scope 1, 2 and 3 emissions goals, methane capture is a major component of the company's carbon reduction strategy.

While manure on hog farms is highly regulated at the federal and state level, Smithfield Renewables takes manure management a step further. The company is leading the way with voluntary, innovative environmental management practices that reduce emissions by capturing fugitive emissions from on-farm anaerobic lagoons and converting them into clean, low-carbon renewable energy. This allows Smithfield to provide more nutrient-dense, nutritionally important protein to feed a growing population while continuing to reduce its carbon footprint.

Since 2018, Smithfield's company-owned operations have been rapidly adding anaerobic digesters to complement traditional manure management systems on its farms. Anaerobic digesters capture natural emissions from manure and convert them into pipeline-quality, renewable natural gas (RNG).

RNG derived from biogas has the lowest carbon intensity score of all alternative fuels; in fact, it is actually carbon-negative, as it captures significantly more GHG emissions from biomass than are released from its end use in power plants, homes, and businesses. Not only is Smithfield reducing GHG emissions from the farm, the company is replacing conventional fossil fuel with lower-carbon RNG.

As of 2022, Smithfield operates more than 100 digesters–covering over one million hog spaces–and produces more than 800,000 dekatherms of RNG annually. This represents an annual emissions reduction of 367,000 metric tons of carbon dioxide equivalent (MTCO2e) and is the energy equivalent of heating 10,200 homes for one year, taking 79,000 cars off the road, or planting 6.2 million trees.

In the U.S., Smithfield primarily feeds RNG to existing pipelines and grids as a clean, renewable source of energy, while its operations in Mexico heat barns with RNG to reduce energy costs and emissions. Since 2018, Smithfield's Mexico operations have reduced energy consumption from the grid from 161 kWh to 143 kWh for an approximate cost savings of $500,000.

Smithfield's RNG projects represent a substantial financial commitment to continuing to make improvements that will better protect the environment and benefit surrounding communities by reducing methane emissions, providing a diverse income stream for family farmers, and producing clean, low-carbon energy to power homes and businesses. The company is paving the way to a sustainable future by efficiently producing safer, more affordable food for global populations while limiting its carbon footprint, reducing GHG emissions, and producing clean, low-carbon renewable energy.

SOAR FOUNDATION; THE UNIVERSITY OF CALIFORNIA INNOVATIVE GENOMICS INSTITUTE AND GLOBAL METHANE HUB

## Unlocking Research through Innovative Partnerships to Address Methane Emissions

Ahead of COP26, the United States and United Arab Emirates launched the Agricultural Innovation Mission for Climate (AIM4C) with the goal of driving accelerated action in agricultural research and development to advance climate adaptation and mitigation. Since its launch, AIM4C has grown into a coalition of more than 50 governments and over 500 organizational partners who have collectively leveraged $13 billion in funds ahead of COP28 to advance AIM4C's vision of accelerating research into climate-smart action.

A hallmark of this initiative is the AIM4C Innovation Sprints: focused, expedited projects with the goal of driving breakthroughs in agricultural science, financing, and research for the improvement of the world's agri-food systems.

One such project is a partnership between the University of California's Innovative Genomics Institute (IGI) and the Global Methane Hub's Enteric Methane R+D Accelerator. Based out of University of California, Berkeley, with IGI investigators at UC Davis, the IGI leverages world class research talent in genomics and sustainable agriculture to discover and develop innovative approaches to reduce global methane emissions. IGI's project "Engineering the Microbiome with CRISPR to Improve our Climate and Health" deploys genome editing-based strategies on the microbiome in cow rumen to lower methane emissions. The project was recently awarded $70M through the TED Audacious Project, an initiative that encourages the world's greatest changemakers to solve global problems innovatively.

