College of Agriculture and Life Sciences
Virginia Tech

GAP Report®
Global Agricultural Productivity Report®

TROUBLESOME TRENDS AND SYSTEM SHOCKS

2022 GAP Report®

CONTENTS

EXPLORE ADDITIONAL RESOURCES AT
GLOBAL**AGRICULTURAL**PRODUCTIVITY.ORG

Suggested citation: Steensland, A. (2022). *2022 Global Agricultural Productivity Report: Troublesome trends and system shocks*. Thompson, T. and Agnew, J. (Eds.) Virginia Tech College of Agriculture and Life Sciences.

VULNERABLE AGRICULTURAL SYSTEMS REST ON FRAGILE FOUNDATIONS

Global agricultural systems are being rocked by COVID-19, climate change, extreme weather events, and conflicts in Ukraine and elsewhere, driving up prices for food and agricultural inputs.

The agricultural systems of high- and upper-middle-income countries are withstanding the shocks relatively well. However, food insecurity, malnutrition, and poverty rates have risen sharply, especially in low-income countries since 2020. In 2022, 40 million people faced emergency or catastrophic levels of food insecurity, twice as high as in 2020 and six times more than in 2016 (Food Security Information Network, 2022).

The troubling trends in agricultural productivity growth are mainly unnoticed; updated data reveals that the world's shock-sensitive systems rest on increasingly fragile foundations. Reversing the downward trajectory of global agricultural productivity growth demands urgent action from policymakers, leaders, donors, scientists, farmers, and others in the agri-food system.

TOWARD A COMMON NARRATIVE

KEY MESSAGES–VULNERABLE AGRICULTURAL SYSTEMS REST ON FRAGILE FOUNDATIONS

1 Global agricultural productivity growth is in steep decline.

To sustainably produce food and agricultural products for more than 9 billion people in 2050, agricultural productivity must increase an average of 1.73 percent annually. **From 2011-2020, global agricultural productivity grew at an average of just 1.12 percent per year,** a significant drop from the average growth rate of 1.99 percent from 2001-2010 (USDA ERS).

2 Productivity growth is not scale-dependent.

The prospects for agricultural productivity growth are not exclusive to large farms. An increasing number of agricultural technologies and farm management services are designed for use at smaller scales. Unfortunately, most small-scale producers cannot access the innovations and information they need to ensure a productive, profitable, and sustainable future (Fuglie et al., 2020).

3 Extreme climate events disrupt productivity gains.

New research by Wei Zhang, assistant professor of agricultural and applied economics at Virginia Tech, shows that extreme climate events are estimated to have, on average, a negative and statistically significant impact on the TFP growth rate (See page 12). The estimated impact of droughts is more than three times the impact of an average extreme climate event. These climate shocks can have a sustained impacts on the growth trajectory of agricultural productivity.

4 Regional differences in productivity growth reveal areas of concern, alarm, and hope.

Productivity growth is no longer the primary driver of agricultural output growth in **Latin America and the Caribbean.** Instead, regional producers rely on input intensification, applying more inputs (labor, fertilizer, capital) per hectare of land to increase output.

In **sub-Saharan Africa,** agricultural output grew a healthy 2.98 percent per year (2011-2020). However, most of the growth was driven by opening up new land for cultivation and pasture, while **agricultural productivity contracted by 0.12 percent annually.** Converting grasslands, forests, and other wildlands to agricultural production can decrease biodiversity and wildlife habitat, and increase soil degradation and erosion.

South Asia, especially India and Bangladesh, has had steady productivity growth since 2001. TFP grew by an average of 2.34 percent annually from 2001-2010, remaining steady at 2.28 percent annually from 2011-2020.

Alarmingly, global agricultural productivity growth has fallen well below the level needed for sustainable growth of agricultural output.

5 Productivity growth supports resilience during system shocks.

Agricultural productivity-enhancing innovations and services reduce risks for producers and support resilience. This includes drought-tolerant seed varieties, drip irrigation systems, cover crops, improved animal genetics, mobile phone-based extension programs, and access to financial and insurance services.

6 Current efforts to accelerate productivity growth are inadequate to the scope of the challenge.

Governments, the private sector, research institutions, international development organizations, and civil society groups must take urgent and vigorous action to accelerate productivity growth. Only then can the world be assured that its agricultural systems are sustainable and resilient to shocks.

GAP LAUNCH 2022– A COMMON NARRATIVE EMERGES

By Tom Thompson, GAP Report Executive Editor

The *Accelerating Agricultural Productivity Growth for a Sustainable, Resilient World* event, co-hosted by Virginia Tech's GAP Initiative, the Sustainable Productivity Growth Coalition, and the United States Department of Agriculture, was held on October 4, 2022 at the National Press Club in Washington, DC. The launch of the 2022 GAP Report was featured during this event. The event was attended by 440 individuals in person and online, and featured data and discussions considering agricultural productivity growth from various perspectives. During presentations and panel discussions, several common themes emerged. These themes aligned with calls to action that emerged from the *Accelerating Agricultural Productivity Growth in East Africa: An agenda for urgent action* event hosted by the GAP Initiative in Nairobi, June 2022. A common narrative for how we can reverse the recent declines in global TFP growth is emerging. This will help us to align our collective efforts and investments in improving productivity globally.

EMERGING THEMES

Investment in public agricultural R&D is sorely needed to advance agricultural productivity.

Technology needs to be accessible to growers everywhere.

Improvements to agricultural productivity must be sustainable.

Progress is greater through partnerships.

Photo: Erica Corder, 2022

First, it is abundantly clear that more investment in public agricultural R&D is sorely needed to advance agricultural productivity–in low and high-income countries alike. In the U.S., public agricultural R&D investments are at their lowest level since 1970, when adjusted for inflation. This trend must be reversed if the declining TFP growth in the U.S. is to be reversed. In countries in Africa and Latin America, governments must carefully consider investments in national agricultural research systems. As USDA-ERS Senior Economist Keith Fuglie told the audience, "What underlies TFP growth are new technologies that help farmers improve efficiency and productivity. So, if we don't see enough new technologies being developed that could slow down the rate of TFP growth...we need to consider what are the R&D investments, what are the trends in the research, is enough progress being made to generate those new technological breakthroughs?"

Second, technology needs to be accessible to growers everywhere, especially in Africa. As Canisius Kanangire, executive director of the African Agricultural Technology Foundation, said, "I think that the major issue is that we need to bring technology and innovation to the hands of the farmers so that they can improve productivity and also address other issues such as post-harvest losses, which still take more than 40 percent of farmer production". Kanangire also highlighted the need for science-based regulatory systems and deregulation of biotechnologies and gene editing to improve farmer access to these productivity-enhancing tools. Another panelist, Robert Fries, Chief Technical Officer of ACDI/VOCA, remarked that "...technologies are available that are relevant and feasible for smallholder producers...but the systems and incentives to encourage access are often not in place."

Third, whatever we end up doing to improve agricultural productivity must be sustainable–environmentally, economically, and socially. Fortunately, best practices for improving agricultural productivity can contribute to the sustainability of natural capital and the resilience of human capital. As Andrés Rodriguez of the Embassy of Chile said, "Sustainability is a huge part of why we're trying to pursue TFP growth." The GAP Initiative is keenly interested in working towards a more comprehensive understanding of the linkages between TFP, sustainability, and resilience.

