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GAP REPORT®
GLOBAL AGRICULTURAL PRODUCTIVITY REPORT®

STRENGTHENING THE CLIMATE FOR SUSTAINABLE AGRICULTURAL GROWTH

2021 GAP Report®

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The GAP Initiative and Virginia Tech CALS Global

The Global Agricultural Productivity (GAP) Initiative is central to the mission of CALS Global in the Virginia Tech College of Agriculture and Life Sciences (CALS): *build partnerships, drive thought-leadership, and create opportunities for students and faculty to serve globally.*

In addition to producing this annual assessment of global progress toward productive, sustainable agricultural systems, the GAP Initiative creates opportunities for collaboration and learning between its partners, the university, and stakeholders worldwide.

The GAP Initiative brings together experts from the private sector, NGOs, conservation and nutrition organizations, universities, and global research institutions. Supporting Partners provide financial support and serve on the Leadership Council, offering essential perspectives on critical issues facing agricultural systems worldwide. Consultative Partners contribute their knowledge of agricultural R&D and extension, natural resource conservation, human nutrition, international development, gender equity, and the needs of small-scale farmers.

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KEY MESSAGES: 2021 GAP REPORT®

The 2021 Global Agricultural Productivity Report® (GAP Report®) urges the acceleration of productivity growth at all production scales to meet consumers' needs and address current and future threats to human and environmental well-being.

Productivity growth remains the primary source of agricultural output growth globally. Still, the USDA Economic Research Service's new methodology for calculating total factor productivity (TFP) reveals it is not growing as fast as previously thought.

Globally, TFP grew by an average of 1.36 percent annually (2010 to 2019), well below the Global Agricultural Productivity Index™ target of 1.73 percent. (USDA ERS, 2021)

Middle-income countries, including India, China, Brazil, and the countries of the former USSR, continue to have the most robust TFP growth rates.

Low-income countries, home to many small-scale farmers, have a negative TFP growth rate of -0.31 percent annually.

Nearly all agricultural output growth in low-income countries comes from land-use change, the destruction of forests and grasslands for cultivation and grazing.

Human-caused climate change has slowed global agricultural productivity growth by 21 percent since 1961. In drier regions of Africa and Latin America, climate change has slowed productivity growth by as much as 34 percent. (Ortiz-Bobea et al., 2021)

Maximizing agriculture's climate change mitigation potential is essential for sustainability, yet for most of the world's producers, adapting to climate change and protecting their livelihoods is the most immediate challenge.

Small and large farms can be equally efficient: with access to various productivity-enhancing inputs, agronomic knowledge, and markets, producers of all scales can optimize their productive potential. (Fuglie et al., 2019)

Given its proven effectiveness in boosting productivity and economic growth, investments in public-sector agricultural research and extension need significant increases. (FAO, 2018)

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PRODUCTIVITY IN ACTION

THE AGRICULTURAL PRODUCTIVITY IMPERATIVE

During the next 30 years, the world's population will grow larger and more prosperous. Demand will soar for food and agricultural goods, including meat, dairy, fruits, vegetables, timber, oilseeds for cooking and industrial uses, and biomass for energy, heat, and cooking.

At the same time, the natural resource base and ecosystems are under stress from climate change, soil degradation, and poor water management.

Poverty, food insecurity, and malnutrition remain stubbornly high, condemning hundreds of millions of people to ill health and unfulfilled potential.

Accelerating productivity growth at all scales of production is imperative to meet the needs of consumers and address current and future threats to human and environmental well-being.

The human, economic, and environmental consequences of not meeting productivity targets are profound.

WITHOUT **PRODUCTIVITY GROWTH**

36%
of the world's land is used for agriculture.

Forests and biodiverse areas will be destroyed for planting or pasture.

$2T (USD)
in economic losses and 4 million deaths are attributed to diet-related diseases each year.

Low-income households will not be able to afford fruits and vegetables, complicating their ability to eat a healthy, diverse diet.

90%
of the earth's soils could be degraded by erosion by 2050.

Low-income countries will need to import more agricultural products, leading to higher food prices.

37%
of methane emissions from human-influenced activity come from cattle and other ruminants.

20 million more dairy cattle and buffalo will be needed in India alone to meet domestic demand.

WITHOUT **EFFICIENT IRRIGATION**

40%
of irrigation water is lost due to inefficient irrigation.

Water sources will be depleted, making prime agricultural land unusable.

Citations for pages 6-7. (Food and Agriculture Organization, 2018), (Food and Agriculture Organization, 2019), (World Bank, 2018), (Miller et al., 2016), (Ortiz-Bobea et al., 2021), (Science Daily, 2019), (OECD & FAO, 2019), (Balsom, 2020)

Productivity Growth Is Possible at All Scales

Large-scale, commercially-oriented farms are more likely to have access to the latest innovations and agronomic information. As a result, they have been the most productive. Research proves that small-scale farms in countries such as Kenya, India and Vietnam, can achieve productivity gains similar to large-scale farms in places like Brazil, primarily if they use improved technologies, tools, and services designed for smaller farms. (Fuglie et al., 2019)

Using the latest improvements in precision agriculture and data analytics, in combination with high yielding, herbicide-tolerant crops, a large-scale farmer in BRAZIL can produce soy for the global market without cutting down forests to increase output.

With healthier feed and improved housing, a small-scale dairy farmer selling to local markets in KENYA can increase milk output using fewer animals and generating less methane emissions.

By cultivating mangos with drip irrigation, a farmer in INDIA can harvest a robust crop using less land and water.

Integrating pig, feed crop, and aquaculture production enables an emerging farmer in VIETNAM to sustainably increase output and diversify income sources.

THE CASE FOR **PRODUCTIVITY**

The world's agricultural producers face a daunting challenge: sustainably produce food, feed, fiber, and bioenergy for a growing population while grappling with a rapidly changing climate, a deteriorating natural resource base, uncertain markets, and evolving consumer tastes.

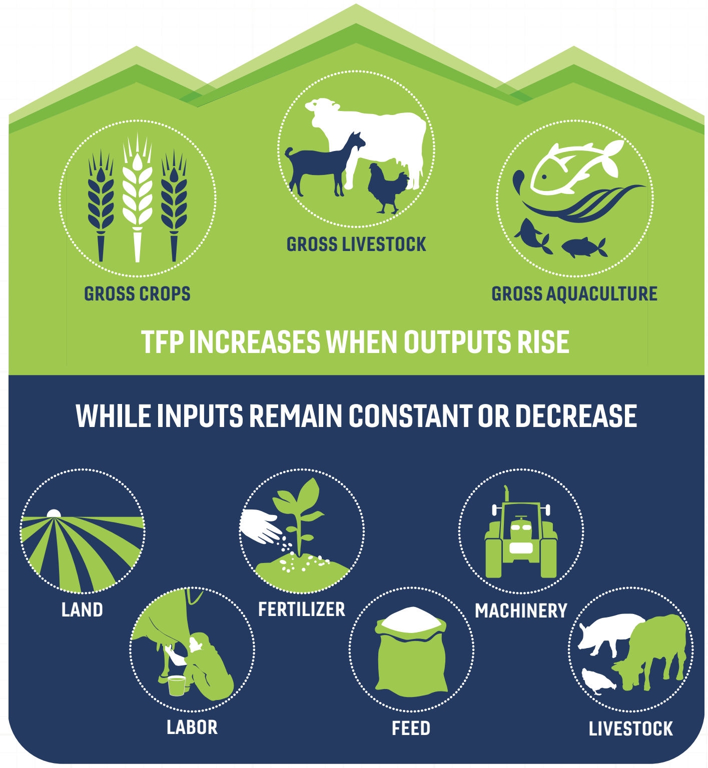
The task is complicated by the COVID-19 pandemic that upended local and global food systems and increased the already staggering number of people struggling with hunger, malnutrition, and poverty.

Accelerating agricultural productivity growth at all scales of production is imperative to meet the needs of consumers and address current and future threats to human and environmental well-being.

What Is Agricultural Productivity?

In agriculture, productivity increases when more agricultural products are produced with the same amount or fewer resources (Figure 1.) Total factor productivity tracks changes in how efficiently agricultural inputs (land, labor, fertilizer, feed, machinery, and livestock) are transformed into outputs (crops, livestock, and aquaculture products.)

Figure 1: Total Factor Productivity (TFP)



Advanced seed varieties, precision mechanization, efficient nutrient- and water-management techniques, improved animal care practices, and attention to ecosystem services such as pollinators and soil health are the building blocks of productivity growth. Technologies and practices that strengthen productivity growth also support resilience for small-scale farmers vulnerable to climate change.

Productivity growth at all scales of production can reduce greenhouse gas (GHG) emissions, minimize agriculture's impact on natural resources, and mitigate climate change.

ARE TOTAL FACTOR PRODUCTIVITY AND YIELD THE SAME THING? NO!

Yield and total factor productivity are ratios of outputs to inputs, but they are not the same, and ***the distinction matters.***

Yield measures output per unit of a single input, for example, the amount of crops harvested on a hectare of land. Yields can increase through productivity growth, but they can also increase by **applying more inputs, called input intensification.** Therefore, **an increase in yield may or may not represent improvements in sustainability.**

Total factor productivity captures the interaction between multiple agricultural inputs and outputs (Figure 1). (Ortiz-Bobea et al., 2021) TFP growth indicates that more farmers generate more crops, livestock, and aquaculture products with the same amount or less land, labor, fertilizer, feed, machinery, and livestock. As a result, TFP is a **powerful metric for evaluating and monitoring the sustainability of agricultural systems.**

Productivity Trends Raise Concerns for Sustainable Growth

Data show that TFP is still the primary driver of agricultural growth. Yet, TFP is growing globally at 1.36 percent (annual average, 2010-2019), less than the GAP Index target of 1.73 percent to sustainably meet the needs of consumers for food, feed, fiber, and bioenergy in 2050 (Figure 2.) Suppose the TFP growth rate remains at current levels. In that case, the "productivity gap" will grow over time, generating higher food prices, lower economic growth, increased food insecurity, and adoption of unsustainable production practices.

The TFP trend for small-scale farmers, many of whom live in low-income countries, is alarming. The 2015 GAP Index reported a TFP growth rate in low-income countries of a robust 1.5 percent. Today, TFP in low-income countries is contracting by an average of 0.31 percent per year. These farmers have minimal access to productivity-enhancing technologies or agronomic knowledge, exacerbating their vulnerability to climate change.

Driving the decline in productivity growth are methodological changes made by USDA ERS in the TFP calculation. A new data series from FAO provides a more comprehensive measure of agricultural capital. It shows that investment in capital goods (machinery, structures, breeding stock, tree stock, etc.) is higher than previously thought.

The data also indicates that the impact of climate change on TFP is accelerating. Strategies to improve productivity must incorporate climate resilience as growers grapple with an increase in the incidence and severity of climate change and weather disruptions. (Jayne et al., 2020)

ECONOMICALLY AND SOCIALLY SUSTAINABLE PRODUCTIVITY GROWTH IN INDIA

India has seen strong TFP and output growth this century. The most recent data shows an average annual TFP growth rate of 2.81 percent and output growth of 3.17 percent (2010-2019.)

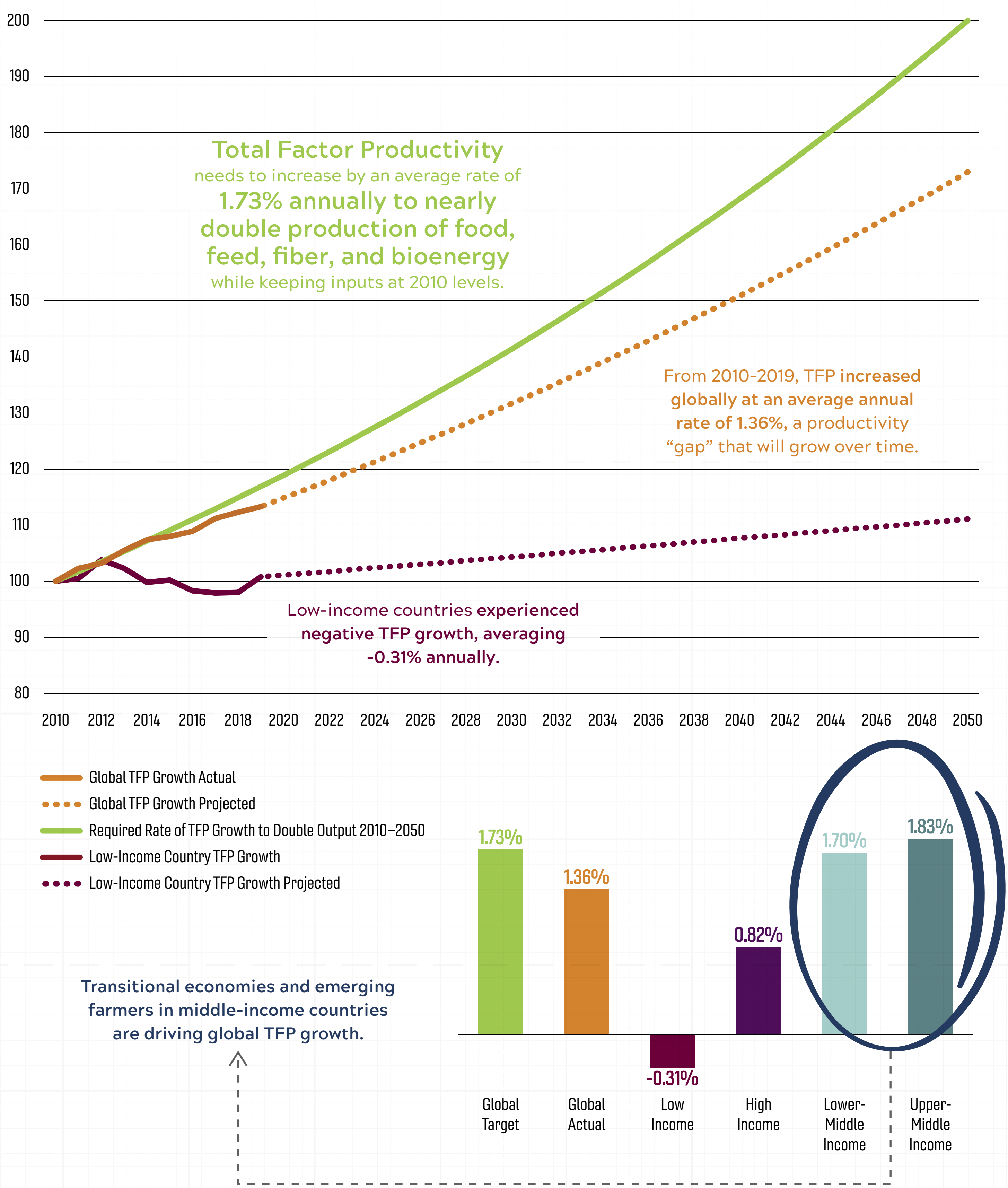
The implications of climate change for India's agricultural sector are profound. By the end of the century, the mean summer temperature in India could increase by five degrees Celsius. This rapidly rising temperature, combined with changes in rainfall patterns, could cut yields for India's major food crops by 10 percent by 2035. (Naresh et al., 2017)

In addition to the challenges for environmental sustainability, India's small-scale farmers face significant obstacles to economic and social sustainability. Of the 147 million landholdings in India, 100 million are less than two hectares in size. (India Ministry of Agriculture, 2020) Family members do the bulk of the farm work because there are not enough off-farm jobs available and mechanization rental or ownership are more expensive than family or hired labor. (Fuglie, 2017)

Not only is this an inefficient use of labor, but it also contributes to high rates of rural poverty and food insecurity. For example, the income from a one-hectare farm, even if it is high-yielding, must meet the needs of as many as 12 people. Nearly 90 percent of farmers farming less than two hectares participate in a government food ration program. (India Ministry of Agriculture, 2020)

Figure 2

2021 GLOBAL AGRICULTURAL PRODUCTIVITY INDEX



Source: USDA Economic Research Service (2021).

THE RESILIENCE OF AGRICULTURAL SYSTEMS TO EXTREME CLIMATE EVENTS: AN ANALYSIS BASED ON TOTAL FACTOR PRODUCTIVITY

By Wei Zhang, Virginia Tech College of Agriculture and Life Sciences, GAP Initiative Faculty Research Fellow, with Jean Paul Chavas, University of Wisconsin-Madison

Climate change affects many dimensions of agricultural production and could threaten regional and global food security and social stability. (Wheeler & von Braun, 2013) Our research will examine the dynamic relationship between extreme climate events and the resilience of farming systems through the lens of TFP growth. Our ultimate goal is to shed light on the design of government programs and potential private-public partnerships for climate adaptation and agricultural sustainability.