IGI's project focuses on a key component of ruminant methane: the microbiome. Many climate problems directly result from the collective behavior of microbiomes. Human-driven changes to and creation of new environmental microbiomes (e.g., livestock production and agriculture) represent a significant source of global greenhouse gas (GHG) emissions, like methane from livestock animals and farmed soils. These microbiomes account for more than half of global methane, a GHG that has contributed to 30% of global temperature rise since the industrial revolution. Microbiomes in the digestive tracts of animals and in diverse ecosystems (e.g., wetlands, landfills, and waste lagoons) drive the majority of these emissions; livestock alone account for nearly 15% of all human-driven global GHG emissions. The EPA estimates that by 2030, we will not be able to mitigate 91% of the non-CO2 emissions from agriculture, even with full implementation of available technology.

By combining two cutting edge technologies, CRISPR genome editing and genome-resolved metagenomics–the approach needed to edit the genomes of whole communities of bacteria–the IGI team endeavors to create a first-in-class precision microbiome editing platform that will enable safe and scaled manipulation of agricultural microbiomes to reduce or even eliminate methane emissions over a cow's entire lifetime. Methane emissions from cattle come from their unique digestive system and the bacteria in their rumen that help break down grasses and other feed. One of the only established ways to minimize methane emissions is by adding seaweed-derived additives to the cattle's feed. These additives provide immediate, but temporary, reductions in methane emissions from cattle. The IGI team's aim to transform the microbiome of the bacteria in the rumen, however, should provide a methane mitigation intervention that lasts the cow's lifetime.

Critical to that impact is IGI's partnership with the Global Methane Hub's R+D accelerator. The Global Methane Hub is a global philanthropic organization working to find solutions to global methane emissions, including those from agriculture and cattle. The Hub recently launched a $200 million Enteric Fermentation R+D accelerator through AIM for Climate, $35 million of which is funding from the IGI's Audacious Project, providing a unique financial leveraging mechanism to advance IGI's research and complimentary research worldwide. This partnership presents a model that other researchers pursuing breakthrough climate adaptation and mitigation research through agriculture can look to for inspiration, both within and beyond the context of AIM for Climate.

Photo: Tanager

TANAGER

## Addressing the Gender Gaps in Agriculture to Improve Productivity

*Mary Kate Cartmill, John DiGiacomo, Ioana Lungu*

Agricultural productivity for smallholder farmers depends on good agricultural practices, quality inputs, and mechanization, in which women play a vital role.

Globally, among crop, livestock, fishery, and forestry industries, women make up over one-third (38%) of the primary producers in agriculture. That percentage dramatically increases in more rural, low-income regions. In sub-Saharan Africa, for example, women comprise nearly 50% of primary producers. Women also make outsized contributions throughout the food system as processors, retailers, and marketers.

Despite their significant contributions, women remain marginalized within the agricultural sector. Social and gender norms limit women's access to productive assets, agricultural inputs, extension services, and information, as well as limit their contributions to household decision-making. These norms also dictate the type of work women conduct in agriculture, often limiting them to participation in informal, labor-intensive activities in lower-paid and less-profitable value chains.

Tanager is addressing these trends through the Impacting Gender and Nutrition through Innovative Technical Exchange (IGNITE) project, which offers tailored technical assistance to African agricultural institutions to mainstream gender and nutrition in their interventions, systems, and business activities.

Building on a robust body of research in this area, IGNITE has conducted more than 20 gender or nutrition studies with institutions through its learning consortium of Tanager, Laterite, and 60 Decibels. While methodologies have differed by specific report, these studies employ mixed methods, from longitudinal in-person household surveys to phone surveys to focus group discussions and in-depth interviews. The overall goal of these studies is to help institutions make decisions on their gender or nutrition programming and identify successful models of implementation.