Finally, progress is greater through partnerships. At a GAP Report event in Nairobi, Kenya in June 2022 (see page 45) and at this event in Washington, the need for partnerships rose often to the surface. But questions remain–how can they be most effective? How do we transition to local ownership and sustainability of projects and programs tackled by partnerships? How do partnerships support local priorities and objectives while also bringing best-in-class solutions and innovation to the regions that need them most? Stewart Leeth, Chief Sustainability Officer of Smithfield Foods, offered an example of how Smithfield, the world's largest pork supplier, partnered with the Environmental Defense Fund to improve fertilizer management on 600,000 acres of grain production-an example of organizations with very different missions accomplishing a worthy goal together. For more examples of win-win partnerships, check out the partner stories in this Report.

To reverse the troublesome trend in agricultural productivity growth presented in this Report, increased investments in agricultural R&D are imperative, with public investment leading the way. These investments should catalyze the creation of technologies and knowledge that can benefit producers at all scales of agriculture. But if the products of R&D can't reach producers, change will not happen. Lowering barriers that prevent access to technologies is just as important as their development. The fruits of agricultural R&D and their employment must happen within the context of a commitment to sustainability and resilience. And through partnerships, we can often achieve more than we can alone–the whole is often greater than the sum of the parts.

PARTNER STORY

Photo: USDA/Lance Cheung

SUBMITTED BY: **Supporters of Agricultural Research Foundation (SOAR)**

TODAY'S INVESTMENT IS TOMORROW'S PROSPERITY

Agricultural research and development (R&D) investment in the U.S. is uniquely both a domestic and a global concern. U.S. publicly funded agricultural R&D drives the majority of domestic agricultural innovation but is also the engine that drives much of global agricultural progress.

Current investment trends, however, are not rising to the challenge. Closing the investment gap and accelerating gains in global total factor productivity will take a sustained, but achievable, approach-and such actions pay dividends.

A recent analysis by the USDA Economic Research Service found that investment in agricultural R&D has a 20-to-1 return on investment (ROI): for every $1 invested in research in the U.S. from 1900-2011, $20 of value was produced (Fuglie & Nelson, 2022).

U.S. public investment in agricultural R&D has fallen by a third since 2002 in inflation-adjusted dollars and is now at its lowest level since the early 1970s. This investment shortfall is causing the U.S. to fall behind other countries like China in agricultural R&D investment and threatens to curtail the vital global spillover effects of U.S. research that drive growth in total factor productivity.

Fortunately, this trend is reversible.

Recent modeling from the Breakthrough Institute finds that agricultural R&D investment directly boosts total factor productivity: the greater the investment, the greater the gains (Baldos & Blaustein, 2021). Were the U.S. to commit to 7 percent annual growth in public investment over the coming decade, total factor productivity of global agriculture would increase 20 percent over baseline by 2050.

U.S. investment in research can also drive reductions in agriculture's total global footprint, reducing both greenhouse gas emissions from agriculture as well as the cost of grains and foods worldwide. These global reductions in the costs of agricultural production would be a result of improved productivity of U.S. domestic agriculture relative to global output–part of agricultural research investment's overall ROI.

Agriculture is facing complex challenges in the coming decades, but focused investment in public-sector agricultural R&D can and must play a significant role in addressing these head on. The "slow magic" of agricultural R&D is why organizations like the Supporters of Agricultural Research Foundation and its partners work to ensure these investments are prioritized and that policymakers, scientists, and farmers alike know that through research, agricultural science can deliver the tools farmers across the world need to adapt and thrive.

CHAPTER 1: TROUBLESOME TRENDS IN TFP GROWTH

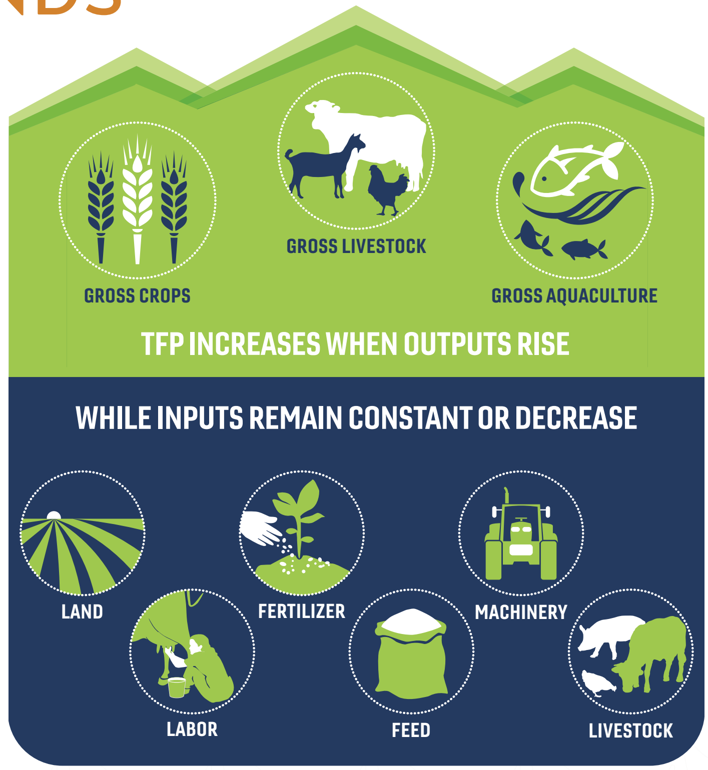


Figure 1: Total Factor Productivity

Agricultural productivity growth will be the linchpin of strengthening the world's agricultural systems in the next decade. It increases producers' incomes, can lower consumer costs, and reduces the environmental impact of food and agricultural production.

Agricultural productivity growth, measured as *total factor productivity* (TFP), increases when producers increase their output of crops, livestock, or aquaculture products, using the same amount or less land, labor, capital, fertilizer, feed, and livestock (Figure 1).

In other words, TFP rises when producers utilize innovative agricultural technologies to increase output with the same amount or fewer resources. For example, healthy animals produce more meat so that the farmer can increase their output without additional animals. By combining precision equipment, data analytics, and advanced seed varieties, producers know when to plant, where every seed is located, and the exact amount of fertilizer or crop protection products needed in every section of the field.

Since TFP incorporates a range of inputs and outputs in its calculation, it is "the broadest available measure of technical efficiency and productivity over time" (Fuglie & Steensland, 2022). As a result, tracking changes in TFP reveals a great deal about agricultural systems.

First, an increase in TFP shows that a large and increasing number of producers are adopting new technologies and practices. This also indicates the extent to which new technologies are accessible to farmers. It may also show the effectiveness of farmer training and extension systems.

Second, TFP growth makes the agriculture sector, including producers, more competitive by lowering production costs. A one percent increase in productivity growth is equivalent to a one percent decrease in the cost of producing, storing, and selling one unit of a particular product. Consumers can also benefit since the per-unit price for the producers works its way through the value chain, influencing the prices consumers pay.

Third, TFP encompasses three inputs that contribute significantly to agriculture's environmental impact: land, fertilizer, and livestock. Therefore, an increase in TFP generated by more efficient use of land, fertilizer, or livestock reflects progress toward a more sustainable approach to agricultural production.

The 2022 GAP Index reveals the lowest level of global TFP growth to date, an average of 1.12 percent per year (2011-2020), far below the target of 1.73 percent annual growth (Figure 2). If this rate remains unchanged, the gap will widen over time, making it increasingly difficult to close.

The implications of this growing gap are the widespread use of unsustainable agricultural practices, including the conversion of wild and marginal lands to agricultural production. As a result, a portion of the gap will remain unfilled, leading to unacceptably high levels of hunger, malnutrition, and rural poverty.