Conventionally, TFP growth is viewed as capturing technological progress. In the context of agricultural systems, technological advancement should be interpreted in a broad sense to include efficiency gains from better management practices. For example, planting cover crops reduce soil erosion and could increase soil organic matter and improve soil structure over time. Strategically timed irrigation is an effective mitigation strategy under reduced-water scenarios for agricultural production. (Grant et al., 2017) These practices can boost agricultural productivity and mitigating some of the negative environmental impacts of agricultural production. Thus, TFP growth, when interpreted broadly, can be viewed as one of the indicators of the sustainability of agricultural systems.

Recent work has emphasized the importance of TFP growth for agricultural sustainability and resilience. (Coomes et al., 2019) The resilience of a system generally refers to the system's ability (or capacity) to withstand shocks and recover quickly. Sustainability and resilience are concepts used to assess the long-run health of agricultural systems. Resilience is a necessary (but not sufficient) condition for sustainability. The resilience of agricultural systems to extreme weather shocks and subsequent adaptation is crucial for global food production and security. Our research seeks to understand better the role of TFP growth in this complex relationship through the vital link of agricultural resilience to extreme climate events.

We know very little about the dynamic impact of climate change on agriculture, except for crop yield adjustments to growing season temperature and rainfall. (Chavas & Di Falco, 2017) Dynamic effects are long-lasting, representing the impacts of climate change on the adjustment path of agricultural systems. For example, extreme heat lowers seasonal crop yields leads to the adoption of drip irrigation. Both changes affect TFP, but the latter will change agricultural TFP growth in the long run. Our research will investigate the impacts of extreme climate events on the path of agricultural TFP growth.

Looking ahead, this project represents a crucial step in our research agenda to deepen the understanding of the relationship between TFP growth and agricultural sustainability. Evidence indicates that global agricultural TFP growth is slowing down. Though this pattern varies across countries, degradation of natural capital and associated ecosystem services plays a critical role. (Alston et al., 2020) More research is needed to understand the relationship between TFP growth and agricultural sustainability. (Fuglie et al., 2016)

Wei Zhang is an assistant professor of agricultural and applied economics at Virginia Tech, collaborating with Jean Paul Chavas, professor emeritus in agricultural and applied economics at the University of Wisconsin-Madison. The GAP Initiative funds their research, and findings will be published in the 2022 GAP Report.

Agricultural Ecosystems Strengthen TFP Growth

As climate change tightens its grip on the world's agricultural ecosystems, it is more important than ever to understand the interaction between the environment and productivity growth. The inputs and outputs incorporated in the TFP metric have a "marketable" value, making them easier to measure and estimate. Still, it does not include elements critical to agricultural productivity, including seeds, water, and ecosystem services.

Many of the world's farmers do not purchase **seeds** every year. They use open-pollinated seed varieties, storing the seeds and reusing them for multiple seasons and generations. Some of these indigenous varieties hold genetic secrets to climate change adaptation and mitigation. (See story below.) Nevertheless, it is difficult to calculate the market value of these seeds and incorporate them into the TFP calculation.

Water is equally challenging to value. Eighty percent of agriculture is rainfed, and in most places, the amount and value of irrigation and groundwater used in agricultural production are not measured.

The interaction between agricultural activity and the surrounding plants, water, soil, air, microbes, and animals can create benefits, known as **ecosystem services,** including pollination, erosion prevention, carbon sequestration, soil fertility, air and water quality control, and pest and disease management. Environmental outputs can also impact the productivity, health, and resilience of ecosystems. Some are desirable, such as soil carbon sequestration (see story below); others are undesirable, including GHG emissions, water contamination, and soil degradation.

Total resource productivity (TRP) is a measure that integrates ecosystem services and environmental outputs into TFP. TRP has the potential to be a powerful metric for evaluating and monitoring the productivity *and* sustainability of agricultural systems.

Ecosystem services, water, and seeds are "natural capital" in agricultural production. When combined with innovative technologies and agronomic best practices, they boost and sustain productivity growth and sustainability. (Gaffney et al., 2019) More research is needed to find a reliable way of estimating the cost of environmental inputs and output to be integrated with TFP. (Fuglie et al., 2016)

PARTNER STORY

CONTRIBUTOR: International Potato Center (CIP)

Protecting and researching potato biodiversity in the Andean region

The Andes region is the birthplace of the potato and is home to at least 4,500 types of native tuber cornucopia, including more than 100 wild potato species. Local farmers grow and eat an array of native potatoes that provide relatively high levels of zinc, iron, potassium, vitamin C, and antioxidants and are fundamental to the health of Indigenous communities.

Adaptable and highly productive, the potato has saved millions from hunger. Yet one study has estimated that climate-induced weather extremes could drive 13 wild potato species to extinction by 2055 – and we know that the loss of just one species could be catastrophic. In 2007 one of many unexpected frost events wiped out the entire potato harvest in Peru's Huancavelica region, except for the variety yana. This single variety came between local families and extreme hunger.

The Andes' potato agrobiodiversity remains key to strengthening the resilience of farming communities and is used by scientists to breed nutritious, disease-resistant potato varieties for the world.

This year marks the **CIP's 50th anniversary.** The International Potato Center recognizes biodiversity's fundamental contribution to human and planetary health and works with Andean farmers to maintain potato diversity.

In Potato Park in Cuzco, Peru, six communities have come together to preserve the biodiversity of potatoes. Photo: Sara Fajardo, CIP, 2018

PARTNER STORY

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

Farmer-led irrigation is about more than the farmer

Farmer-led irrigation is not a new concept. For decades, governments and NGOs alike have focused on engaging farmers in implementing irrigated agriculture and its potential to increase local food production and improve livelihoods.

The focus of farmer-led irrigation is on small-scale, local, and contextual solutions to expand or improve irrigation access for farmers. The goal is to improve food security for hundreds of millions of people worldwide without the need to build large, centrally-managed infrastructure projects. Past projects have seen failure due to building infrastructure that does not effectively or cost-efficiently fit the needs of local growers – the ultimate users of irrigation systems. For farmer-led irrigation to work, practitioners need to understand the challenges farmers face and the conditions of the broader entrepreneurial ecosystem that support them.

The **Daugherty Water for Food Global Institute (DWFI)** has been doing extensive work to determine sustainable irrigation solutions for smallholders fueled by local entrepreneurs. If irrigation is implemented in this way, all members of that larger ecosystem make enough money to provide decent livelihoods for the people involved, growers included. Equally important, the ecosystem is sustainable over the long term.

In 2020, an interdisciplinary University of Nebraska team led by DWFI received a three-year, one million dollar grant from the International Fund for Agricultural Development (IFAD) to advance sustainability and resilience around smallholder farmer irrigation in sub-Saharan Africa through entrepreneurial approaches. IFAD, an international financial institution and specialized agency of the United Nations, invests in the prosperity and resilience of rural communities throughout the world. Supporting small-scale agriculture, a proven method of poverty reduction is central to their development model.

PARTNER STORY

CONTRIBUTOR: HarvestPlus

Women entrepreneurship: bringing resources and training to historically disadvantaged and marginalized women farmers

Investments in women-led enterprises and food systems are essential to productivity growth. HarvestPlus is working to support women through business support and the introduction of nutritious and high-value biofortified crops. Supporting women in agriculture is integral to improving the food security, nutrition, and overall well-being of rural communities.

DINAVANCE KYOMUHENDO’S STORY

Dinavance Kyomuhendo, a single mother of five children and a guardian to ten children, has been building her life as a biofortification farmer for the past eight years. She has become an advocate in her Ugandan community. After collaborating with HarvestPlus, Kyomuhendo has worked her way from being without a home and farmland to have a thriving farm business.

Through funding by **USAID, HarvestPlus** has been working to bring Orange Sweet Potatoes (OSP) to Kyomuhendo’s region. Orange Sweet Potatoes are biofortified to have high amounts of Vitamin A, which helps vision, skin, and the immune system. In Sub-Saharan Africa, 40 percent of children under 5 have are vitamin A deficient. Consuming 100g of OSP each day can solve this problem for most children.

After Kyomuhendo’s first year of growing OSP, her entrepreneurial determination led her to start a vine multiplication business. After seeing Kyomuhendo’s efforts, HarvestPlus trained her and provided supplies for her business. In addition to selling vines to her neighbors, Kyomuhendo has become the leading chicken producer in her area by using OSP flour as feed and sells OSP cakes in her town.

A CHALLENGING CLIMATE FOR PRODUCTIVITY GROWTH

Population growth and rising incomes are the primary drivers of demand for food and agricultural products.

The COVID-19 pandemic has made demographic and economic growth projections problematic. Nevertheless, trends continue upward, although at a slightly slower rate.

Despite COVID-19, the OECD-FAO Agricultural Outlook for 2021-2030 predicts that demand will multiply for several essential commodities, especially meat proteins, dairy, and fish. (OECD et al., 2021)

Global consumption of meat protein will grow an estimated **14 percent from 2020 to 2030.**

Dairy production will need to grow by at least **1.7 percent annually to meet demand in 2030.**

Fish consumption is projected to increase by **14.8 percent to 181 million metric tons in 2030.**

Meeting this demand sustainably, especially under the pressure of climate change, is a formidable challenge.

Photo: International Rice Research Institute/CGIAR

New modeling on the impact of climate change on productivity suggests that the GAP Index target of 1.73 percent average annual TFP growth could be the minimum threshold to meet growing demand sustainably. **Human-caused climate change has slowed global agricultural productivity growth by 21 percent** since 1961. (Ortiz-Bobea et al., 2021) That is the equivalent of losing the last seven years of global productivity gains.

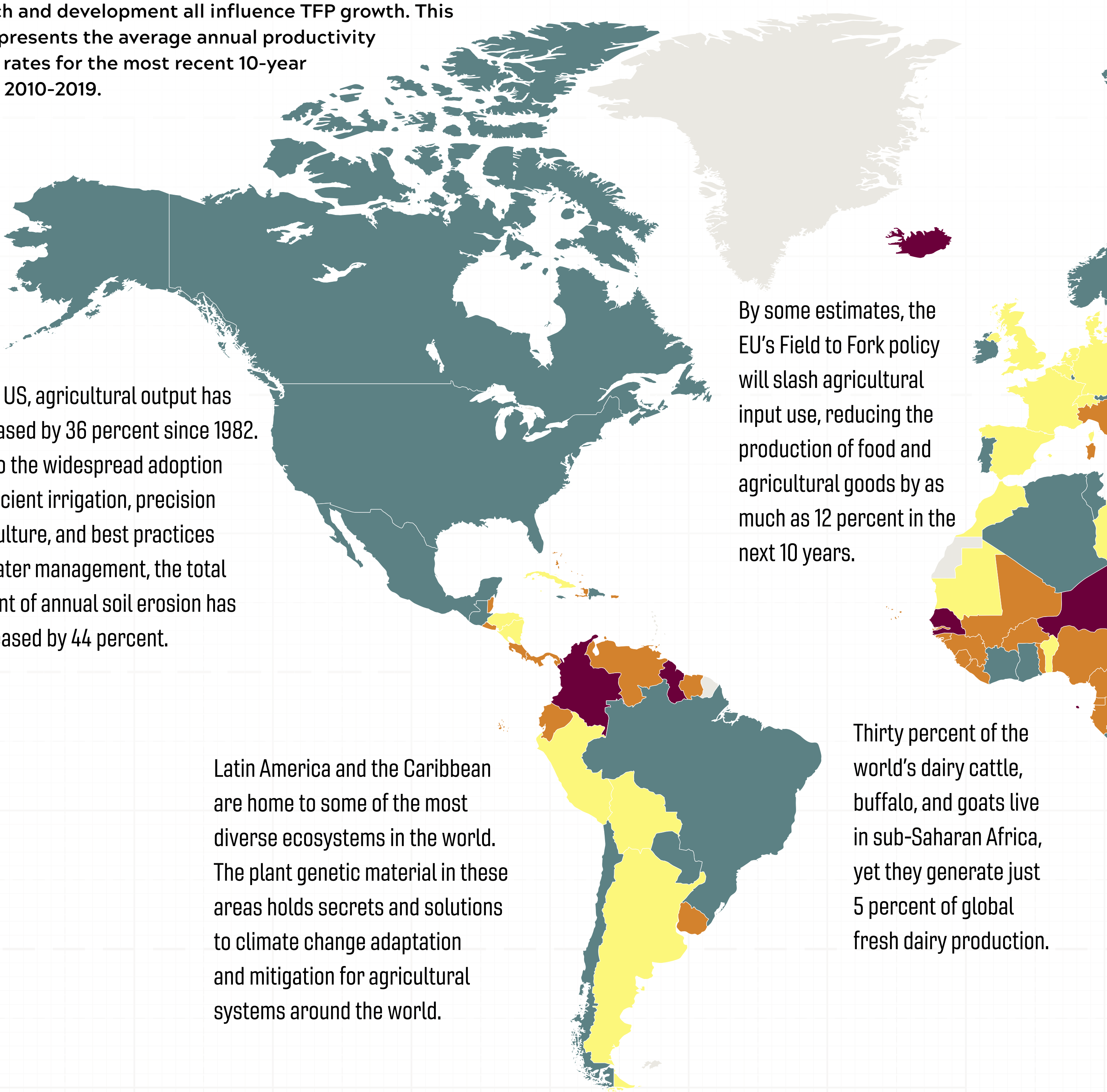
Farmers in low-income countries are the most vulnerable to climate change, given their minimal access to technologies and agronomic knowledge that could help them adapt to the increasingly extreme weather and climate conditions. In drier regions of Africa and Latin America, climate change has slowed productivity growth by as much as 34 percent.

Agricultural productivity growth is becoming more sensitive to climate changes over time. Accelerating investments in agricultural R&D to increase and preserve productivity gains is urgently needed, especially for small-scale farmers.

Figure 3

AGRICULTURAL PRODUCTIVITY AROUND THE WORLD

Productivity growth rates vary significantly by region and country. Climate change, weather events, changes in fiscal policy, market conditions, investments in infrastructure, and agricultural research and development all influence TFP growth. This map represents the average annual productivity growth rates for the most recent 10-year period, 2010-2019.



In the US, agricultural output has increased by 36 percent since 1982. Due to the widespread adoption of efficient irrigation, precision agriculture, and best practices for water management, the total amount of annual soil erosion has decreased by 44 percent.