One study, for example, led by Laterite, examined how men and women smallholder cassava farmers in Southwest Nigeria benefit from the use of mechanization technologies, such as tractors. The study found these technologies save farmers significant time and labor–but they often benefit men more than women. Mechanization technologies are typically targeted to the roles that men undertake, such as land preparation, planting, and harvesting. For roles that women tend to occupy in this context, either the technology is not readily available, or the process is not mechanizable. In these cases, institutions should consider offering mechanization for activities commonly performed by women to potentially increase their time savings and subsequent gender or nutrition outcomes. Targeting gender roles through social and behavior change (SBC) trainings is another useful approach for addressing underlying social norms that limit women's participation to more time-intensive tasks.

Another IGNITE study examined the gender factors that influence the adoption of best practices in teff-farming households in Amhara, Ethiopia. The study found that 14 percent of women reported limited or no access to agricultural information, compared to just 2.5 percent of men. In another study in Ethiopia–where 78 percent of women and 95 percent of men are involved in wheat-farming activities–women with access to information reported greater involvement in wheat farming, greater knowledge and adoption of best practices, and more decision-making power related to decisions on wheat farming and income. These findings point to the need for institutions to improve women's access to information by implementing strategies to increase training attendance by women or developing SBC campaigns to address barriers that may be limiting their participation.

Gender-related constraints have real consequences for global agricultural productivity. Recent findings indicate there is an estimated 24 percent gap in land productivity between farms of the same size managed by women versus by men. This represents not just a major loss in potential food production, but also consequences for food security and household poverty levels worldwide. Addressing gender-related gaps in agrifood systems would reportedly net a USD 1 trillion increase in global GDP and a corresponding decline in food insecurity by 2 percent, or 45 million people.

## Recommendations

Based on findings from the IGNITE project, as well as Tanager's 30 years of experience implementing gender and social inclusion, women's empowerment, and nutrition-sensitive interventions in the agriculture sector, the following recommendations offer a starting point achieving gender equality and improved development outcomes.

**Recommendation 1: Collect gender-specific data in all projects and programs.** Collecting and analyzing all organizational data through a gender lens uncovers potential gaps in service delivery, programmatic coverage, household-level dynamics, and decision-making that may impact outcomes. Strategically designing research to include women's, men's, and youth voices is a vital first step to exploring gender in agriculture in any project. When collecting data, speaking to both women and men from each household–considering different household compositions–and anticipating how the gender of the enumerator and the way data is collected (i.e., over the phone, time of day) may impact data quality. Conducting a gender analysis at the design stage of any project will also help identify unique gender-related needs and potential programmatic impacts on participants.

**Recommendation 2: Design projects, services, and products with gender in mind.** By applying learnings from Recommendation 1 to inform the design of projects, products, and services, institutions can ensure they are addressing the unique needs of small-scale farmers, which regularly differ for women and men.

**Recommendation 3: Adopt a gender policy to mainstream commitments to gender equality across the institution.** A gender policy is a set of goals, standards, and guidelines through which all departments can orient their gender approaches and set key indicators. Such a policy will ensure that gender is considered systematically and maximizes the potential for increasing women's empowerment, inclusion, and productivity.

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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.

Our vision is that every farmer has access to every proven tool for creating sustainable agricultural productivity growth. The GAP Initiative mobilizes and advocates for 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:

1. Creating outstanding communication resources, especially the annual GAP Report®
2. Convening and attending internationally recognized events
3. Conducting and catalyzing research and data analysis
4. Promoting evidence-based solutions
5. 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.

## GAP INITIATIVE SUPPORTING PARTNERS

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ACDI VOCA — Expanding Opportunities Worldwide

CIP — International Potato Center — A CGIAR Research Center

Farm Foundation

HarvestPlus — Better Crops • Better Nutrition

Heifer International

IFDC — Developing Agriculture from the Ground Up

IICA

The Nature Conservancy — Protecting nature. Preserving life.

NML — New Markets Lab

Purdue University

SAA — Sasakawa Africa Association

Sehgal Foundation

SoAR Foundation

tanager — an ACDI/VOCA affiliate

Water for Food — Robert B. Daugherty Institute, University of Nebraska

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