Explore productivity by country via our interactive map

TFP growth rates have declined for all country income groups, but low-income countries, where TFP has contracted by 0.04 percent annually during 2011-2020, are of significant concern. This contraction in TFP growth may exacerbate the already high levels of food insecurity and malnutrition and threaten the prospects for economic development in these nations. The experience of China and Southeast Asia shows that the agriculture sector can be a driving force for economic growth if producers can access innovations and services to increase their productivity (Fuglie et al., 2012). Given the current negative TFP growth rate in low-income countries, it is clear that current approaches are not sufficient.

The middle-income countries have rates of TFP growth above the global average yet less than the global target. Productivity growth has slowed in two regions that experienced high TFP growth in the 2000s: China and the countries of the former Soviet Union (See pages 9-10).

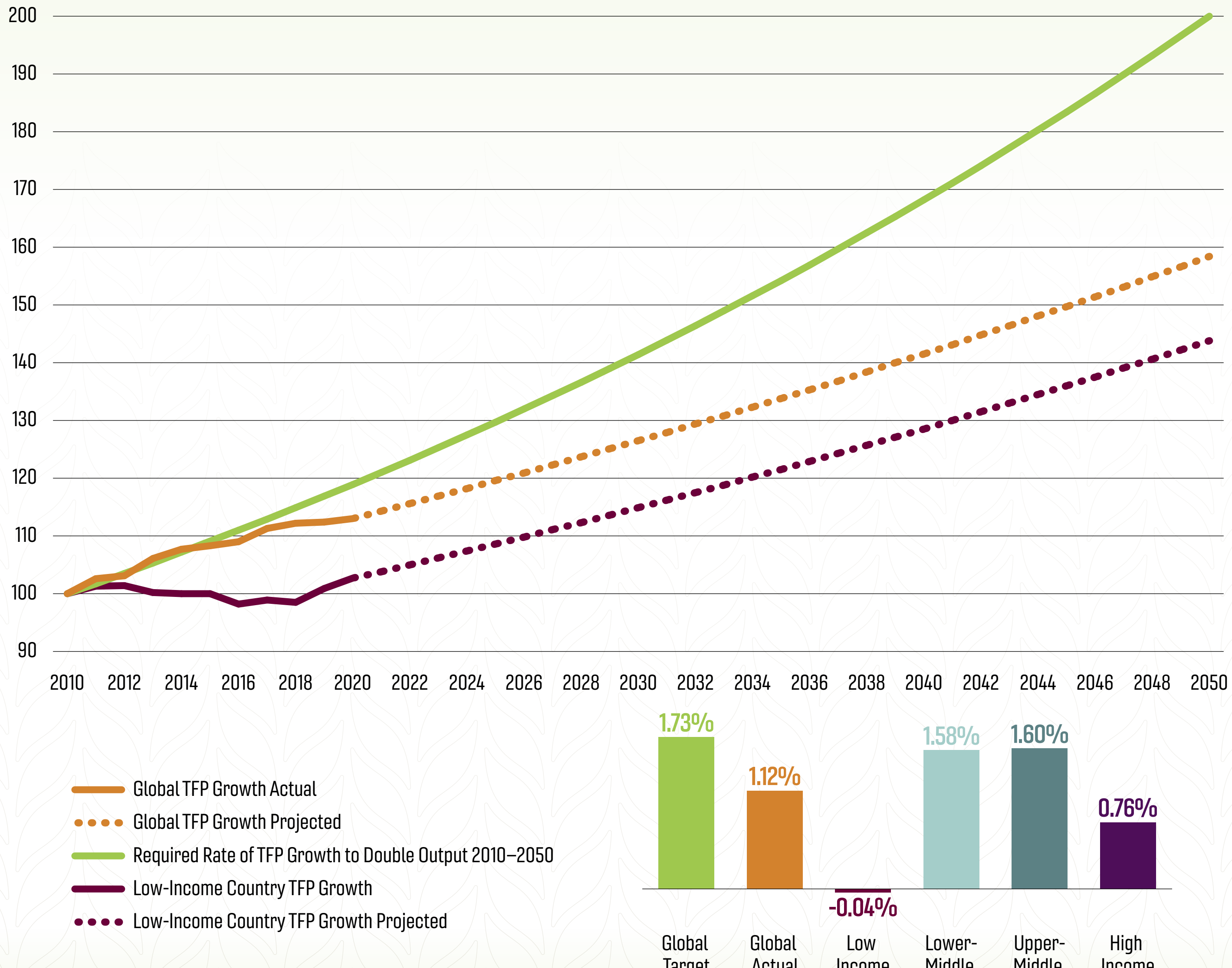
A GLOBAL VIEW OF TFP TRENDS

To appreciate the role of total factor productivity growth in agricultural systems, it is helpful to compare agricultural output and input use over time (Figure 3). Since 1961, gross agricultural output has increased four-fold while input use has slightly more than doubled. The distance between the two lines reflects the output that

Figure 2:

2022 GLOBAL AGRICULTURAL PRODUCTIVITY INDEX

TFP growth rates are based on a 10-year rolling average over a ten-year period.



Source: USDA Economic Research Service (2022).

can be attributed to the efficient use of agricultural inputs, some with a substantial environmental impact: land conversion, fertilizer, and livestock. In other words, TFP growth. Moreover, comparing agricultural input to output use over time demonstrates the essential role of TFP growth in the sustainability of agricultural systems (Fuglie et al., 2012).

Agricultural productivity growth is the primary source of global agricultural output growth since the 1990s (Figure 3). When TFP grows, land expansion can be limited or eliminated, and fewer inputs are needed on each acre of agricultural land. Extension of irrigation, especially in China, supported TFP growth and allowed producers to intensify their crop rotations, producing more crops on the same plot of land.

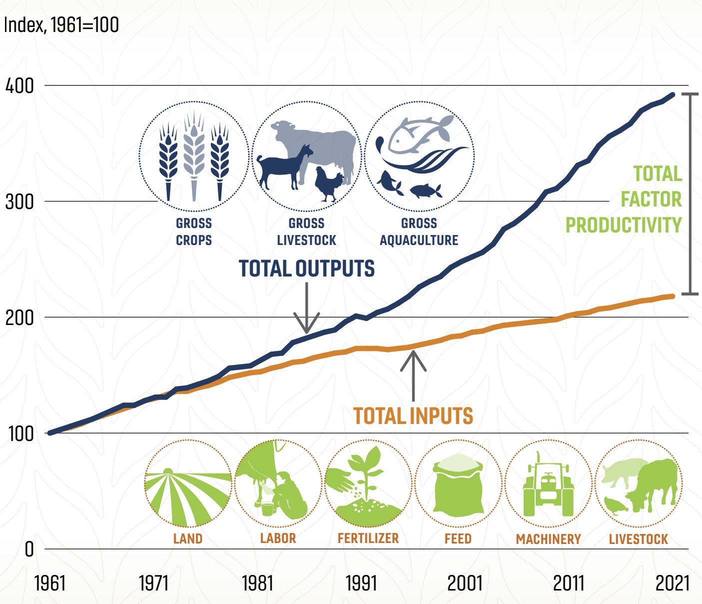
In contrast to global trends shown in Figure 3, low-income country agricultural output growth (more than 400 percent since 1961) has relied largely on increasing inputs, especially land expansion, arguably the least sustainable way to grow agricultural output. TFP growth in low-income countries continues to lag well behind the rest of the world, and suggests that agricultural sustainability and food security will continue to be elusive (Figure 4).