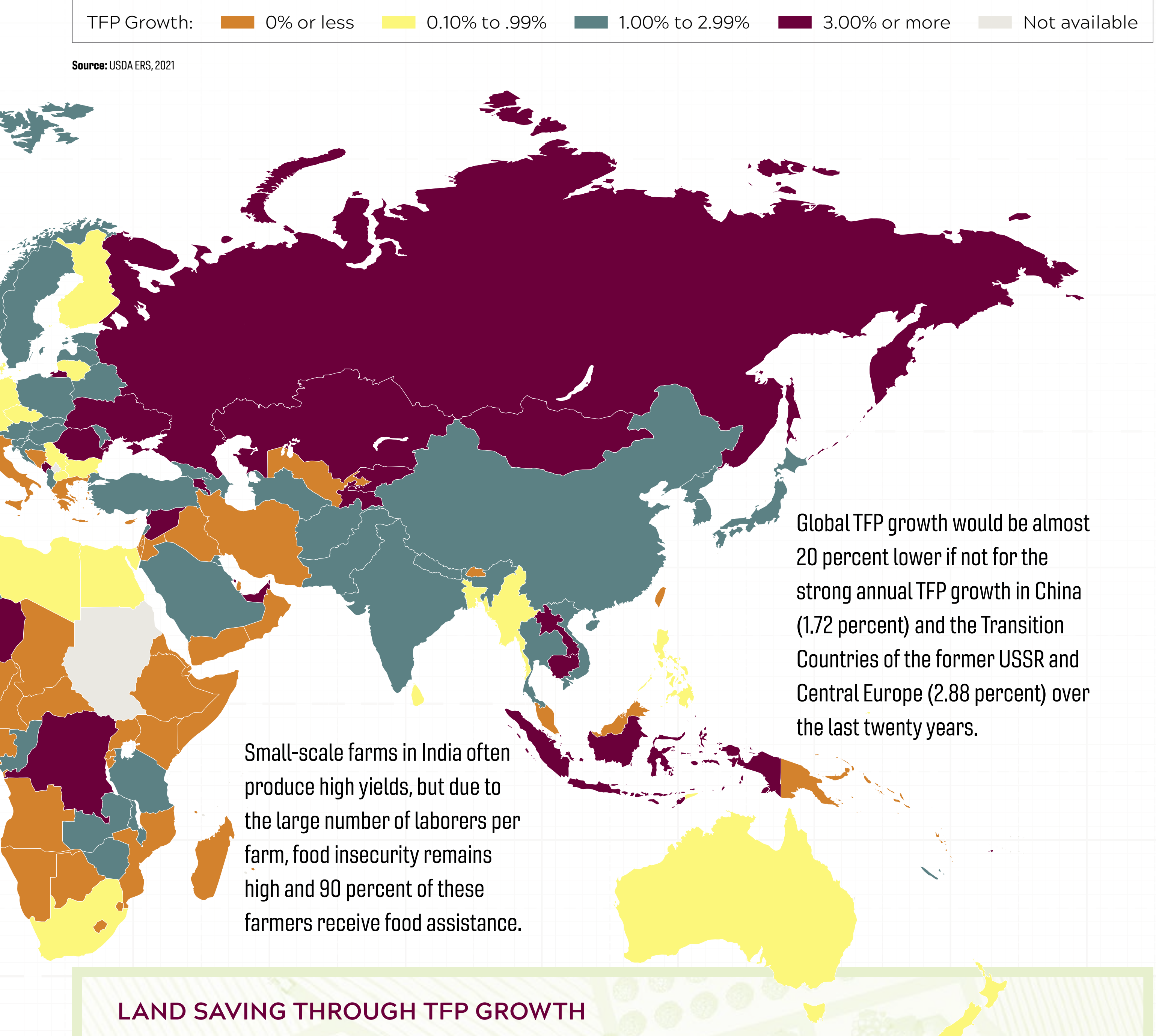
By some estimates, the EU's Field to Fork policy will slash agricultural input use, reducing the production of food and agricultural goods by as much as 12 percent in the next 10 years.

Latin America and the Caribbean are home to some of the most diverse ecosystems in the world. The plant genetic material in these areas holds secrets and solutions to climate change adaptation and mitigation for agricultural systems around the world.

Thirty percent of the world's dairy cattle, buffalo, and goats live in sub-Saharan Africa, yet they generate just 5 percent of global fresh dairy production.

Explore the Interactive TFP Map at GlobalAgriculturalProductivity.org

Average Annual Productivity Growth Rates by Country, 2010–2019



Source: USDA ERS, 2021

Global TFP growth would be almost 20 percent lower if not for the strong annual TFP growth in China (1.72 percent) and the Transition Countries of the former USSR and Central Europe (2.88 percent) over the last twenty years.

Small-scale farms in India often produce high yields, but due to the large number of laborers per farm, food insecurity remains high and 90 percent of these farmers receive food assistance.

LAND SAVING THROUGH TFP GROWTH

Saving land from being put into production is one of the most significant sustainability outcomes of productivity growth. From 2001 to 2010, 18 million hectares of land were converted to crop and livestock production. At the same time, 34 million hectares of global "land savings" were generated by TFP growth in North America. In other words, without TFP growth in the US and Canada during those ten years, 52 million hectares of new land would have been needed to generate the same output of food, feed, fiber, and bioenergy. (Villoria, 2019) Land saving through TFP growth is especially urgent in Africa, where biodiversity and wildlife habitat are being lost at an alarming rate.

PARTNER STORY

CONTRIBUTOR: Smithfield Foods

Regenerative practices in feed production promote sustainable productivity growth in the pork value chain

Smithfield Foods buys substantial amounts of grain every year, more than 10 billion pounds. Grain purchases account for approximately 15-20 percent of Smithfield Foods' total carbon footprint.

In 2013, Smithfield Foods, in collaboration with the **Environmental Defense Fund,** introduced holistic regenerative agriculture solutions throughout its grain supply chain via the **SmithfieldGro** program. SmithfieldGro provides free agronomic advice and tools to farmers to: optimize nutrient absorption, utilize less fertilizer, improve soil health, and reduce water runoff and improve water quality

Smithfield Foods' agronomists travel to grain farms across the US to develop site-specific strategies to support these ends. The company utilizes nitrogen management tools, which develop model water, soil, planting, and field management dynamics to assess opportunities for improvement.

Cover crops grow in a field where corn is about to be planted. Photo: Brandon O'Conner, USDA NRCS.

With this analysis in hand, agronomists might suggest using cover crops or developing curated seed mixes to accommodate soil needs. They assist farmers with sourcing these products, supporting regenerative agriculture efforts at discounted rates.

As of 2018, Smithfield Foods successfully engaged 80 percent of its grain supply chain regarding sustainable fertilizer and soil health practices. These efforts support Smithfield Foods' industry-leading carbon reduction goals: to reduce greenhouse gas emissions by 25 percent by 2025 and to become carbon negative by 2030.

PARTNER STORY

CONTRIBUTOR: The Mosaic Company

4R Technology is a solution for a sustainable future

Over application of fertilizer increases the potential for nutrient losses, including runoff, volatile ammonia emissions, and de-nitrification while also reducing profitability for the farmer. **The Mosaic Company** supports and promotes **4R Nutrient Stewardship, a science-based framework to utilize the R**ight nutrient source, at the **R**ight rate, at the **R**ight time, and in the **R**ight place.

By educating farmers on best management practices for fertilizer use, more food is grown with fewer resources. Investing in fertilizer technology allows for the most effective and efficient utilization of nutrients. Incremental adoption of 4R practices increases crop yields and profitability while minimizing runoff, ammonification, and de-nitrification that are detrimental to the environment.

Since 2012, 100 farmers and retailers have been recognized as 4R Advocates by implementing and sharing 4R principles impacting over 246,000 acres across 25 states in the US.

Using soil testing to understand the distribution of nutrients in a field allows a farmer to apply fertilizer at the right amount and in the correct areas. They are incorporating 4R methods that allowed this Illinois farmer to **decrease costs per acre between $16.49 and $25.31,** while reducing greenhouse gas emissions (CO_2E) by 34.7 percent from 9.4 CO_2E per bushel to 6.14 CO_2E per bushel.

Making 4R innovation accessible for producers is beneficial for everyone. **Producers spend less and make more money while also being good stewards of the land.**

The Benefits of Sustainable Agricultural Productivity Growth

Global initiatives such as the UN Food Systems Summit seek to make agricultural systems more sustainable and resilient. For all of the ideas and excitement created by these endeavors, the fact remains that ***nothing has transformed agriculture more than productivity growth.***

At the start of the twentieth century, producers opened up new land for cultivation and grazing to increase their output. Then in the 1960s, the Green Revolution gave millions of farmers access to effective pesticides, fertilizer, and irrigation, sharply increasing output and preventing mass starvation.

Over time, improved technologies and practices enabled producers to use their land and inputs more efficiently. By the 1990s, global agricultural productivity growth was the primary driver of global agricultural output growth (Figure 4.)

For the past 60 years, agricultural productivity has been driven by an economy-wide structural transformation in industrialized countries (Figure 5.) (Jayne et al., 2020)

A consistent flow of improved machinery, seeds, irrigation, crop nutrient and protection products, animal genetics and feed, and agronomic knowledge enabled producers to optimize their productivity, increasing their output using less land and fewer inputs per hectare.

Workers left the farm for employment in other industries, supporting growth in the manufacturing and service sectors and the knowledge economy. Well-functioning markets for agricultural inputs and output incentivized producers to invest in their operations. Productivity gains at the farm level benefited consumers with a reduction of real agricultural prices. (Fuglie et al., 2012)

TFP — Gross amount of crop, livestock, and aquaculture products produced per inputs of labor, materials, and capital.

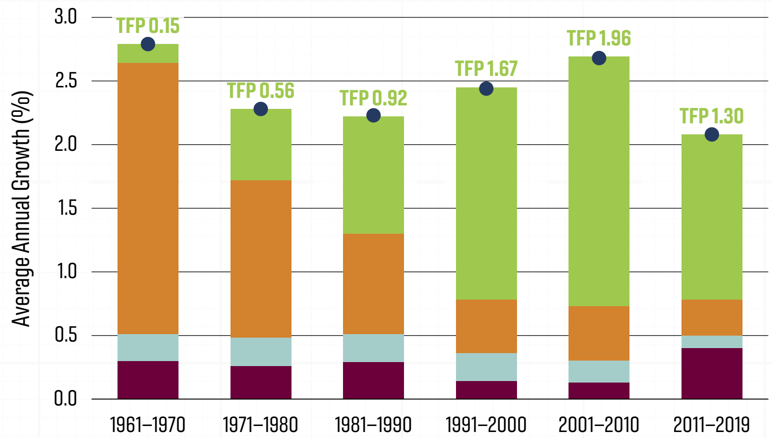
Input Intensification — Gross amount of labor, materials, and capital used per hectare of land.

Irrigation Extension — Extension of irrigation to agricultural land.

Land Expansion — Extending agriculture to previously forested areas or grasslands.

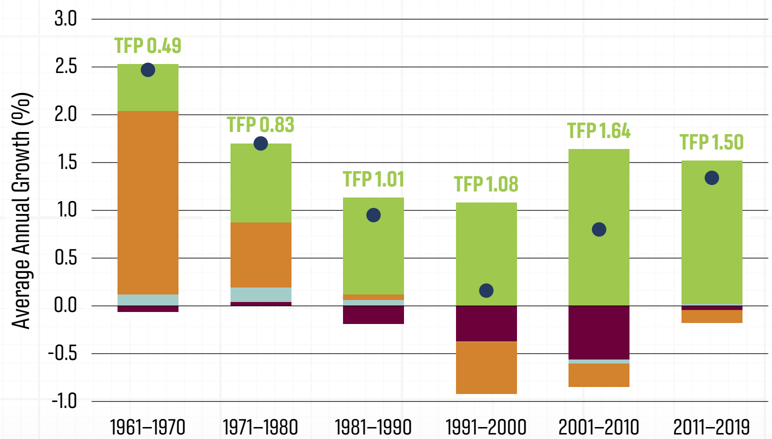
Output Growth — The change in the gross amount of crops, livestock and aquaculture products produced.

Figure 4: Global Sources of Agricultural Growth, 1961–2019



Source: USDA ERS, 2021.

Figure 5: Sources of Agricultural Growth: **Industrialized Countries,** 1961–2019



Source: USDA ERS, 2021.

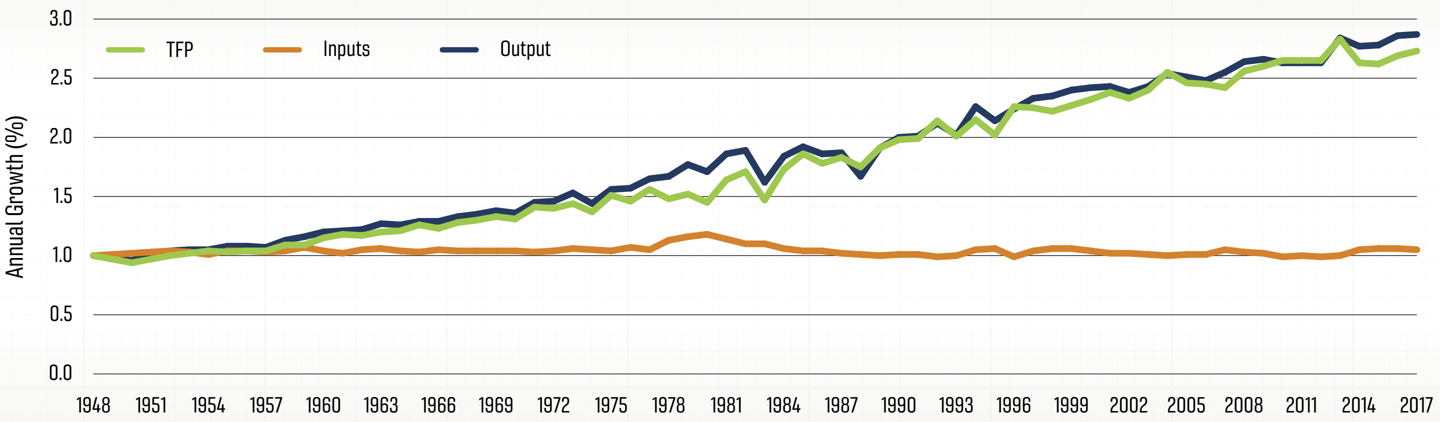
US AGRICULTURAL PRODUCTIVITY BENEFITS CONSUMERS

The **United States** is the clearest example of structural transformation driving productivity growth. **TFP has been the primary source of US agricultural growth for decades.** Agricultural output in 2017 is nearly three times what it was in 1948. At the same time, input use grew by only 0.07 percent annually, due mainly to increasing labor productivity. As the adoption of advanced mechanization soared, farms employed less agricultural labor. Today, less than 2 percent of the US population is actively involved in agricultural production (Figure 6.)

US consumers have benefited from sustained and robust productivity growth in the form of low food prices. In 2020, US consumers spent just 8.6 percent of their disposable personal income on food, sharply declining from 2019.

COVID lockdowns and social distancing protocols meant Americans had more disposable income. At-home food consumption rose as families spent months confined at home, cooking for themselves. Conversely, the amount of food consumed away from home declined due to restaurants, universities, schools, and other institutions being closed temporarily or permanently.

Figure 6: U.S. Agricultural Output, Inputs, and Total Factor Productivity, 1948–2017



Source: USDA ERS, 2021.

CLIMATE CHANGE AND EXTREME WEATHER EVENTS THREATEN CROP YIELDS AND TPF GROWTH IN THE US

US farmers enjoy a steady pipeline of innovation and agronomic knowledge, a bulwark against the worst impacts of rising temperatures and water scarcity. A more significant threat comes from the increasing frequency and intensity of extreme weather events attributed to changing climate patterns.

Researchers at USDA ERS modeled a climate-change scenario with an average temperature increase of 2 degrees Celsius and a 2.5 cm decrease in average annual precipitation. (Ling Wang et al., 2019) The impact on TFP varies across the country. Louisiana, Mississippi, Missouri, Florida, North Dakota, and Oklahoma would be hit hard by changes in temperature and rainfall.

Figure 7: Percentage Change in US Field Crop Production, Averaged Across Climate Scenarios, 2020–2080

	2020	2040	2060	2080
Barley	-1.90%	-0.60%	-3.50%	1.00%
Corn	-8.10%	-8.70%	-13.80%	-16.20%
Cotton	-7.90%	-6.10%	-5.60%	-5.90%
Hay	-4.00%	-0.60%	2.70%	4.20%
Oats	-8.70%	-10.70%	-16.10%	-20.80%
Rice	-2.20%	-2.50%	-4.20%	-6.10%
Silage	-6.90%	-9.50%	-13.10%	-14.40%
Sorghum	-15.10%	-5.40%	-14.00%	-17.00%
Soybeans	-8.10%	-8.80%	-11.90%	-14.30%
Wheat	-2.80%	1.30%	5.60%	11.60%

Note: Adapting to climate change is essential for row crop producers to meet domestic and global demand. Percent change in production for the 2020 timeframe are calculated as average conditions across projected years 2011–2030, those for 2040 are averaged across 2031–2050, those for 2060 are averaged across 2051–2070, and those for 2080 are averaged across 2071–2090. Averages are compared to the "reference" period of 2001–2008.

Source: USDA ERS, 2017.

PARTNER STORY

CONTRIBUTOR: Bayer Crop Science

Agriculture offers climate change solutions

Agriculture is the second-largest contributor to global greenhouse gas (GHG) emissions worldwide, accounting for one-fourth of carbon emissions. Bayer Crop Science is developing carbon sequestration incentives for farmers and promoting climate-resilient food systems to address this problem.

Bayer supports carbon sequestration practices through conservation tillage, cover crops, crop genetics, and precision technology. Guided by sustainable intensification, Bayer started the **Carbon Program** to tackle supply-chain-based carbon emissions by rewarding farmers for capturing carbon. The initiative launched in the 2020-21 growing season, with 1,200 farmers in Brazil and the United States representing 45,000 acres.

Enhanced crop genetics have vast potential for reducing carbon emissions. Rice, a staple food for more than 3.5 billion people, is an excellent example of how combining improved technologies and ecosystem services can increase rice output while reducing environmental impacts. Rice production accounts for 9 percent of total methane emissions. Rice varieties planted into dry soil minimize methane emissions. Improving the ability of crop varieties to use nitrogen efficiently and increasing soil microbial mineralization of nitrogen can also decrease supply chain emissions produced by fertilizers.

For corn, a staple crop consumed at 1 billion tons annually, enhanced crop varieties contribute significantly to resilience. Bayer has been developing a short-stature variety of corn, which is more resilient in extreme weather patterns and produces higher yields. Drought-resistant and -tolerant crop varieties will become increasingly important as water scarcity grows.

With improved technology, crop genetics, and agronomic practices, agriculture can reduce its carbon footprint. Giving farmers the resources and incentives to invest in climate change solutions can contribute to a more productive, resilient future.

Cover crops capture soil carbon, reducing the environmental impact of agriculture and increasing the productivity and resilience of the soils. Photo: Garrett Duyck, NRCS, 2016

Austrian agricultural landscape. Photo: Billy Wilson, 2019

TFP GROWTH IN EUROPE OUTPACES AGRICULTURAL OUTPUT GROWTH

Productivity growth can yield different outcomes.In the US, TFP growth has enabled American farmers to increase the output of safe, affordable food sold to consumers worldwide (Figure 6.)

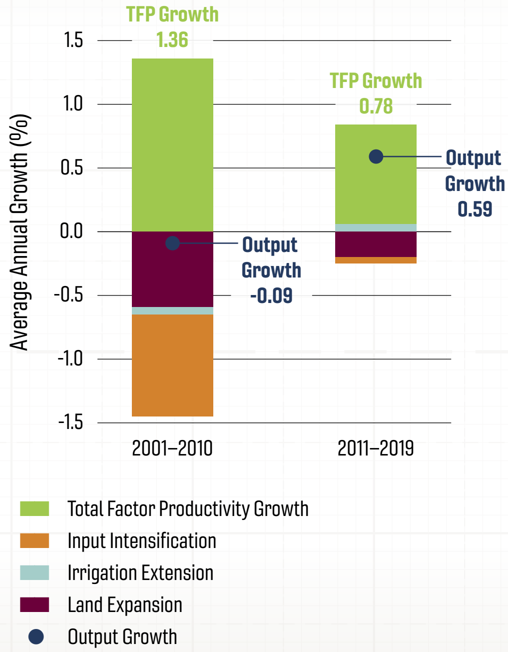
By contrast, agricultural productivity in the **European Union** has consistently outpaced the growth rates for crop, livestock, and aquaculture production (Figure 8.) In the 2000s, TFP grew by a healthy 1.36 percent annually, but there was negative agricultural output growth. Farmers took land and other inputs out of production, with the goal of increasing sustainability and preserving the natural resource base.

The **Farm to Fork policy** currently being debated by the EU focuses on the amount and type of inputs used in agricultural production. If implemented, the policy would reduce the use of fertilizer (20 percent), pesticides (50 percent), antimicrobials for livestock (50 percent), and agricultural land (10 percent) in a single decade (2020 to 2030). (Beckman et al., 2021)

According to USDA ERS, **agricultural output In the EU could decline by 12 percent if these targets are met.** (Beckman et al., 2021) If the world were to adopt similar targets for reducing agricultural inputs, **global agricultural output would decrease by 11 percent.**

Reducing agricultural inputs from production may not be sufficient to achieve the EU's sustainability goals, and it threatens Europe's standing as a global breadbasket. The example of the US is that a focus on productivity growth – using agricultural inputs wisely and efficiently – can enhance sustainability while feeding the world. (Fuglie & Hitaj, 2019)

Figure 8: Grow Rates for TFP, Inputs, and Output in the European Union, 2001–10 and 2011–19



Source: USDA ERS, 2021

CHINA, TRANSITION COUNTRIES, AND EMERGING FARMERS DRIVE GLOBAL TFP GROWTH IN THE TWENTY-FIRST CENTURY

In the past 20 years, China and the Transition Countries (former USSR and Central Europe) have contributed significantly to global TFP growth (Figure 9.)

In China, TFP growth was under 1 percent in the 1970s. Transition Countries were experiencing negative TFP growth as recently as the 1990s.

It is encouraging to see that market-driven policy changes have sparked a TFP transformation in these countries. Yet history shows that these reforms have a shelf life. Once these changes are integrated into the agricultural sector, TFP growth settles down.

China is a case in point. China's TFP growth averaged 2.48 percent from 2001 to 2010, falling to 1.61 percent from 2011-2019. The next challenge for countries is maintaining a steady rate of growth through continued policy improvements and investments in agricultural R&D.

Sub-Saharan Africa is a cautionary tale in this regard. Policy reforms in the 1980s and 1990s generated respectable TFP growth, but with minimal investments in agricultural R&D, the region has been unable to sustain or improve TFP growth. The most recent data show that the region is experiencing negative TFP growth (Figure 10.)

Figure 9: Impact of China and Transition Countries on Global TFP Growth, 2001–2019

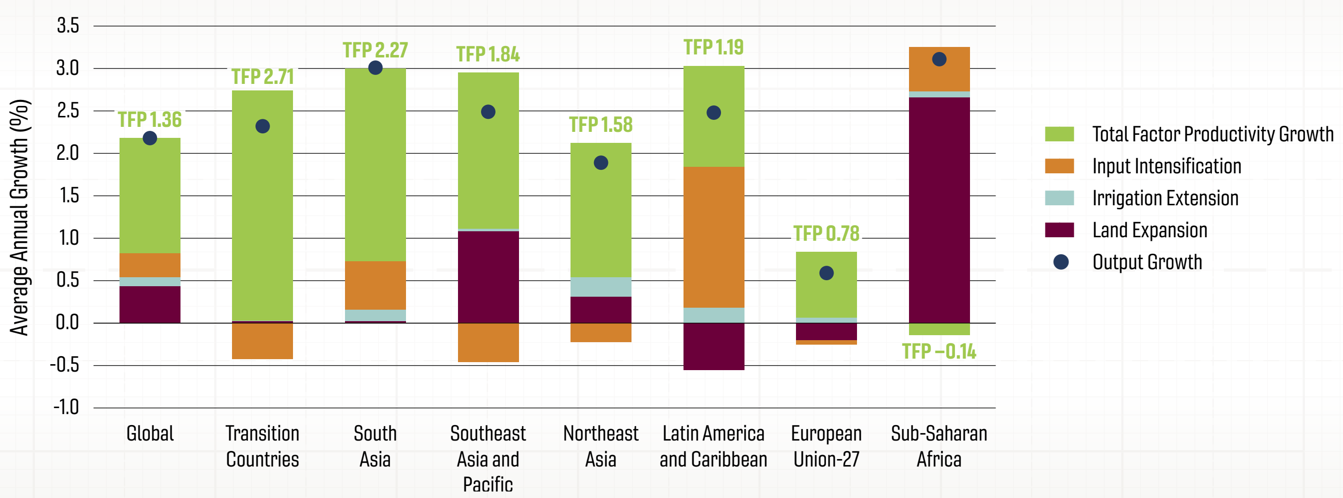
	TFP Growth
Global	1.37
China	1.72
Transition Countries	2.88
Global without China & Transition Countries	1.11

Note: Transiton countries are states of the former USSR and Eastern Block.

Source: USDA ERS, 2021.

Regions that have invested in the success of **emerging farmers** (market-oriented, cultivating five to 20 hectares) have made significant strides in TFP growth, including South Asia and Southeast Asia. Sub-Saharan Africa has a small but active population of emerging farmers. They have the most potential for productivity growth but urgently need access to a variety of improved technologies and agronomic information.

Figure 10: Sources of Agricultural Growth: **Key Regions**, 2011–2019



Source: USDA ERS, 2021

PARTNER STORY

CONTRIBUTOR: Corteva Agriscience

Improving productivity and incomes of emerging farmers in Zambia

Ensuring we can feed the world's growing population in the years to come requires collaboration. Key to that is public-private-producer partnerships, which support agricultural development, gender equity, and nutritious food systems.

Partners agree to share the risk, responsibilities, and benefits of their joint investments to increase agricultural productivity and sustainability, improving the lives of producers and rural communities.

In Zambia, **Corteva Agriscience** is embarking on an initiative to enrich lives and catalyze the growth of the agriculture sector with public and private partners through the **Zambia Emerging Farmers Partnership** with the **US Agency for International Development (USAID).**

The project aims to increase the productivity and incomes of 10,000 emerging farmers who cultivate

Zambian farmers show off a healthy maize crop.
Photo: Ann Steensland, 2016

20 to 60 hectares of land. Together with the USAID, **John Deere,** and **Global Communities,** Corteva provides training on sustainable farming practices, increasing access to technologies and capital, and developing market linkages.

Through this unique collaboration, agronomists from Corteva are working directly with emerging farmers to increase the adoption of improved agricultural technologies such as hybrid seeds and enhance their farming practices.

The partnership will leverage more than $37 million (US) in loans for inputs and equipment. More than 50,000 hectares of crops will be planted using climate-adaptive seeds and other sustainable technologies.

PARTNER STORY

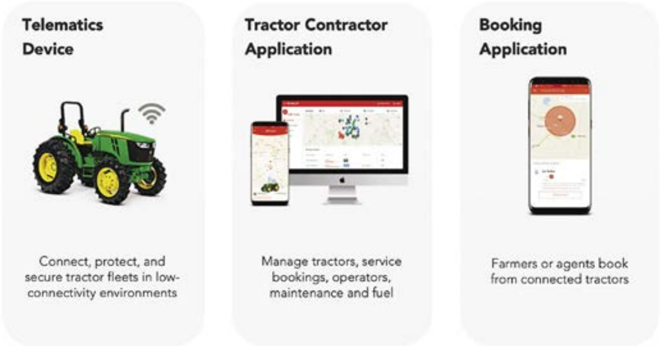
CONTRIBUTOR: John Deere and Hello Tractor

COVID-19 spurs rapid innovation in African agriculture through John Deere and Hello Tractor collaboration

Globally there is an average of 200 tractors for every 100 square kilometers of arable land. With only eight tractors per 100 square kilometers of arable land, farmers in sub-Saharan African struggle to increase their productivity, threatening their livelihoods and food security.

The COVID-19 pandemic has further intensified the need for agricultural mechanization, shrinking local labor markets, migrant and rural labor restrictions essential for farming, and negative impacts on overall food supply chains.

To address this need, **John Deere** is leveraging **Hello Tractor**'s internet-based platform to increase productivity by unlocking pent-up demand for mechanization services. The companies are launching the innovative **Pay As You Go (PAYG) tractor financing**



model for tractor ownership across Kenya, Côte d'Ivoire, Tanzania, and Nigeria. Hello Tractor has partnered with Mastercard to unlock additional value for farmers and John Deere equipment owners by expanding their banking and payments infrastructure access.

John Deere's work with Mastercard and Hello Tractor will not only make mechanization and financing more accessible to smallholder farmers across emerging markets, but it will also contribute significantly to a more sustainable and secure global food system.

AN ENABLING ENVIRONMENT FOR PRODUCTIVITY GROWTH

Sustainable productivity growth is not just about how and which foods are produced. The escalating risk and uncertainty of climate change, market volatility, population trends, and shifting consumer preferences are reshaping agricultural systems worldwide. There are no one-size-fits-all solutions given such a broad set of environmental, economic, and social challenges.

Public investments in foundational agricultural research and extension services are the building blocks of productivity. (Fuglie et al., 2012) Productivity-enhancing innovations and information need to be tailored to meet the needs of producers, be they small-scale aquaculture producers in Indonesia or large-scale canola growers in Canada. (Fuglie et al., 2019)

Innovative inputs alone are insufficient to address the interwoven environmental, economic, and social uncertainties that hinder agricultural systems from reaching their potential. Innovations need to be accompanied by attention to ecosystem services and investment in human and social capital: improvements in education, healthcare, and racial and gender equality. (Carter, 2020)

Reliable access to stable, well-managed markets and financial systems incentivize growers to make sustained and sustainable investments in their operations. Risk management tools, such as weather index insurance and social protection programs, reduce the shock of a lost harvest or fluctuating output and input prices.

Producers cannot accommodate growing consumer demand by simply producing more food. Food system sustainability can only be secured by a sizable decrease in post-harvest loss and food waste.

Effective public policies and investments improve the quality and access to agronomic knowledge and best management practices and increase the resilience of food systems and the livelihoods of the people who depend on them.

This chapter describes these goals, accompanied by stories from the GAP Initiative's Consultative Partners showing how policies, investments, and innovations strengthen the climate for sustainable agricultural growth and improve the lives and livelihoods of producers and consumers.

USDA LAUNCHES THE COALITION FOR SUSTAINABLE PRODUCTIVITY GROWTH

In preparation for the UN Food Systems Summit, USDA established the Coalition for Sustainable Productivity Growth for Food Security and Resource Conservation. The goal is to accelerate the transition to more sustainable food systems through productivity growth that optimizes agricultural sustainability across social, economic, and environmental dimensions. Coalition members will include countries, farmer and producer groups, agribusinesses, NGOs, civil society groups, youth organizations, UN agencies, universities, think tanks, and research institutions. The SPG Coalition will advance a holistic approach to productivity growth that considers impacts and tradeoffs among multiple objectives. Members will be responsible for implementing actions, tracking progress, and reporting on achievements and lessons learned.

Deputy Secretary of Agriculture Jewel Bronaugh announced the creation of the Coalition for Sustainable Productivit Growth in conjunction with the UN Food Systems Summit. Photo: USDA

SIX KEY STRATEGIES TO **ACCELERATE PRODUCTIVITY GROWTH**

STRATEGY	PRODUCTIVITY GROWTH	TRANSFORMATION
INVEST IN R&D AND EXTENSION	In low- and middle-income countries, every $1 invested in public R&D is returned ten-fold in the form of greater food abundance, lower food prices, reductions in hunger and poverty, and a smaller environmental footprint for agriculture. (Alston et al., 2020)	ADAPT TO CLIMATE CHANGE
EMBRACE SCIENCE	Science-based and information technologies and practices give producers the tools to plan for, respond to, and recover from pest and disease outbreaks, extreme weather events, and sudden market fluctuations.	LESS RISK, MORE RESILIENCE
IMPROVE INFRASTRUCTURE	Efficient transportation, information, and finance infrastructures provide producers affordable and equitable access to input and output markets and facilitate sustainable economic growth.	ECONOMIC GROWTH

STRATEGY	PRODUCTIVITY GROWTH	TRANSFORMATION
CULTIVATE PARTNERSHIPS	Public-private-producer partnerships facilitate the transfer of environmentally and socially relevant technology and knowledge to producers.	EMPOWERED PRODUCERS
EXPAND TRADE	Improving the systems and services that support the global trade of fruits and vegetables would generate income for producers and increase the quality and variety of nutritious foods available to consumers. (Miller et al., 2016)	SAFE, NUTRITIOUS, AND AFFORDABLE FOOD
REDUCE 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.	HEALTHY ECOSYSTEMS

Invest in Publically-Funded Agricultural R&D and Extension Systems

Publicly-funded agricultural R&D and extension programs are the principal drivers of agricultural productivity growth. Along with the private sector and collaborative research, public R&D plays an essential role in fostering agricultural innovation. Innovations, technologies, and practices developed through publicly-funded agricultural research help producers worldwide remain competitive by increasing the productivity and sustainability of production, reducing loss and waste in the value chain, and enabling them to adapt to, and even mitigate, climate change. Consumers of agricultural products benefit from the lower, more stable prices and increased access to safe, nutritious food resulting from these investments.

PARTNER STORY

CONTRIBUTOR: Virginia Tech College of Agriculture and Life Sciences

Funding agricultural research and development to spark critical, needed innovation

A four-wheeled robot roams the diverse terrain of a cow pasture as a drone flies overhead the herd, providing almost real-time modeling and analysis.

Using the data provided from the drone and animal and environmental sensors, the robot performs management tasks, demonstrating the capabilities of an integrated suite of technologies to monitor pollutant hotspots, soil and water characteristics, and cattle movement in pastures.

The researchers doing this work aim to build a suite of affordable, small-scale technologies for use on small- and medium-sized livestock operations to facilitate meaningful improvements in rural land management and agricultural water quality, and ultimately a more resilient agricultural landscape. Through the improved capacity to study and understand the relationships among cattle, soil, forage, and water in pasture systems, the research can help design management practices to minimize the runoff of harmful pollutants into sensitive waterways.