The most recent data show a sharp decline in TFP and output growth (Figure 5). The average annual TFP growth rate declined from 1.99 percent in 2001-2010 to 1.12 percent in 2011-2020. The contribution of land expansion (much of this in sub-Saharan Africa) to output growth more than doubled between the two decades, while the contribution of input intensification declined by 17 percent.

In addition to the significant drop in TFP growth, the USDA Economic Research Service is reporting for the first time that agricultural output grew by less than 2 percent (average annual growth, 2011-2020). This raises concerns about the prospects for reducing the recent increases in food insecurity and malnutrition. It is important to note that these data reflect impacts from only the first nine months of the COVID-19 pandemic, and no influence from the Russia-Ukraine war. In other words, the 2011-2020 TFP data illustrate a worrisome global trend of declining TFP growth. Climate change and other types of resource degradation may be taking a larger toll on productivity as well as a slower pace of change in the development and adoption of improved technology.

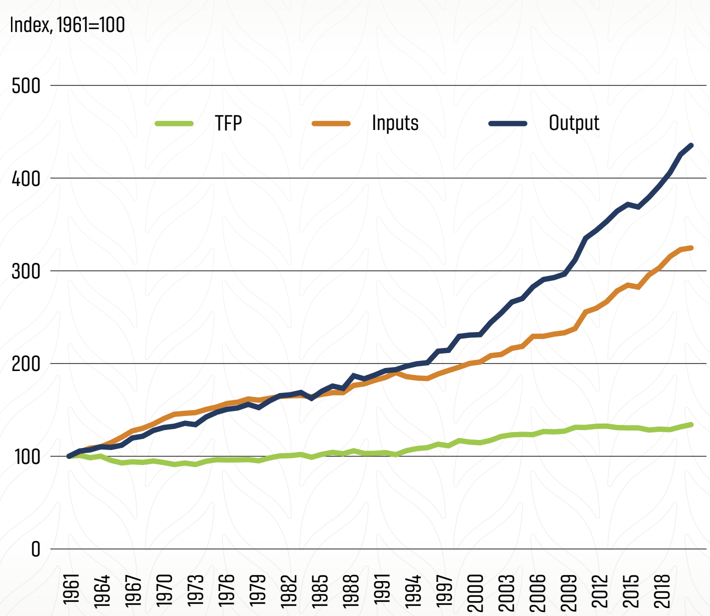
At the start of the twentieth century, producers around the world opened up new land for cultivation and grazing to increase their output. Then in the 1960s, the Green Revolution gave millions of farmers access to effective pesticides, fertilizer, and irrigation, sharply increasing output and preventing mass starvation (Figure 5). Subsequently, improved technologies and practices enabled producers to use their land and inputs more efficiently (i.e. TFP increased). By the 1990s, global agricultural productivity growth was the primary driver of

Figure 3: Global Agricultural Outputs, Inputs, and Total Factor Productivity (TFP), 1961–2020



Source: USDA Economic Research Service (2022).

Figure 4: Low-Income Country Agricultural Output, Input, and Total Factor Productivity, 1961–2020

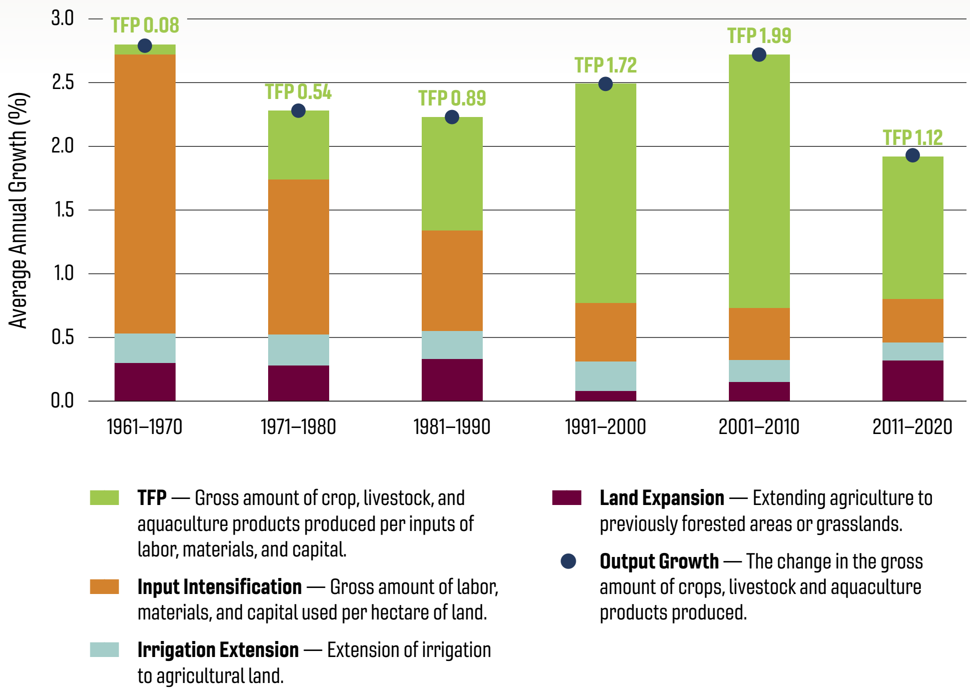


Source: USDA Economic Research Service (2022).

global agricultural output growth, and was well above the target 1.73 percent annual growth during 2001-2010. However, as noted above, TFP growth declined sharply during 2011-2020.

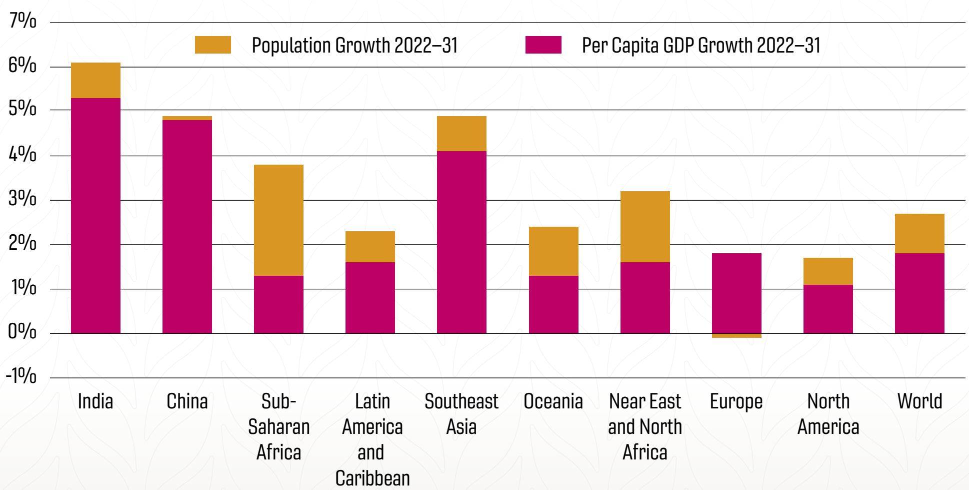
The Organisation for Economic Co-operation and Development (OECD) is predicting 1.4 percent annual growth in food demand during 2022-2031, mostly due to population growth. Total agricultural output growth averaged 1.93 percent during 2011-2020 (Figure 5). According to OECD's population growth projections (Figure 6), world per capita GDP growth will exceed population growth, meaning that net per capita income should increase worldwide. This trend is predicted to be especially pronounced in India, China, and Southeast Asia. In contrast, population growth in sub-Saharan Africa will be more than twice that of GDP. Thus, increasing TFP growth will be especially critical in this region to meet food demand and maintain an affordable food supply while protecting the natural capital on which agricultural production relies.