This is the type of critical innovation needed to build productive, sustainable food systems. But research like this is not possible without investment. This research was one of 31 total grants funded by **Virginia Tech's College of Agriculture and Life Sciences.** Twenty-eight of the grants were awarded to affiliated faculty in the Center for Advanced Innovation in Agriculture (CAIA).

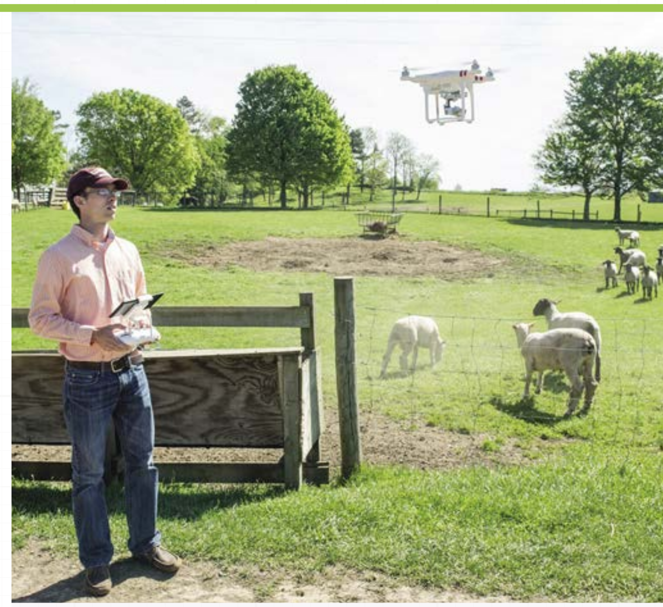


Photo: Virginia Tech

The recently formed center in the college is a catalyst for research that spans disciplines to advance technologies and enhance decisions for expanding agricultural and food systems. CAIA-affiliated projects are composed of teams across agriculture and life sciences academic units, data analytics, and engineering, including faculty from other colleges, to tackle the significant challenges and future opportunities in agriculture and food systems.

Embrace Science- and Information-Based Technologies

Innovations such as drought-tolerant seeds, data analytics, veterinary medicine, mobile phone market platforms, and nutrient management techniques must be available, scalable, and affordable for all farmers. Science-based and information technologies help producers manage the ever-present risks in agriculture while improving sustainability and competitiveness.

Advanced plant breeding through biotechnology and the use of naturally occurring microbials enhances drought tolerance and yields, while disease management practices keep livestock healthy and productive. Efficient irrigation and cultivation technologies improve water productivity and reduce labor burdens, particularly for women and small-scale farmers, enabling them to increase their output and profitability.

Innovative storage and cold chain technologies ensure that more agricultural products reach markets rather than landfills. Information technology allows farmers to access vital information on market prices, weather, pests, soil health, and precision agriculture, and data management tools help producers reduce costs and conserve scarce resources. New bio-innovation is building a bio-economy with broad benefits for the environment and society.

PARTNER STORY

CONTRIBUTOR: Purdue Center for Global Food Security

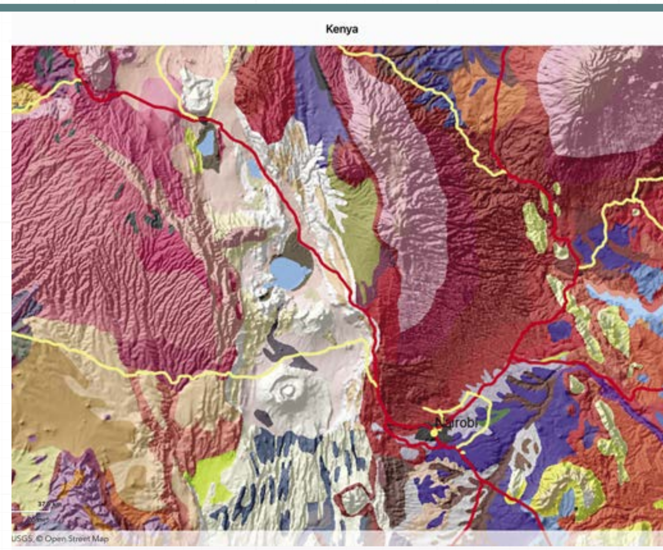
Making soil maps for African development

Agriculture depends on healthy soils to produce food, feed, fiber, and fuel. Recent advances in procedures for making soil maps and soil data visualization make it possible to deliver soil information directly to farmers in the field via mobile electronic devices.

By understanding their soils, farmers can better choose crops to grow and the soil's limitations. If good soil maps are available, you can obtain information about soil properties without physically visiting an area.

There are not as many soil maps available for Africa as for some other parts of the world, but the situation has improved significantly during the past decade.

Much of Purdue's work focuses on the visualization and delivery of soil information. Soil Explorer, a soil map delivery tool developed at Purdue University, is a free mobile app for iPhone/iPad and Android devices and a web page. The US is the primary focus of the project. Maps for other countries, including Kenya and Peru, are now available.



Purdue has successfully tested Soil Explorer as a delivery tool for digitized soil maps in rural western Kenya. Photo: Purdue Center for Global Food Security

Improve Infrastructure for Transportation, Information, and Finance

Infrastructures for transportation, electricity, banking, and communications facilitate the dissemination of agricultural inputs, outputs, technology, services, and agronomic knowledge. Without this infrastructure, small-scale farmers have limited access to the things they need to increase their productivity sustainably. Nor do they have access to markets where they can sell their products.

Farmers make 78 percent of the on-farm agricultural investments. Without efficient and affordable infrastructure, they have little opportunity or incentive to invest.

Infrastructures are essential public goods benefiting all citizens and are the primary responsibility of government. Sadly, the countries that most need to develop their infrastructure do not have the resources available. As a result, there is a $1 trillion (USD) gap between current and needed investment for infrastructure in low- and middle-income countries. (Runde et al., 2016)

The private sector, international development agencies, and foundations have vital roles in bridging the investment gap. Coordinating their efforts with local communities is the most effective way of securing a productive, sustainable agricultural future.

PARTNER STORY

CONTRIBUTOR: International Institute for Cooperation on Agriculture (IICA)

Digital technology for family farmers in Latin America

In recent decades, family farming (FF) has demonstrated that, with support from well-coordinated policies on productive inclusion, it has the capacity to generate employment and income for rural dwellers, and to become a pillar for the development of rural territories. These capabilities are further bolstered under associative models, which include different types of cooperative undertakings. These models have played a key role in increasing the quality and quantity of family farming products, in bolstering the capacity of family farming to access markets, and in increasing equal access to the benefits of agri-food activities.

New telecommunication tools, information technologies and digital tools for managing production and marketing processes afford a new opportunity to strengthen the management of FF cooperatives. The active involvement of agricultural and other types of cooperative undertakings is necessary in order to fully capitalize on this opportunity.

To provide these services, cooperatives can set up management units for this purpose or collaborate with other cooperatives of professionals, specialists and transporters, or packaging, financial, risk management and insurance cooperatives. This is not a novel idea, given that these service management units already exist. However, we must strengthen these units and improve access to new technologies. To this end, it is important to analyze agricultural and other types of cooperative undertakings that provide services for FF.

Within the framework of the agreement between Cooperatives of the Americas and IICA, a cooperation program will be designed to strengthen the capabilities of cooperative undertakings that provide services for FF, with a view to bolstering their capacity to foster the dissemination and adoption of innovative ICT-based technologies among different types of cooperatives. This, in turn, will allow for improving the productive and commercial management of FF in selected chains.

Cultivate Partnerships for Sustainable Agriculture, Economic Growth, and Improved Nutrition

Public-private-producer partnerships supporting agricultural development, equity, and nutritious food systems leverage public and private investments in economic development, natural resource management, and human health. Technology alone is not sufficient to strengthen productivity and resilience. Partnerships play an important role in enhancing human capital: a set of skills and knowledge possessed by producers and others in the agricultural value chain that are essential in a time of pandemics. Likewise, social networks among people who live and work in a particular society provide many forms of support.

PARTNER STORY

A CALL TO ACTION BY: Ana Bilik, President, Tanager

Interventions to improve economic and social outcomes for small-scale farmers

The Shubb Mint Project in India is increasing incomes for women farmers. Photo: Tanager

The Sustainable Development Goals have become a standard set of metrics behind a movement, "a shared blueprint for peace and prosperity for people and the planet." While we have the will to reach these ambitious goals, our collective efforts remain siloed.

Sector-specific work focused on impact along an area of technical expertise, such as gender or nutrition, and crop- or commodity-specific work focused on creating impact for farmers along one crop or commodity supply chain.

We can go further together by building multi-stakeholder partnerships that focus on a geographic region, are driven by the private sector and foundations, incorporate data and learning at every implementation stage, and place the farmers' lives and livelihoods at the center.

Tanager implements both crop- and sector-specific interventions – we know how effective these approaches can be.

In India, the Shubh Mint project has made noteworthy gains to farmers' income from the mint. In Burkina Faso, the SELEVER II project addresses gender and nutrition gaps by working through poultry supply chains.

However, these interventions tackle either a portion of farmers' income or specific challenges that farmers face. Issues of poverty and income are more extensive than any single commodity and intersect with issues of gender inequality and dietary diversity. Interventions could have a more profound impact by working on multiple crops or income streams on the economic side and addressing complementing social concerns, including gender inequality and dietary diversity.

On the economic side, the Living Income Benchmark – developed by the Sustainable Food Lab, ISEAL, and GIZ – gives us the ability to quantify how much a farmer needs to have a decent quality of life in any specific geographic region.

In public-private partnerships, governments, development agencies, companies, and foundations deploy their resources according to their vision and area of expertise. The agricultural development sector is far more effective and efficient when we bundle funding and deploy these resources in a specific geographic region, tackling a diverse range of priorities at one time while maintaining a focus on what each donor knows and does well.

CONTRIBUTOR STORY

CONTRIBUTOR: International Maize and Wheat Improvement Center (CIMMYT)

Partnership pursues new approaches to productive, sustainable food systems

Food production systems across the globe can have adverse outcomes. In the worst cases, systems degrade the environment, contribute to climate change, and fail to deliver healthy diets for a growing population.

A multi-disciplinary team of agricultural researchers and development practitioners proposes a new approach to tackle these unwieldy problems and find solutions that prioritize sustainably and collaboratively improving food security and nutrition through targeted, custom practices and technologies for agricultural productivity growth.

Developed by the **International Maize and Wheat Improvement Center (CIMMYT)** in collaboration with the **Alliance of Bioversity International** and the **International Center for Tropical Agriculture (CIAT),** this new methodology aims to transform national food systems by achieving consensus between multiple stakeholders and building on successful participatory agricultural research experiences.

The Integrated Agri-food System Initiative (IASI) is designed to generate strategies, actions, and quantitative, Sustainable-Development-Goals-aligned targets that have a significant likelihood of supportive public and private investment.

The IASI methodology is based on successful integrated development projects implemented by CIMMYT in Mexico and Colombia, the latter in partnership with the Alliance Bioversity-CIAT, which engaged multiple public, private, and civil sector collaborators in local maize systems enhancement.

These initiatives took advantage of socio-political "windows of opportunity" that helped build multiple stakeholder consensus around health, nutrition, food security, and development aspirations in both countries.

The work also relies on CIMMYT's knowledge management framework for agri-food innovation systems: Agricultural Knowledge Management for Innovation (AKM4I). This framework was designed to help agricultural development practitioners understand how farming skills and abilities are developed, tested, and disseminated to improve farming systems in real-life conditions.

With the AKM4I framework in mind, the IASI methodology offers public officials and development practitioners the possibility to transform food systems by scaling out innovative farming practices and technologies that lead to sustainably managed natural resources and improved nutrition and food security.

The IASI methodology authors propose building a "global food systems transformation network" to co-design and co-implement agricultural development projects that bring together multiple partners and donors for agricultural system transformation.

Expand and Improve Local, Regional, and Global Trade

Only eight percent of fruit and vegetable production is traded internationally, an impediment to availability and affordability. (FAO, 2020), (Miller et al., 2016) 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. Trade plays several essential roles during times of pandemics. It brings food to places where food crops have been devastated by pests. Animal vaccines and crop protection products, such as pesticides, need to be brought into impacted areas. Access to agricultural inputs, such as seed and fertilizer, helps farmers recover quickly following a crisis.

CONTRIBUTOR STORY

CONTRIBUTOR: Food Enterprise Solutions

Strengthening the sale and trade of safe, affordable foods in Africa

Food Enterprise Solutions (FES) is bringing more attention to the role of business in the food supply chain with its Business Drivers for Food Safety (BD4FS) program, launched in collaboration with USAID's Feed the Future program in June 2019.

The BD4FS approach aims to engage with small-to-medium-sized growing food businesses to identify possible actions to make food safer jointly. By strengthening the capacities of these food businesses, the goal is for them to become agents for change to improve food safety, reduce malnutrition, hunger, food loss, and lessen the incidence of foodborne pathogens and foodborne disease.

AGRA's Africa Agriculture Status Report (2019) estimated that 40 percent of food sales on the continent are by small-to-medium sized businesses that purchase food from small-scale farmers who then process, transport, and sell it to consumers.

BD4FS will help these innovative and growing food businesses adopt safer food handling, processing, distribution, and storage practices. Ultimately, the approach spans far beyond just food safety and institutes a food system that includes consumers and key stakeholders.

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. COVID-19 has underscored for many people around the world the critical importance of reducing food waste. When food was not as readily available in stores, many consumers realized how much they were wasting and took measures to waste less. However, COVID-19 also saw a significant increase in post-harvest loss.

CONTRIBUTOR STORY

BY: Rick McNary, co-founder of Shop Kansas Farms and vice president of strategic partnership at The Outreach Program

Shop Kansas Farms: Addressing the Pandemic food system supply chain disruption by connecting farmers to consumers

In the early months of the COVID-19 pandemic, the news was full of stories farmers plowing under their fields and dumping their milk because of labor shortages and a broken supply chain.

One evening my wife mentioned that the meat counter was empty at the grocery store that day, yet we had just dined on beef we purchased from a local farm. I began the Facebook group Shop Kansas Farms in April of 2020 to help farmers find a market for their products. I created Shop Kansas Farms to connect consumers with farmers selling meat, produce, dairy and eggs.

In three hours, the group grew to 400 members; in 24 hours, it grew to 5,000; in 7 days, it grew to 50,000; it currently has 148,000+ and continues to rise.

LESSONS LEARNED

Kansas Farmers Calmed Public Fears – The pandemic caused fear in consumers as the food system supply chain broke. A new type of food insecurity arose as people with money could not find food to purchase. Suddenly, through the Shop Kansas Farms group, the public discovered the food they needed was just down the road at the farms they passed by each day.

Real-Life Education – As farmers posted items for sale, consumers began to ask questions. Those conversations – especially regarding buying beef in quarters, halves, and wholes – gave opportunities for farmers and consumers to communicate and learn from each other.

Farms Prospered Significantly – Research revealed that many farms saw an increase of more than 500 percent. One young farmer who began selling quarters, halves, and whole beef to consumers the previous year had 20 customers in 2019. However, in 2020, she had 550 customers. Direct to consumer sales is key to rural prosperity.

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FILLING THE GAPS: **EXPERT ESSAYS, 2021**

The GAP Report editors invited scholars and experts to submit essays based upon their research and fieldwork about strategies for strengthening the climate for sustainable agricultural growth.

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GAP REPORT® GLOBAL AGRICULTURAL PRODUCTIVITY REPORT®

SOIL HEALTH AND GLOBAL AGRICULTURAL PRODUCTIVITY

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ABSTRACT

The Green Revolution (GR) of the 1960s doubled the world's average cereal yield. It saved hundreds of millions from starvation through the timely intervention of growing high-yielding crop varieties with inputs of agro-chemicals and irrigation. Over six decades, the GR is also often linked with soil degradation, contamination and overdraw of water, pollution of air, emission of greenhouse gases into the atmosphere, and loss of biodiversity. While the quantity of food produced was increased, its nutritional quality decreased, with adverse effects on human health. With the projected increase in world population from 7.8 B in 2021 to about 9.8 B by 2050, food demand is projected to increase by 60 percent, which supposedly may need additional land and water resources. In this context, the GR of the 21st century must be soil-centric, based on restoration of soil health and its resilience, ecosystem-oriented, based on an increase in ecoefficiency and less dependence on external inputs, and science-based, using proven scientific knowledge, which produces enough food from less land, water, and other external inputs. The strategy is to protect, restore, manage, and return some land to nature without

horizontal agroecosystems. Rather than a problem, restoration and sustainable soil health management will make agriculture a solution to environmental issues. It is essential to reconcile the need for meeting the food demand with the necessity of improving the environment by restoring soil health. Good soil health equals good and nutritious food, good human health, and good environmental quality.

INTRODUCTION

Ensuring food security has challenged humanity throughout recorded history. Whether the rate of food production can exceed that of population growth pre-dates the Malthusian era. These concerns have challenged humanity and necessitated innovations in agriculture, of which the most prominent is the so-called "Green Revolution" (GR) of the 1960s, which enormously boosted agronomic productivity. The GR was based on growing high-yielding crop varieties and using chemical fertilizers and pesticides, irrigation, and other fossil-energy-based inputs for soil tillage and other farm operations. (Lawrence, 2019) While the population is increasing at about 100 million per year, and it is expected to reach 9.8 B by 2050 (U.N., 2019), cropland area has peaked at about 1.5 B ha since the early 2000s. (FAO, 2020; Thenkabail, 2010) Because of the GR, global cereal yields have more than doubled from 1.5 Mg/ha in the 1960s to 3.2 Mg/ha in 2018. (Chávez-Dulanto et al., 2021) Per capita, world food production has increased by 24 percent to 40 percent through the adoption of GR technologies. (Shanka, 2020) However, there is no cause for complacency. Many argue the need for a further doubling of cereal yield by 2050 under the growing risks of a warming climate, degrading soils, dwindling biodiversity, increasing water scarcity, and growing plant parasites and pathogens risks.

It is also argued that the historic GR was not green enough (Harvey, 2009) because of the severe problems of soil degradation affecting 1.9 B ha or 30 percent of the land area. (IPBES, 2019) Thus, there has been a call for a greener revolution. (Kesavan & Swaminathan, 2008) Further, large amounts of grains are fed to cattle, and one-third or 1.3 Gt of food is wasted on a global scale. (FAO et al., 2019) For 1.7 B small landholders and resource-poor farmers, 70 percent of which are women, the GR prescription has been considered a bitter pill (Vercillo et al., 2020) because of the growing dependence on chemical fertilizers, pesticides, and other inputs with adverse impacts on the environment and increasingly worsening soil health of agroecosystems. These inputs also aggravate emissions of greenhouse gases (GHGs) and accelerate anthropogenic global warming. A study in Pakistan showed that a one percent increase in area irrigated, agricultural tractors, and fertilizer application increases CO2 emissions by 0.35, 0.33, and 0.32 percent, respectively. (Arif & Dilawar, 2020)

Therefore, the objective of this essay is to deliberate agricultural innovations that reconcile the need to produce an adequate quantity of nutritious food for the growing and increasingly affluent human population with the absolute necessity of restoring degraded soils, improving the quality and renewability of water, increasing above and below ground biodiversity, and adapting to and mitigating anthropogenic global warming. Rather than a problem, the strategy is to make agriculture a solution to addressing environmental degradation.

ECO-FRIENDLY AGRICULTURE

Science-based and innovative agriculture has a bright future ahead. So-called eco-friendly agriculture must address environmental issues (i.e., soil functionality, climate change, water quality, biodiversity) while producing enough and nutrient-dense food for the growing population. Indeed, more changes in food production and consumption systems will occur between 2020 and 2050 than have happened since the onset of settled agriculture about ten millennia ago. Therefore, GR of the 21st century must be: i) soil-centric, based on soil health and resilience, ii) ecosystem-centric, based on eco-efficiency of inputs, iii) knowledge or innovation-centric, based on scientific principles, and iv) nature-centric, based on nature positive solutions which restore and enhance nature.

The new GR must also recognize the "One Health" concept, which states that the "health of soil, plants, animals, people, ecosystems, and the planetary processes is one and indivisible." (Lal, 2019a, 2019c) The soil-food security-human health nexus must be recognized and strengthened. (Oliver & Gregory, 2015) Therefore, food production systems must address environmental and resource management issues. Human health, a fingerprint of soil health

(Brevik et al., 2020), must be improved by adopting innovative options which restore and sustain the health of degraded, polluted, contaminated, depleted, and desertified soils. The strategy is to connect food and people (Ball et al., 2018) and soil and people (Poch et al., 2020) because these connections have been lost and must be reestablished. Basic concepts of innovative agricultural practices outlined in Figure 1 emphasize the One Health concept, the importance of soil and environmental protection and restoration, nature-positive approaches, and reduced dependence on external inputs.

TECHNOLOGIES FOR IMPROVING SOIL HEALTH AND INCREASING GLOBAL AGRICULTURAL PRODUCTIVITY

About 2 billion people are malnourished because of the deficiency of micronutrients, protein, and vitamins. The COVID Pandemic has rendered an additional 160 M food-insecure through December 2020. Soil degradation is among the principal causes of human malnutrition. (Lal, 2009) Higher concentrations of atmospheric CO2, which has increased drastically since the 1950s, enhance biomass production but decrease wheat, rice, and other C-3 plants. (Ebi et al., 2021) There is also strong evidence of widespread micronutrient deficiencies (e.g., Zn, Cu, B, Fe, Mo) in the cropland soils of Sub-Saharan Africa (Kihara et al., 2020) and elsewhere in developing countries. Kihara et al. (2020) observed that micronutrient fertilization (agronomic biofortification) increases micronutrient concentration in edible plant components.

Examples of innovative options, in accord with basic concepts outlined in Figure 1, are listed in Table 1. These technologies, specifically designed to reduce conflict between humans and nature (Lal, 2019b), are climate-friendly, pro-nature, and soil restorative and regenerative. To be fine-tuned for site-specific conditions, these practices enhance soil health, increase the ecoefficiency of inputs, sustain agronomic productivity, and improve the nutritional contents of food. Adopted on a landscape basis, following a holistic approach, these practices would reduce agrochemical dependence and impart disease-suppressive characteristics to the soil.

Major issues that need to be addressed through scientific innovations are soil degradation (i.e., accelerated erosion, depletion of soil organic matter (SOM), decline of soil structure, nutrient imbalance and decline, salinization, acidification, contamination, and plastic pollution); excessive/indiscriminate use of agrochemicals and other inputs based on fossil fuels; relentless expansion of agriculture, leading to conversion of natural to managed ecosystems; and plastic pollution and lead contamination in croplands, which have become significant threats to long-term food security in China (X. Zhang et al., 2020; Y. Zhang et al., 2019) and elsewhere. Soil, finite and fragile and teeming with life, is taken for granted and made prone to climate change and other anthropogenic perturbations. One-third of global soils are already affected by moderate to severe degradation by diverse processes. (Rojas et al., 2016)

In this context, the focus should be on regenerative practices (Lal, 2020a) that restore soil health, enhance SOM content, improve soil structure, strengthen activity and species diversity of soil biota, and reinforce the food-energy-water-soil (FEWS) nexus. (Lal, 2014b, 2015a; Lal et al., 2017; Mabhaudhi et al., 2016) The FEWS nexus is strengthened through the restoration of SOM content by adopting strategies of integrated soil fertility management or ISFM (Imran, Amanullah, & Al-Tawaha, 2021; Imran, Amanullah, Hussain, et al., 2021; Voltr et al., 2021) such as recycling of biomass-C and use of various organic amendments. The nexus also highlights the dictum that "good soil = good food = good human health." (Outwater, 2001) This concept must be taught at all levels of education, beginning with elementary school. The COVID pandemic has also amply demonstrated the necessity of strengthening local food production systems. In this context, the importance of urban farming and soil-less agriculture (i.e., aquaponics, hydroponics, aeroponics) can never be over-emphasized. (Lal, 2020; Lal et al., 2020)

Conservation agriculture (CA) is practiced on some 180 Mha of global cropland. (Kassam et al., 2019) The effectiveness of CA can be significantly enhanced if used in combination with cover cropping (Eash et al., 2021; Haider et al., 2019), retention of crop residue mulch (Noor et al., 2021; Salahin et al., 2021), and complex crop rotations. Nunes et al. (2018) documented that no-till (CA) performance in temperate regions is enhanced by integrating other practices such as cover cropping and crop rotations. Nunes and colleagues observed that the benefits of introducing grass or legume cover crop mixtures into the cropping system are evident after four years for SOM content, plant-available water capacity, and Fe and Zn contents and that effects of cover cropping were greater under CA than with conventional tillage. Furthermore, better soil quality under CA results in higher agronomic yields in loamy sand and silt loam soils, but not in clayey soils. (Nunes et al., 2018)

Figure 1: Innovating Agricultural Technology

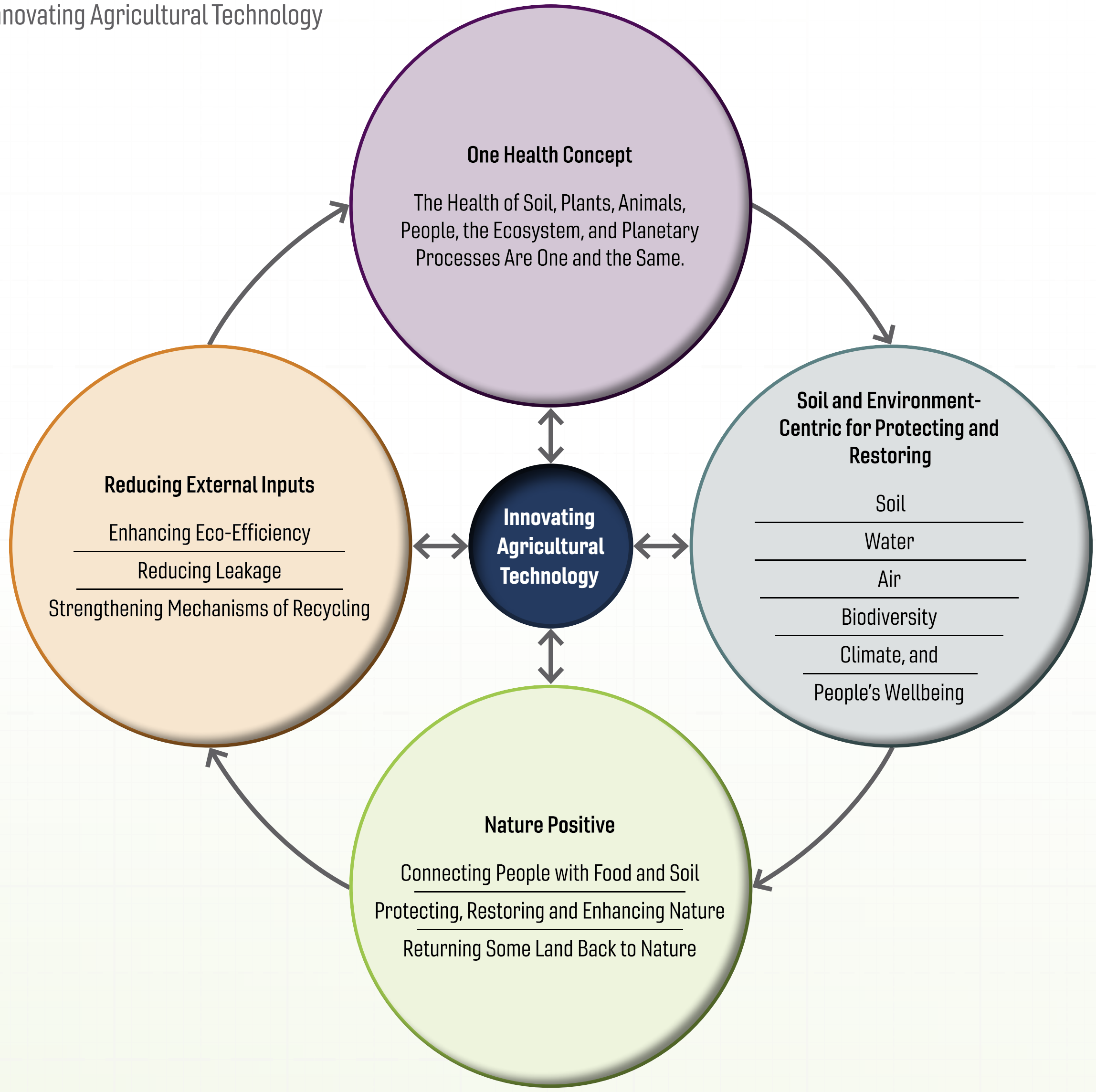

Table 1: Some Examples of Soil-Centric and Nature-Positive Agricultural Technologies for Food, Climate, and Environmental Security

Technology	Description	Reference
Blue-Green Revolution	Rice-Fish Cultivation	Nesar & Turchini (2021); Thenkabail (2010)
Carbon Farming	Commodification of Carbon	Poch et al. (2020); Lin et al. (2013)
Climate-Smart Agriculture	Adaptation/Mitigation of Climate	Lin et al. (2013); Kichamu-Wachira et al. (2021); Jumiyati et al. (2021)
Connection Between Food and People	Sustainable Food Systems	Ball (2018); Poch et al. (2020)
Conservation Agriculture	System-Based and Wholistic	Lal (2015)
Cover Cropping	Soil-Water Conservation	Eash et al. (2021); Cumming (2014); Haider et al. (2019);
Drip Irrigation	Enhancing Water Productivity	Assefa et al. (2019)
Eco-Intensification	Redesigned Sustainable Systems	Jules (2018)

Technology	Description	Reference
Home Gardening/Urban Agriculture	Local Food Production	Lal (2020)
Nano-Fertilizers	Innovative Fertilizers	Sharma et al. (2021)
Nutritional Quality of Crops	Food as Medicine	Ebi et al. (2021), Kihara et al. (2020)
Permanent Mulch	Agrimats	Mgolozeli et al. (2020)
Precision Agriculture	Remote Sensing	Sishodia et al. (2020)
Regenerative Agriculture	Soil Restoration	Nunes et al. (2018); Rhodes (2017); Lal (2019)
Restoration of Soil Organic Matter	Integrated Soil Nutrient Management	Imran, Amanullah, & Al-Tawaha (2021); Imran, Amanullah, Hussain, et al. (2021)
Soil-Human Health Nexus	Interconnectivity	Lal (2021), Oliver et al. (2013), Rush & Yan (2017); Brevik & Sauer (2015);
Soil-Less Agriculture	Aquaculture, Aeroponics	French & Roth (2019)
Soil-Water-Air-Energy Nexus	Wholistic Approach	Rhodes (2017)
Vertical Farming	Sky or Vertical Farming	Despomier (2018)
Zonal Tillage	Guided Traffic/Minimizing Soil Compaction	Kurstjens (2007), Tullberg (2010), Hussein et al. (2021)

Rather than bringing new land under agriculture, as proposed by some (Lal, 2021; Ranganathan et al., 2018), the prudent strategy is to protect, restore, manage, and return some land to nature. (Lal, 2021) The global land area under agriculture of 5 B ha (1.5 B ha under cropland and 3.5 B ha under grazing land/pasture) is far more than needed to adequately feed the current and projected population and generate other ecosystem services. With proven scientific technologies (Table 1), Prudent management can double agronomic production in developing countries, narrow the yield gap, and facilitate the return of some land (e.g., marginal to agricultural use) to nature. The set-aside land will also be a major sink of atmospheric CO2 by sequestration of carbon in soil and vegetation. Furthermore, widespread adoption of improved and scientifically proven practices will make agriculture a solution to mitigating global warming and improving the environment.

Widespread adoption of improved technologies can be facilitated by identifying and implementing policies at local, regional, national, and global scales. There is a strong need for a soil protection and restoration act. In the U.S., for example, there is a Clean Water Act, Clean Air Act, but there is no Soil Health Act. In addition to nature-positive legislation, farmers must also be incentivized to adopt recommended management practices through payments for ecosystem services. Funds allocated for subsidies (e.g., for irrigation, nitrogen fertilizer) can be re-appropriated towards payments for ecosystem services such as sequestering carbon in soil and trees, improving renewability and quality of natural waters, and strengthening the above and below-ground biodiversity. Payments to farmers, such as sequestration of carbon, must be based on societal value (Lal, 2014a) just, fair, and transparently. Undervaluing a precious resource (i.e., such as SOM) can lead to a tragedy of the commons. Furthermore, soil carbon credits need clear standards for assessment and upscaling to farm level.