Figure 5: Global Sources of Agricultural Output Growth, 1961–2020



Source: USDA Economic Research Service (2022).

Figure 6: Population and Income Growth Projections, 2023–2032



Source: OECD/FAO (2022).

TFP TRENDS BY REGION

Examining TFP growth in key regions provides additional perspectives on productivity trends (Figure 7). Although global TFP growth during 2011-2020 was alarmingly low at 1.12 percent, TFP growth continues to be robust in South Asia and the Transition Countries (former Soviet Union) at 2.28 percent and 1.89 percent, respectively. In China, TFP growth was under 1 percent in the 1970s, and Transition Countries were experiencing negative TFP growth as recently as the 1990s. Market-driven policy changes have sparked a TFP transformation in these countries. Yet history shows that once these changes are integrated into the agricultural sector, TFP growth will slow down. China is a case in point. China's TFP growth averaged 2.48 percent from 2001 to 2010, falling to 1.59 percent from 2011-2020. The next challenge for countries is maintaining a steady rate of TFP 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 annual TFP growth rates of greater than 0.65 percent during 1980 through 2010, but with minimal investments in agricultural R&D, the region has been unable to sustain or improve TFP growth. The region is now experiencing negative TFP growth. Countries 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. These farmers have the most potential for productivity growth but urgently need access to improved technologies and agronomic information, as well as an enabling policy and trade environment for TFP growth.

In sub-Saharan Africa, underinvestment in agricultural research and development and farmer training throughout most of the continent has left farmers with few options for increasing output (Fuglie and Rada, 2013). With limited access to productivity-enhancing technologies such as mechanization, advanced seeds, fertilizer, and improved livestock breeds and feed, farmers are expanding crop and grazing lands at an alarming rate, with negative impacts on biodiversity.

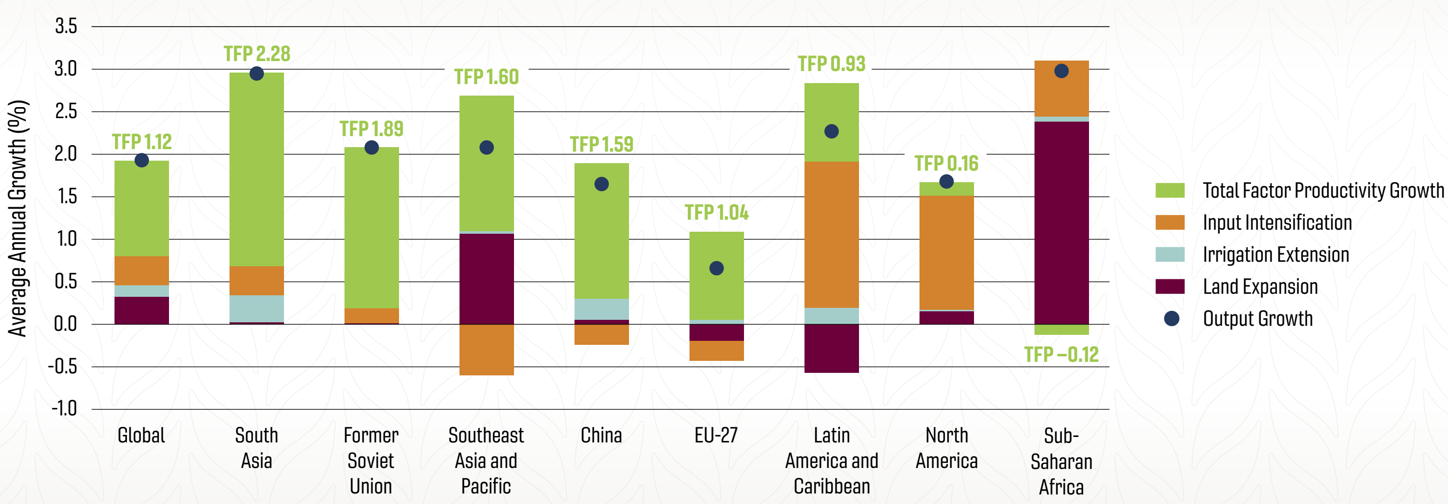
In South Asia, TFP grew at a robust average annual rate of 2.28 percent during 2011-2020, essentially the same growth rate as during 2000-2010. Input intensification and irrigation extension are also contributing significantly to output growth. Extending and improving India's irrigation systems boosted productivity on already cultivated land. Increased access to mechanization services and improved seed genetics have reduced the need for agricultural labor. Land expansion for agriculture is now near zero.

The rate of TFP growth in North America has slowed from 1.6 percent annual growth during the 1990s and 2000s to a paltry 0.16 percent during 2011-2020. The slowdown coincides with decreased public-sector agricultural research and development investments–the cornerstone of TFP growth. According to the USDA Economic Research Service, in 2019 U.S. public agriculture and food R&D expenditures in constant dollars reached its lowest level since 1970. A renewed commitment to public investment in agricultural innovations, especially in the United States, is crucial to return to robust TFP growth. Furthermore, U.S. agricultural R&D innovations can benefit other countries as well.

Similar to North America, TFP growth in Latin America and the Caribbean (LAC) was robust, growing at more than 2 percent annually during 1991-2010. Precision agriculture, advanced seed technologies, and improved livestock management systems have driven substantial TFP growth in feed grains and livestock production in countries such as Brazil and Chile. However, during 2011-2020, TFP growth in LAC decreased to less than 1 percent annually, and input intensification became the leading contributor to agricultural output growth.

TFP growth in Europe remains sluggish at about 1 percent annually. Output and TFP growth have been strong in breadbaskets of the former Soviet Union, particularly Russia and Ukraine, far above those of EU countries. However, the current Russia-Ukraine conflict is creating input and food supply and price crises globally, and will undoubtedly reduce TFP growth. The full impact of the conflict remains to be seen.

Figure 7: Sources of Agricultural Output Growth by Region, 2011–2020



Source: USDA ERS, 2021

CHAPTER 2: SYSTEM SHOCKS






The Greek philosopher Heraclitus said that “change is the only constant in life”. We’ve been forcefully reminded of this during the past two to three years. Until 2020, much (but not all) of the world had enjoyed years of strong economic growth, booming trade and improving food security. But in 2020 that all changed with the appearance and spread of the COVID-19 virus and the resulting response by almost every national government. The ensuing health shock was compounded by restrictions that limited the pursuit of livelihoods, locked down huge sectors of the economy, damaged educational progress, and cost vast sums of money. And, when recovery had begun from the pandemic by early 2022, the Russian invasion of Ukraine rocked agricultural input and export markets. The fragility of many of the systems we rely on for producing and moving agricultural products has been exposed, and the implications are sobering.

In this chapter we will explore the shocks of the COVID-19 pandemic, the conflict in Ukraine, the ongoing trade and transport restrictions, as well as longer-term shocks brought on by drought, climate change, and extreme climate events on our agricultural systems, and the possible short- and long-term impacts on growth in total factor productivity. It is most important that we understand how these and future shocks may impact agricultural systems and TFP growth, and how we might strengthen agricultural and food systems to be resilient in the face of shocks.

EXTREME WEATHER EVENTS AND PRODUCTIVITY GROWTH: NEW RESEARCH

By Wei Zhang, Assistant Professor, Agricultural and Applied Economics, Virginia Tech

Professor Zhang is the GAP Initiative Faculty Research Fellow. Funding for her research was provided by CALS Global in the College of Agriculture and Life Sciences at Virginia Tech.