CONCLUSIONS

The Green Revolution of the 1960s, an important and timely innovation, saved humanity by providing food to hundreds of millions prone to undernutrition and malnutrition and saved the world from widespread risks of civil strife and political unrest caused by desperation and suffering. The adverse effects on the environment, caused by excessive/indiscriminate use of chemicals and in-field burning or removal of crop residues and monocropping of cereals grown with excessive plowing and flood-based irrigation, must be addressed the adoption of scientifically proven practices. Paramount among these is conservation agriculture practiced in combination with cover cropping and residue retention as mulch along with complex rotation and integrated soil fertility management. This is an example of regenerative agriculture that restores SOM content, enhances soil health, and makes agriculture a solution by adapting to and mitigating anthropogenic climate change and restoring the environment (soil, water, air, biodiversity). The soil of good heath produces food of good nutritional quality and leads to good human health because good food is good medicine. Adopting improved agricultural practices will narrow the yield gap and enable the return of some agriculturally marginal lands to nature. Urban agriculture and soil-less food production systems can promote vertical/sky-farming and strengthen local food production systems. Indeed, agriculture and world food systems are set for a major paradigm shift and drastic transformation to nature/soil-centric solutions.

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GAP REPORT® GLOBAL AGRICULTURAL PRODUCTIVITY REPORT®

A NOTE ON AGRICULTURAL PRODUCTIVITY IN LATIN AMERICA AND THE CARIBBEAN: A CALL TO INCREASE INVESTMENT IN INNOVATION[1]

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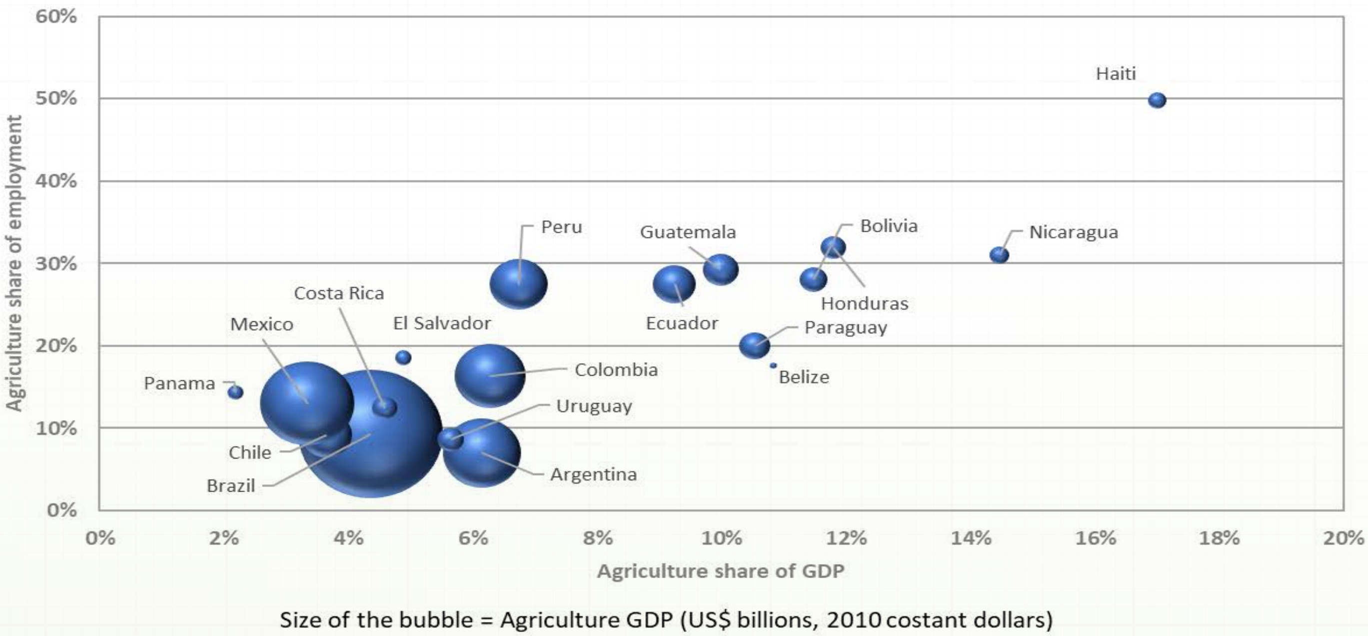
Rural societies and agri-food systems in Latin America and the Caribbean (LAC) face common and unprecedented challenges such as: improving the efficiency of food and agricultural systems; increasing the sustainability of agriculture; building the resiliency of communities, agriculture, and ecosystems to adapt to climate change; and increasing economic and social inclusion, while contributing to opportunities for employment and income generation.

Innovation is critical to address such challenges. Therefore, technical and institutional change should be high on the agenda of policymakers, civil society, and the private and public sectors. Despite the development of agricultural innovation programs in the region during the past two decades, there is still a need to strengthen agricultural research, technology, and innovation systems (including digital innovation) to face such challenges. The LAC region offers an excellent opportunity to seek innovative, tangible, and large-scale rural development and agri-food systems results, particularly if it continues being the most significant net food exporting region (a challenge in terms of productivity), as well as maintaining its role as an essential provider of global environmental services such as biodiversity, water, soils, forests, and other ecosystem services.

Such challenges become even more relevant due to major global trends, such as changing consumer needs, climate change, low levels of public funding for agricultural research in the Global South, and the need to make agri-food systems healthier, sustainable, and more resilient. Furthermore, the severe overweight and obesity epidemic (combined with persistent hunger) in the LAC region and the mixed agricultural research and innovation capacity at the national level to respond to such challenges highlight the need to rethink how to innovate to realize impacts at scale.[2]

The current global technological innovation trends allow us to consider digital, data science, artificial intelligence, genomics, and new biological tools that can significantly improve agri-food systems and livelihoods. All these key challenges and opportunities for research, development, and innovation should be addressed considering the substantial heterogeneity of LAC countries, particularly regarding the diverse contribution of agriculture to economic growth and employment across countries (Figure 1.)

Figure 1: Contribution of Agriculture to GDP and Employment, LAC Countries, 2018



Source: World Bank, 2020. Future Foodscapes: Re-imagining agriculture in Latin America and the Caribbean

A critical dimension of heterogeneity for agricultural innovation in the region is that small-scale family farms are almost 85 percent of all farms. Of the approximately 15 million farms in the region, probably 13 million could be considered small-scale family farms. However, smallholder family farming is not a homogeneous sector. For example, a group of commercial family farms integrated into markets is already part of the science and technology innovation system. There is also a group in transition to commercial markets where technical assistance could play a key role. Finally, a more traditional or subsistence group of smallholders is not integrated into markets and is often marginalized from formal innovation systems and processes.[3]

INNOVATION AND PRODUCTIVITY

In the early 2000s, the performance of LAC's agriculture sector was the best it had been in many years. This growth was short-lived. By the early 2010s, agricultural development was sluggish. The lesson is often repeated but remains true: only much more significant investment in research and development and innovation can sustain medium- and long-term improvements in productivity, sustainability and resilience, and social inclusion.

In 2000-2010, regional agricultural growth was strong, driven by a favorable macroeconomic environment and high prices for primary commodities. The sector saw a steady growth of total factor productivity (TFP), output and input per worker, and a reduction of the TFP gap between the region and OECD countries.[4] Remarkably, even during the 2008 worldwide recession and the high phase of the commodity price cycle, some LAC countries were still increasing output per worker at an average annual rate of 4.4 percent between 2003 and 2012, compared with 0.7 percent in the 1980s.

The upward phase of the commodity price cycle that started in the early 2000s was over by 2011, with commodity prices falling or remaining stable, reflecting an anticipated increase in commodity supply along with weaker demand from China and other major commodity-importing economies.[5] The past decade shows sluggish growth in several LAC countries, not only because of lower commodity prices but also because of macroeconomic difficulties and policy readjustments. Worsening fiscal conditions and a persistent increase in debt ratios brought back fiscal adjustments and recessions in the region.

Regional agricultural growth decelerated after 2012. The average annual growth of output per worker between 2003 and 2011 was 4.4 percent, decreasing to 2.8 percent during 2012-2016. Output growth was driven almost equally by growth in TFP and input per worker. During the fast-growing period of 2003 to 2011, output growth was driven by TFP growth. TFP grew on average at an annual rate of 2.2 percent, the same as growth in input per worker. Regional agricultural growth decelerated after 2012. The average annual growth of output per worker between 2003 and 2011 was 4.4 percent, decreasing to 2.8 percent in 2012-2016. With the slowdown of production after 2012, TFP growth fell to an annual average of 1.3 percent, while growth in input per worker dropped to 1.5 percent. Although these growth rates are significant when compared to historic trends, the change signals the end of the favorable period for LAC's agriculture.

TFP growth in agriculture was mainly driven by technical change, with average annual TFP growth rates of 2.2 percent during 2003-2011 and 1.1 percent after 2012. During the commodity price boom, crop and livestock production grew at an annual growth rate of 3.4 and 3.1 percent, respectively. TFP growth for both subsectors was slightly higher for crops (2.5 percent) than 2.2 percent for livestock. After 2011, annual growth in crop production dropped from 3.4 to 2.8 percent, and TFP decreased by half (from 2.5 to 1.2 percent). Growth rates of livestock output in 2012-2016 dropped to one-third of those in 2003-2011, from 3.1 to 1.0 percent, and TFP growth decreased from 2.2 to 0.7 percent. Livestock TFP seemed to reach a plateau after 2012, and crop production is the subsector driving growth.[6]

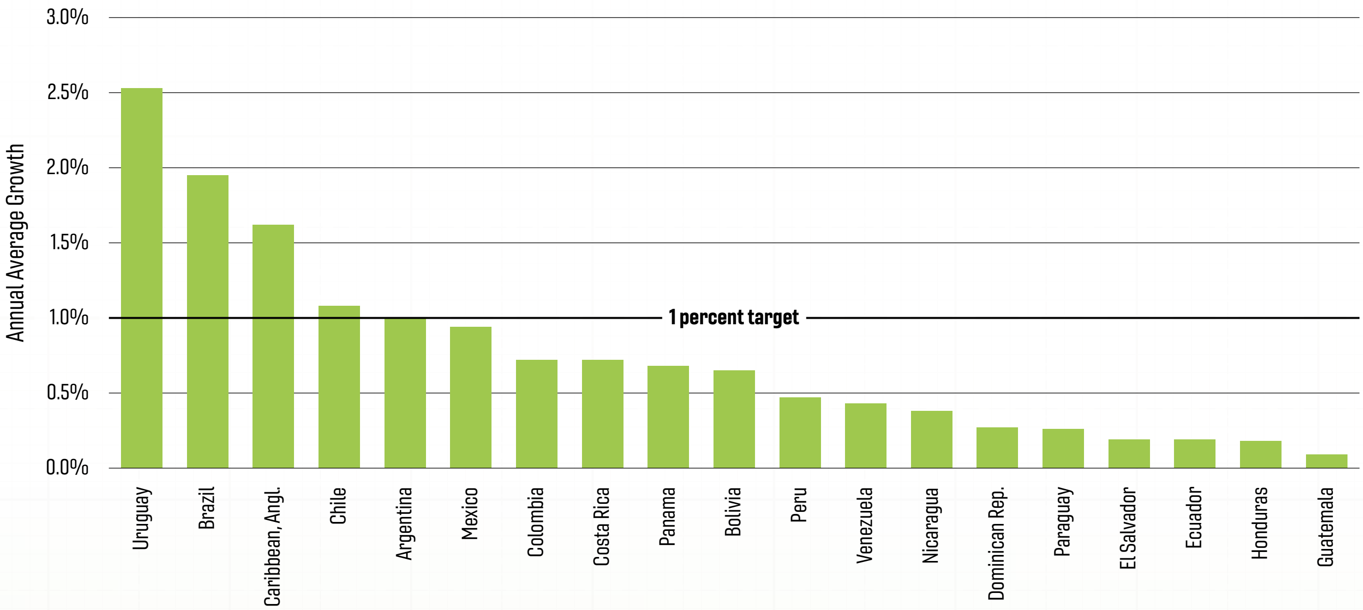
Greenhouse gas emissions increased much faster in crop production (3.4 percent) than in livestock production (0.8 percent), although emissions from livestock are six to eight times higher than crop emissions. Most of the emissions from agriculture come from enteric fermentation in ruminants and manure. In crop production, a primary source of emissions was synthetic fertilizer (more than half of the total emissions), rice cultivation, and crop residues. At the country level, between 2003 and 2011, Brazil, Paraguay and Uruguay were the countries with the fastest-growing agriculture, driven mainly by growth in crop production and the boom of soybean production for export, followed by Peru, Nicaragua, and Guatemala, all with agricultural production growth rates above 4 percent.[7]

THE NEED FOR MORE SIGNIFICANT INVESTMENT IN INNOVATION

There is no future for productive, sustainable, resilient, and inclusive agri-food systems in the region without a much greater commitment to investment in research, development, and innovation from the public sector, civil society organizations, and private companies. Investments in agricultural technologies in LAC are still relatively low, reaching only 1 percent of the venture capital investment in the region.[8] As shown in Figure 2, only a few countries invest above 1 percent of agricultural production in research, compared with countries like China, Vietnam, and India that are investing over 2 percent of agricultural GDP in research and the higher income countries that have been continuously investing above 4 percent of agricultural GDP.

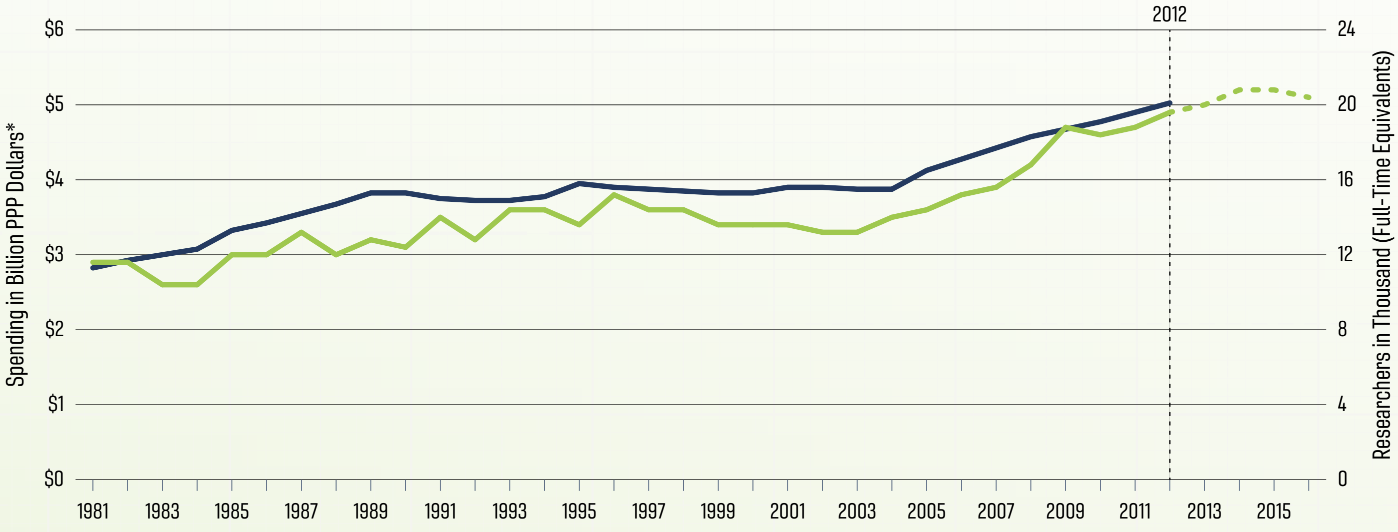
Furthermore, most of the research investment is focused on staple crops. Only a few countries have national research systems with high civil society participation and the private sector in the region.[9] The public sector employed more than half of agricultural researchers in the mid-2000s, the higher education sector about 40 percent, and non-profit organizations 5 percent. However, there are significant variations across countries. For instance, in Brazil, the Dominican Republic, Ecuador, Panama, and Venezuela, the government sector employed more than 70 percent of each country's agricultural researchers. In Mexico and Peru, roughly two-thirds of agricultural researchers were employed within higher education institutes. In Colombia and Honduras, producer organizations accounted for approximately 40 percent of the total number of researchers.

Figure 2: Agricultural Research Spending as a Share of AgGDP by Country, 2012–2016



Source: ASTI-IFPRI based on data from ASTI, OECD, RICYT, Embrapa, and Word Bank. Intensity ratios are for 2016 except for Ecuador (2014), Bolivia and Paraguay (2013), Anglophone Caribbean, Honduras, and Nicaragua (2012).

Figure 3: Total Number of Researchers and Agricultural Research Expenditures in LAC, 2016



*inflation=adjusted; 2011 prices

Source: ASTI-IFPRI based on data from ASTI, OECD, RICYT, and Embrapa. All researchers and research expenditures, excluding private companies. The 2014–2016 spending data for Argentina and Chile were updated using the OECD's agricultural S&T spending trends; 2013–2016 spending data for Costa Rica, El Salvador, Guatemala, Panama, Peru, Uruguay, and Venezuela were updated using RICYT's agricultural S&T spending trends; 2014–2016 data for Colombia and Mexico were estimated using RICYT's general S&T spending trends; 2014–2016 spending data for Brazil were updated using Embrapa's spending trends, and 2013–2016 spending trends were generated through a new ASTI survey round. All other countries were estimated using historical trends.

By 2016, the region invested about USD 5 billion annually in agri-cultural R&D (Figure 3), representing a significant increase over the previous decade. Total researcher numbers – measured in full-time equivalents - also increased to close to 20 000 agricultural researchers, nearly twice as many as in the early 1980s. Most of the growth in spending and number of researchers was driven mainly by the three countries with LAC's most prominent agricultural research systems: Argentina, Brazil, and Mexico.

Considering the slowing down of growth in the agricultural sector during the past decade and the relatively low levels of investment in research, development, innovation, new partnerships, and financing mechanisms should be promoted by an endowment funded by several countries of the region and Spain. However, the current amount in the endowment (approximately USD 100 million) is still small to reach a significant regional scale. A unique institutional innovation was the creation, two decades ago, of the Regional Fund for Agriculture Technology (FONTAGRO) to support regional research projects on a competitive basis. The Fund operates with the income generated.

The region has benefited from the historical presence of relevant international agricultural research centers from the CGIAR based in LAC (CIAT, CIMMYT, and CIP) and others working in the region (Bioversity International, IFPRI, ICRAF as well as CATIE) with an important set of programs in the region. LAC has national research institutes with significant scientific capacities, including EMBRAPA in Brazil, INTA in Argentina, INIA in Uruguay and Chile, AgroSavia in Colombia, and INIFAP in Mexico. Furthermore, Universities, civil society organizations such as producer associations, and private companies have had a vital role in agricultural innovation in the region. Yet, despite these structures, LAC lags in terms of the level of investment compared with developed countries and other developing countries, most notably in Asia.

To complement publicly-funded activities, a key sector to promote – through institutional innovations and regulatory frameworks – is the private sector and civil society organizations such as producer associations. Private sector funded and executed research (focused on the primary sector and the rest of the innovation value chain, processing, marketing, and retail) is still at a low level in LAC compared to the rest of the world. Thus, in addition to significantly strengthening public-private partnerships, there is a need to improve coordination, complementarities, and synergies among all agricultural science, technology, and innovation agents.

In addition to increasing funding levels, it is crucial to rethink priorities and the new capacities needed in such systems. For instance, improving strategies, management processes, institutional evaluation, and organizational learning, planning, and business-related articulation for innovation, strengthening intellectual property regimes, and the capacity to develop start-ups and accelerators including government, businesses, and academia. In sum, promoting innovations to have a large-scale impact instead of simply for the generation and diffusion of technology should be prioritized.

Innovation is also required to identify ways to overcome the most common barriers to adopting new technologies. In this regard, sound policies could incentivize much-needed investments in research, technology development, and innovation. According to global assessments, these barriers include training and information (88 percent), policy/institutional (39 percent), economic (30 percent), social/cultural (16 percent), and environmental (9 percent).[10] Specific barriers to technology adoption include low availability of required inputs (such as high yielding seeds for improved varieties or water scarcity during droughts), high costs of installation (e.g., enhanced irrigation facilities) with limited access to credit and markets, high labor costs and a limited level of technical knowledge and skills. Strengthening social networks among producers to share initiatives, good practices, and innovations is critical in this regard.

ENDNOTES

1 Based on Echeverria, R.G. 2020. Innovation for sustainable, healthy, and inclusive agri-food systems and rural societies in Latin America and the Caribbean. Framework for action 2021-2025. Food and Agriculture Organization of the United Nations, Regional Office for Latin America and the Caribbean. FAO, Santiago de Chile.

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GAP REPORT® GLOBAL AGRICULTURAL PRODUCTIVITY REPORT®

PROTECTING ECOSYSTEMS FOR A PRODUCTIVE FUTURE: A FARMER'S STORY FROM ETHIOPIA

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A narrow dirt road winds through Ethiopia's Rift Valley highlands, cutting through fields where there was once nothing but hunger to arrive at a remarkable sight. Behind a fence made of dried corn stalks flourished a veritable Garden of Eden producing a riotous bounty of food.

Beans, peas, potatoes, sweet potatoes, peppers, barley, teff, cassava, coffee, and maize thrive on a rectangular plot covering one-and-one-half hectares (about 4 acres.) Mango, avocado, papaya, apple, and banana trees embroidered the edges of the field. Carrots, cabbage, beets, and tomatoes flourished in garden patches. A dozen cows grazed on tall grass near a stream at the far end of the farm.

"This land was dead; nothing would grow. And now look!" said farmer Abebe Moliso, opening wide his arms to embrace his thriving fields.

It was a stunning transformation from two decades earlier when Abebe and his family depended on international food aid distributed by the United Nations' World Food Programme (WFP). When I first visited this area in 2003, twin disasters striking people and the planet were exploding. Nearly 14 million people across Ethiopia were on the doorstep of starvation, sustained by food aid in the world's first famine of the twenty-first century. Vast stretches of agricultural land were a moonscape of denuded hills, deep gullies, and eerie sand-and-dirt sculptures shaped by wind and erosion over the years. Forests had vanished, and soils were so degraded by decades of mono-crop farming, slash-and-burn agriculture, relentless cattle grazing, and deforestation for fuel that growing anything had become futile.

Entire ecosystems had dramatically changed. The rain became ever scarcer, and when it did come, very little water was absorbed by the barren, sun-baked soil, rushing away instead with valuable topsoil. Water tables sank, streams dried up. Bushes and grasses withered and died. Temperatures rose, winds faded. Birds flew away, as did the pollinators. Few living things remained.

Eventually, farmers had no choice but to leave the land. The WFP distributed food to help suffering people. Providing food aid to farmers who could no longer squeeze enough food from their depleted soils was not a long-term solution. Under the Managing Environmental Resources to Enable Transition (MERET) program, legions of farmers, including Abebe, moved off their land and left the fields to lie fallow for several years. Instead of planting crops, they dug trenches and pans to collect and conserve the rainwater. They constructed terraces and planted grasses and saplings to slow the erosion and naturally return nutrients to the soil. They established community watches to prevent anyone from wandering onto the land for cattle grazing or biofuel harvesting. For their work and vigilance, food began to grow, and families returned to the land.

International development organizations like World Vision and Catholic Relief Services that had also distributed food aid over the decades rallied communities and local governments to create land rehabilitation initiatives. When they moved back, farmers diversified and rotated their corps, planted new tree varieties, and deployed innovative irrigation techniques to ensure water and nutrients stay in the soil and the crops. These landscape restoration efforts spread across the Sahelian countries of Africa and have become an international priority and an ally in transforming the global agriculture system to nourish the planet and preserve the planet. In 2021, the United Nations launched a Decade of Ecosystem Restoration “to prevent, halt and reverse the degradation of ecosystems on every continent and in every ocean.”

Sixteen years after my first visit, I found that restoration efforts had already revitalized large swathes of land. Forests were expanding, new underground springs bubbled through the surface to form wells and ponds, and butterflies, birds, bees, and animals were back.

And so were the people. A group of farmers at the edge of the Humbo forest showed off the benefits of their restoration efforts. We walked through fields thick with grasses and bushes filling the trenches and terraces. We washed our faces with water flowing from a newly emerged spring. We lingered on the banks of ponds that had formed as the pans filled with the rains.

“See, we have ducks now,” noted one of the farmers, pointing to activity on the pond.

We gathered under the spreading canopy of an acacia tree, below the hanging basket-like nests of weaver birds. “We now have shade,” another farmer said. “And a breeze.” It was mid-day. The sun was bearing down. “A couple of years ago, we wouldn’t be sitting here,” he said. “It would have been too hot.”

The farmers brought out plates laden with dripping honeycombs, a gift from their newly-arrived bees. The extraordinary biodiversity has brought more food and income opportunities. Beyond the new hives were rows of maize, beans, onions, cassava, cabbage, sorghum, mango, papaya, and avocado trees.

“Our misery started when our cattle starved, and our crops diminished. You couldn’t find a family that hadn’t lost a child,” Yissac, one of the farmers, said. Abdullah, who was 12 when his family left the land, added, “There were too many deaths. You couldn’t even cry anymore. You realized you might be the next. I was delighted when we could come back. It would be our great happiness if this can be replicated elsewhere.”

On his farm, Abebe, now in his mid-40s, explained how he has deployed all he learned while the land healed. He no longer blankets his land with a single crop – maize – but instead plants a patchwork quilt of alternating crops that allows the soil to refresh from season to season. Between plantings, he nurtures cover crops to shield his soil from evaporation and erosion. He developed a composting system and adopted conservation farming techniques that minimized soil disruption. He planted trees that provide shade and fix nutrients in the soil and bushes that have natural pesticides. When a spring reappeared, he shaped it into a small pond and introduced water lilies to limit evaporation. The water and fruit trees attracted bees, which inspired Abebe to construct hives and produce honey.

Abebe was a young man in his 20s when his family moved off the land to begin the healing. Now, he offers it as a teaching model for his neighbors. Local women gather to see the benefits of vegetables and diversified diets. They have formed growing and saving groups, tending kitchen gardens and sheep and goats to improve their income. They marvel at the health benefits; instead of children weakened and dying from malnutrition, they now celebrate high school and college graduations. Abebe and his wife, Tsehainesh, display the diplomas on the walls of their house.

“Now we’ve realized the fruits of our work,” Abebe said. “And we have seen the mistakes of those who have come before us. Our dead land is living again.”

Abebe and a host of other farmers, both small and large, subsistence and commercial, in Africa and around the world, are charting a course that values ecosystem health, crop diversity, and sustainable productivity growth.

“We have learned that it isn’t wise to plant only one type of crop. It’s too risky,” Abebe said. “We have seen how growing single crops deplete the soil, how the plants are more susceptible to disease and pests, how we become dependent on only one price.”

No longer would he plant row after row of maize year after year, as was common practice. “Why would I do that?” he asked. “No, no. No more. Now I have crops coming ripe all year long. If one fails, another succeeds. We have a steady flow of food and income.”

In 1970, American agricultural scientist and crop breeder Norman Borlaug developed new seed varieties of wheat that boosted global production, saving millions from starvation.

He received the Nobel Peace Prize for sparking what came to be known as the Green Revolution. The Nobel committee praised Borlaug for defusing a grave threat to humanity by accelerating the pace of food production ahead of population growth.

“In this intolerable situation, with the menace of doomsday hanging over us, Dr. Borlaug comes onto the stage and cuts the Gordian knot. He has given us a well-founded hope, an alternative of peace and life - the Green Revolution.” Borlaug, the committee said, had “turned pessimism into optimism in the dramatic race between population explosion and our production of food.”

Five decades later, we find ourselves in a new Gordian knot (a complex, seemingly unsolvable problem) hanging over us.

Today, the dramatic race is between two of our most pressing challenges: nourishing the planet and preserving the earth. How can we produce enough food to nourish an ever-growing and ever-more prosperous population properly – and finally conquer global hunger and malnutrition – while at the same time ensuring that our agricultural systems do not strain our environment, biodiversity, and health.

The essence of today’s challenge lies not in how much we grow (the mission of the Green Revolution) but in what we grow and how we grow it. Food preferences are shifting, and billions of people need proteins, vitamins, and minerals crucial for healthy individual and societal development.

The Green Revolution’s primary focus on increasing agricultural yields to conquer the famines in India and Pakistan and elsewhere in Asia, where starvation was immense and unrelenting for decades. The increase in food production was driven by input intensification, increasing the amount of inputs used per hectare of land, especially fertilizer and irrigation.

Over time, agricultural research generated innovations that allowed farmers to use their inputs more productively. By the 1980s, almost all global agricultural output growth was driven by agricultural productivity, while cultivated land was removed from production and input use per hectare declined. But the increase in productivity was uneven, with large-scale farmers in high-income countries benefiting most, while millions of small-scale farmers, like Abebe, lived harvest-to-harvest, constantly on the brink of extreme hunger and poverty.

All the while our new Gordian knot was forming. The imperative to produce ever-larger quantities of food led to the creation of a food system that has heavily relied on a small number of crops and supporting agriculture systems. Today, three-quarters of the world’s food is generated from only a dozen plants and five animal species. Monocropping has contributed to increasing outbreaks of pests and diseases, degraded soils. depleted water systems, land conversion from forests and fields to cultivation and grazing, and the overuse or misuse of fertilizer and pesticides.

Farmers of all scales are realizing that things must change for agriculture to be sustainable and resilient in the future. Climate change is already slowing productivity, decreasing the crop nutrients in plants, and altering ecosystems. The innvoations, practices, and knowledge that enable farmers to maintain healthy yields in a sustainable way, need to be affordable and available to farmers regardless of location or scale.

Before the pandemic, the UN's Food and Agriculture Organization estimated that more than 820 million people were chronically hungry. In addition, micronutrient deficiency, a lack of crucial vitamins and minerals known as "hidden hunger," afflicts about two billion people. More than 20 percent of children under the age of five are stunted, either physically or mentally, from early childhood malnutrition, leading to a life sentence of underachievement. At the same time, another two billion people are overweight or obese, and their number is rising as well, as is the incidence of diet-related non-communicable diseases. Poor diets are now a leading cause of death globally.

Our planet's health has also become increasingly imperiled: average global temperatures are rising, polar ice caps and glaciers are melting at a quickening pace. Deforestation in many parts of the world continues unabated.

Cutting our twenty-first-century Gordian knot will require more nuanced, integrated solutions. We need to forge a fresh era of human cooperation, united by a shared concern for agriculture, nutrition, environment, climate and biodiversity and the health of humans, animals, plants, insects, soil, water, and air – as well as fostering a universal concern for justice and equality.

Attempts to construct this new movement – often called Planetary Health or One Health – are gaining urgency and momentum. At a conference hosted by his Center for Global Food Security at Purdue University, Gebisa Ejeta, who won the World Food Prize for his pioneering work on sorghum production, outlined the challenge. The task ahead, he said, is not solely a matter of science and technology but also of equity, for global food insecurity is tightly linked to poverty, gender imbalance, and the unequal distribution of global wealth, resources, and knowledge. Food, he insisted, is a fundamental need of all human society. However, the advances that generated higher food production rates haven't eliminated hunger and malnutrition from our world.

Part of the solution, the gathering determined, will be attaining essential goals that are currently crucial in the rising economies of the developing world: investing in women farmers as well as men; enhancing agricultural-based businesses for gainful employment, particularly for the rural youth; equitably deploying research and scientific advances in the field; and, increasing the efficiency of production, processing, distribution and utilization of nutritious food. All this, as well as nurturing healthy soils, preserving water, and broadening crop diversity.

Success will also require creating an even greater appreciation and respect for nature, local ecologies, and social values – where farmers and conservationists are no longer bitter foes but allies, heroes in each other's eyes rather than villains.

"Human society in the past has shown that it can achieve extraordinary feats and solve big societal problems when it builds sufficient common resolve and will," Gebisa said. "Can it now build one such global resolve as a last-ditch effort to eradicate hunger from the face of the earth? And save the planet at the same time?"

This is where the dirt road in the Ethiopian highlands leads, in Gebisa's homeland, to Abebe's farm. Abebe is one farmer taking a swipe at our new Gordian knot as he seeks to nourish his family and preserve his land. "God gave me an open mind to learn," he said. "And I hope I can open the minds of others."

The Global Agricultural Productivity Report® (GAP Report®) is central to the mission of CALS Global in the Virginia Tech College of Agriculture and Life Sciences (CALS): to build partnerships, drive thought leadership, and create opportunities for students and faculty to serve globally.

In addition to producing this annual update on global progress toward doubling agricultural output through productivity growth by 2050, the GAP Initiative coordinates opportunities for collaboration and learning between its partners, the university, and stakeholders around the world.

Direction and input for the GAP Report and related activities are provided by the GAP Initiative Leadership Council.

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