Photo: ©2021 Alianza de Bioversity International y CIAT/Juan Pablo Marin García

KEY FINDINGS

Studies of climate change and agriculture tend to focus on a limited number of environmental or agricultural factors, reducing their usefulness in evaluating complex, system-level threats.

As a performance indicator of a country's agriculture system, total factor productivity growth captures the overall impact of climate events.

Extreme climate events are estimated to have, on average, a negative and statistically significant impact on the TFP growth rate.

The estimated impact of droughts is more than three times the impact of an average extreme climate event.

Climate shocks can have a sustained impact on the growth trajectory of agricultural productivity well beyond the initial event.

Photo: Washington State Department of Agriculture

Climate change affects many dimensions of agricultural systems and could threaten global food security and social stability (Wheeler and Von Braun, 2013). However, studies have disproportionately focused on the effects of changes in average seasonal temperature and precipitation (see, e.g., Schlenker and Roberts, 2009; Lobell et al., 2011). It is increasingly evident that climate change has implications besides rising average temperature or precipitation.

The frequency and intensity of extreme weather events, such as severe droughts, intense storms, or scorching heat waves, have increased over the last few decades. Our research examines the relationship between extreme climate events and agricultural productivity growth across countries. It is hard to overemphasize the importance of enhancing agricultural productivity for poverty reduction and economic transformation (Johnston and Mellor, 1961; Christiaensen et al., 2011; Jayne et al., 2021). Climate change studies that focus on one type of agricultural output, such as crops, are minimally helpful in evaluating the overall performance of agricultural systems under a changing climate. In response to climate change, adjustments in agricultural inputs, such as land, must also be captured (Aragón et al., 2021). Consequently, studies of the impact of climatic factors on aggregate agricultural productivity growth are particularly important for projections of future changes in climate on the agricultural sector and the whole economy (Liang et al., 2017).

We use total factor productivity (TFP) to measure agricultural productivity. TFP is the ratio of aggregate output to aggregate input, including land, labor, capital, and other materials. The data on extreme climate events are from the International Disasters Database (EM-DAT). We include the following climate events in our study: storm, extreme temperature, flood, drought, and wildfire. Though there is no consensus on the classification of extreme climate events, this list includes most of the commonly considered weather and climate events.

When extreme climate events occur, many aspects of agricultural systems are influenced. The immediate outcome is the diminution of agricultural output (Lesk et al., 2016). In addition, regional resource reallocation could follow, such as the diversion of irrigation water or changes in transportation channels. The physical capital of agricultural production, such as machinery and livestock inventory, and the infrastructure of supply chains, such as roads or storage units, could also be negatively affected. The economic consequences often go beyond the impact area of an extreme climate event. Thus, extreme climate events could affect the entire agricultural sector or even a country's economy. Agricultural TFP growth as a performance indicator of a country's agriculture captures the overall impact of climate events.

Climate shocks can have a sustained impact on the growth trajectory of agricultural productivity. Dynamic effects are frequently long-lasting, representing the impacts of climate change on the adjustment path of agricultural systems. When climate shocks result in productive asset destruction, households, communities, and countries may have to save and reinvest to return to the capacity to produce at the level they had before the shock.

In general, one would expect the TFP growth rate to be lower than the trend on impact due to loss of outputs but could be either higher or lower than the trend thereafter. For example, if a drought leads to investment in irrigation systems or adopting drought-tolerant seed varieties, TFP growth could be faster than along the previous trajectory (Caballero et al., 1994). However, institutional constraints, such as lack of credit or access to markets, could affect the long-term impact of extreme climate events. Studies have shown that long-run impacts of extreme climate events are particularly damaging to the economic development of disaster-prone low-income countries (Carleton and Hsiang, 2016; Hallegatte and Rozenberg, 2017). Households and countries struggling to meet basic consumption requirements may have a tough time for reconstruction and asset accumulation, thus staying at a lower growth path or even trapped in a low-level equilibrium (Hallegatte et al., 2007).

Photo: Asian Development Bank

We estimate that extreme climate events on average have a negative and statistically significant impact on the TFP growth rate. The estimate is not sensitive to controlling for changes in temperature and precipitation. To put the estimate in perspective, in a year when the total number of extreme climate events per 100 square km is at the sample mean of 1961-2016 (0.0022), TFP growth rate is estimated to be lowered by 0.46 percentage points. In 2016, Haiti experienced floods, storms, and drought, which put their total number of extreme climate events per 100 square km to be 0.029, at the 99th percentile of our measure of extreme climate events. Based on our estimate, their TFP growth rate would be lowered by six percentage points.

The estimated impacts on TFP growth rate are all negative across different extreme climate event types and are statistically significant for storms and droughts. The estimated impact of droughts is more than three times the impact of an average extreme climate event. At the sample mean of our measure of drought (0.0015), the TFP growth rate would be lowered by 1.11 percentage points. Future analysis could examine the channels through which droughts could affect agricultural productivity growth more than storms or floods. One hypothesis is that droughts affect wider geographic areas than storms or floods. Though not precise, the estimated impact of wildfires on TFP growth is the largest among all types, about six times the impact of an average extreme climate event. One hypothesis is that wildfires damage the capital of agricultural production, such as perennial crops, more than other extreme climate events.

Our study provides an overall assessment of extreme climate events on agricultural productivity growth. Macro-econometric studies like ours do not capture their impact at the sub-national level (Damania et al., 2020). Future finer-scale studies could be insightful on the channels of adaptation of agricultural systems–both institutional and physical–to climate extremes.

Endnotes for this article are available at globalagriculturalproductivity.org. Explore the online map of the number of extreme weather events per 100 square km from 1961-2019. Correspondence for Wei Zhang may be sent to: wzb@vt.edu.

EXPERT ESSAY

EXTERNAL SHOCKS DEMONSTRATE FRAGILITY OF GLOBAL FOOD SYSTEM

By Dr. Stephanie Mercier, Senior Policy Adviser, Farm Journal Foundation

INTRODUCTION

On March 11, 2020, the World Health Organization (WHO) declared that a novel coronavirus that emerged in China in late 2019, had spread so widely and rapidly around the world that it had become a global pandemic. By that point in time, 118,000 cases of COVID-19, had been identified in 114 countries.[1] Within two weeks, 136 countries had imposed an array of health measures in response, including school lockdowns, travel restrictions, and shutdown of most venues in which large numbers of people gathered together in close spaces, such as restaurants, theaters, and sporting events. Businesses deemed to produce and distribute 'essential goods' were exempted from such restrictions, though what goods and services fell into that category varied by country. These restrictions had significant impacts on both the production and consumption of food and agricultural products around the world. According to data reported by the World Trade Organization (WTO), the volume of agricultural product exports fell by 5 percent in the second quarter of 2020, after averaging a 4.1 percent growth rate between 2010 and 2019.[2]

Almost as soon as the economic restrictions imposed to reduce the spread of COVID-19 were relaxed in mid-2021, a second bottleneck emerged stemming from a mismatch of supply and demand for transportation services, both for movement of goods between countries through oceanic shipping and domestic movement via rail and long-haul trucking in many countries. Freight rates and shipping times soared, contributing to a general increase in prices for a range of goods, including food and energy.

As the shipping bottleneck finally started to unwind in early 2022, the world agricultural economy was hit by another major shock, the Russian invasion of Ukraine in late February. This invasion has wreaked havoc on Ukraine's agricultural exports, which prior to the invasion enjoyed a key role in the world's wheat, corn, and oilseed markets. Subsequent sanctions against Russia and their close ally Belarus have also hampered those countries' trade in grain, fertilizer, and energy.

[1] World Health Organization (2020-March 11). WHO Director's opening remarks at the media briefing on COVID-19–11 March 2020. https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020.

[2] World Trade Statistical Review (2021). World Trade and Economic Growth, 2020-21. https://www.wto.org/english/res_e/statis_e/wts2021_e/wts2021_e.pdf.

EXPERT ESSAY

There has been no period in recent history, with the possible exception of World War II, in which world agricultural markets have been disrupted in so many profound ways. The impact on the global food system of these recent shocks has resulted in a more than 150 percent increase in acute hunger globally today as compared to 2019.

IMPACT OF THE COVID-19 PANDEMIC ON FOOD SUPPLY AND DEMAND

COVID-19 first emerged in China in late 2019. However, its arrival was not well known outside of China until authorities imposed restrictions on the people and economies of the city of Wuhan and other cities in Hubei province to prevent further spread of the disease in late January of 2020. Under the quarantine rules, people living in affected cities were barred from leaving their homes except for one person from each household, who could go out to buy food or medicines every other day. Inter-city travel was also barred. A number of countries subsequently established restrictions on travel to and from China but access to reliable methods for detecting infections were limited and cases spread rapidly, first in Asia, then Europe, and then to the United States by mid-February. The WHO declaration of the disease's pandemic status followed shortly, and national governments imposed a variety of public health restrictions in response.

While food production, processing, and food retail outlets were exempted from shutdowns in most countries, COVID-19 outbreaks occurred frequently in individual facilities, leading to short term closures to clean and reconfigure processing lines. Such outbreaks were particularly a problem in the meat-packing sector. Numerous large facilities in the U.S. Midwest experienced multiple outbreaks, causing backups in delivery of animals for slaughter that led to significant farmgate price declines.

A 2021 analysis published by Reuters found that 90 percent of meat packing plants owned by the biggest companies shut down at least once in the first year of the pandemic, and more than 59,000 workers at those plants were infected with COVID-19 during that period.[3] During April and May of 2020, U.S. beef and pork production numbers were down 20 and 12.5 percent respectively compared to the previous year. Prices started to recover during the summer of 2020 (Figure 1).[4] Plant closures declined starting in late April 2020 despite continued outbreaks in facilities, as a result of the Defense Production Act that classified these plants as 'essential infrastructure' to keep them open.

Schools were physically closed across the globe beginning in the last few months of the 2019/20 school year, a move which lasted well into 2021 in most places. In most countries, schools and universities shifted to conducting classes remotely. These closures, as well as closing down in-person restaurant dining, practically wiped out institutional demand for food products. As a result, food processing lines had to shift from producing their goods in bulk quantities. Dairy processors who sold cheese in wheels up to 75 pounds to school districts, for example, had to re-gear their facilities to serve households typically buying one-pound blocks of cheese. Restaurants also had to revise their business models to focus on sales through takeout and delivery options. Not all were successful in this effort–according to a survey conducted by the National Restaurant Association of India, the country's food service sector fell by 53 percent between April 2020 and March 2021.[5]

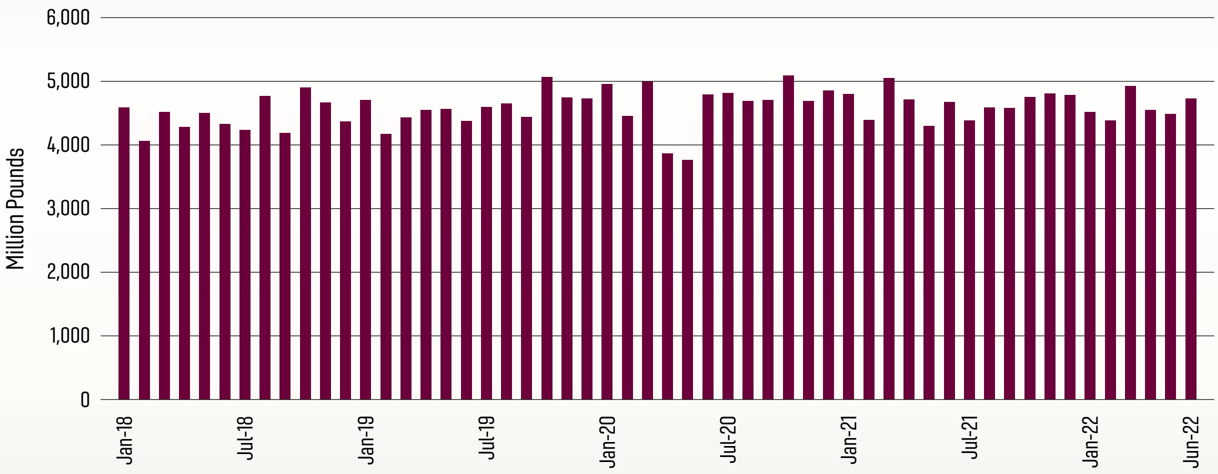
The International Center for Not-for-Profit Law (ICNL) reported in 2022 that curfews had been imposed in 37 of 46 countries in sub-Saharan Africa due to COVID-19. This discouraged food from being delivered to markets and hampered delivery

[3] Douglas, Leah (2022-January 14). Nearly 90 percent of big U.S. meatpacking plants had COVID-19 cases in pandemic's first year. *Reuters*.

[4] National Agricultural Statistics Service, U.S. Department of Agriculture (various issues). Livestock Slaughter.

[5] Suresh, Haripriya (2021–October 26). Indian Restaurants Shrunk by 53 percent due to COVID-19." *The News Minute*.

Figure 1: Monthly Red Meat Production, U.S.



Source: USDA/NASS, Livestock Slaughter report.

of food assistance to rural populations.[6] In June 2020, the Organization for Economic Cooperation and Development (OECD) found that transport and logistics problems were most pronounced globally for perishable high-value products, such as fruits and vegetables. The fruit and vegetable sector was also affected by quarantine measures and delays in border inspections, to the extent that such products were being shipped across national borders.[7]

The COVID-19 shutdowns also wreaked havoc on the demand side of the food system equation. Millions of households had their incomes slashed due to lost employment. In developed countries, national governments were able to deficit-finance assistance to both businesses and individuals. Despite averaging a nearly 11 percent unemployment rate for April through December of 2020 in the U.S., 2020 median household income only fell 2.9 percent compared to 2019.[8] However, governments in developing countries didn't have such resources, and the per capita incomes of their working-class citizens plummeted. On average, per capita Gross Domestic Product (GDP) declined 7.2 percent in sub-Saharan Africa during the same period. A 2022 World Bank study found that between-country income inequality between rich and poor nations increased during the pandemic, partly reversing the gains of the last few decades.[9] Thus, overall purchasing power was little changed in high-income countries, but was more affected in low- and middle-income countries.

Spending behavior was also modified during the course of the pandemic. A survey of U.S. consumers

6 International Center for Non-for-Profit Law (2022–August 5). African Government Responses to COVID-19. https://www.icnl.org/post/analysis/african-government-response-to-covid-19.

7 Organization for Economic Cooperation and Development (2020-April 29). COVID-19 and the food and agriculture sector: issues and policy responses. https://www.oecd.org/coronavirus/policy-responses/covid-19-and-the-food-and-agriculture-sector-issues-and-policy-responses-a23f764b/.

8 Bureau of the Census, U.S. Department of Commerce (2021–September 14). Income: Poverty in the United States.

9 Adarov, Amat (2022–February 7). Global Income Inequality and the COVID-19 Pandemic in three charts. World Bank blogs. https://blogs.worldbank.org/developmenttalk/global-income-inequality-and-covid-19-pandemic-three-charts#:~:text=The%20ongoing%20COVID%2D19%20pandemic,to%20raise%20between%2Dcountry%20inequality.

in 2020 by Inmar Intelligence found that 46 percent had built a stockpile of supplies against fear of product shortages during the early days, with a focus on sanitation goods like toilet paper and hand sanitizer, canned goods, and alcoholic beverages.[10] Similar behavior was documented in China during that country's early 2020 lockdowns, also focused on grocery goods.[11]

The decision to close down much of the global service sector, especially travel and in-person hospitality and entertainment venues, to reduce the spread of the novel coronavirus also led to a significant shift in normal consumer spending patterns. Goldman Sachs estimated that during the pandemic, U.S. consumers increased their usual share of spending from disposable income on goods–both durable and non-durable–by 15 percent as compared to spending on services. That gap persisted through the spring of 2022, although it had declined to five percent.[12]

SHIPPING BOTTLENECK

The changes in food consumption and production patterns during the peak of the pandemic contributed significantly to the disruption of global shipping flows that manifested in early 2021. The seeds of that disruption were sown in 2020, with container ships delivering millions of masks and other medical supplies to ports in Africa and Latin America, to help local populations cope with the COVID-19 outbreak. Rather than wait for locally produced goods to be loaded into the containers, many companies chose to leave empty containers sitting at the ports.[13] Much of the increased demand for goods by American and European consumers was for products manufactured in China and elsewhere in Asia. As the export surge began, shipping companies did not have sufficient containers available for those routes to meet the elevated demand. Freight rates soared as a result, and have stayed high for many months even as companies have diverted ships and containers from less profitable trade routes with lower-income countries to bolster their capacity to carry goods to North America and Europe.

The freight rate changes were not uniform across all trade routes-the highest rates were assessed for carrying goods from Asia to North America and Europe. It became more profitable for ships to unload their goods from Asia at West Coast ports and then leave with empty containers. This strategy hampered export opportunities for U.S. firms, including agribusinesses. According to an analysis conducted by CNBC, it caused a loss of $1.3 billion in U.S. agricultural exports.[14]

The container unloading facilities and staffing levels at many major ports around the world were unable to keep pace with increased trade flows, further contributing to the shipping bottleneck. For example, in January 2022, about 150 civilian container ships were anchored or circling outside various U.S. ports, particularly outside the West Coast ports of Los Angeles and Long Beach, waiting for a berth to open up so they could unload.[15] Bulk vessels use different facilities at ports, so their time spent in port has been affected far less than their counterparts in the container shipping business. In fact, the multinational retail giant Walmart specifically chartered bulk vessels in 2021 and loaded them with 53-foot long containers (typical shipping containers are 40 feet long) filled with goods produced in China to circumvent bottlenecks at U.S. container port facilities. This

[10] Silverstein, Sam (2021–August 11). Fear of shortages spurs consumers to hoard essentials as virus surges, research shows. *Grocery Dive*.

[11] Wang, Holly, and Hao Na (2020-Volume 19(12)). Panic buying? Food hoarding during the pandemic period with city lockdown. *Journal of Integrative Agriculture*.

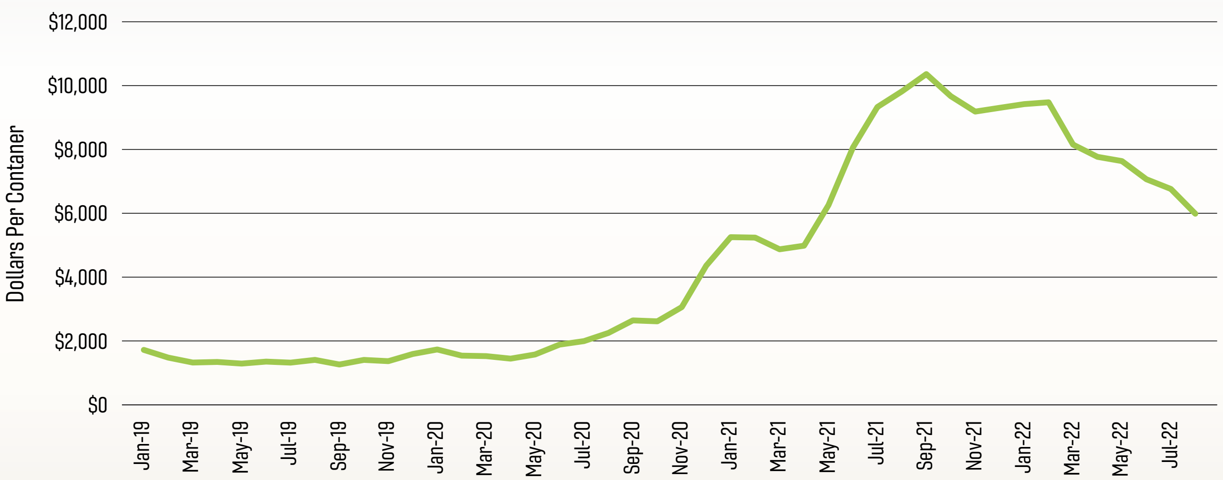
[12] Lynch, David (2022-May 28). Consumers are shifting their spending from goods to services. *Washington Post*.

[13] Goodman, Peter, Alexandra Stevenson, Niraj Chockshi, and Michael Corkey (2021–March 6). Logjam at sea as virus roils global trade. *New York Times*.

[14] LaRocco, Lori Ann (2021–March 15). Carriers rejected at least $1.3 billion in potential U.S. agricultural exports from July to December. CNBC website: https://www.cnbc.com/2021/03/15/carriers-rejected-at-least-1point3-billion-in-potential-us-agricultural-exports.html.

[15] Miller, Greg (2022- July 18). There still over $40 billion in cargo on container ships waiting offshore. *American Shipper*.

Figure 2: Global Container Freight Index (Monthly, in U.S. Dollars)



Source: Statista.

allowed them to meet the demand for products for Christmas gifts in that year.[16]

An analysis by the International Monetary Fund (IMF) released in March 2022 found that the cost of shipping a container on the world's transoceanic trade routes increased nearly seven-fold in the 18 months following the declaration of the COVID-19 pandemic in March 2020[17] (Figure 2). The cost of shipping bulk commodities also rose significantly over roughly the same period. The Baltic Dry Index, which tracks changes in the cost of transporting raw materials such as coal and steel, increased by more than 500 percent between December 2019 and September 2021.

The container shipping bottleneck began to ease and freight rates to abate in early 2022 when the emergence of the more contagious omicron variant of COVID-19 in China led to new lockdowns in Shanghai and other cities, including Beijing. This slowed manufacturing and exports out of China once again. The Purchasing Managers Index (PMI) data indicated that for the first few months of 2022, the entire Chinese economy contracted at a rate not seen since February 2020, when the original COVID-19 wave emerged.[18]

According to a 2014 study, about 23 percent of food produced for human consumption is traded globally.[19] Populations in countries that are heavily import-dependent on food have been affected most directly by the increased shipping costs. While many of the countries who have the largest food import bills (e.g., U.S., China, Germany, Japan) do so primarily to improve the variety of their population's diets, some lower income countries

[16] Baertlein, Lisa, Jonathan Saul, and Siddhartha Cavale (2021-October 7). Containergeddon: supply crisis drives Walmart and rivals to hire their own ships. *Reuters*.

[17] Carriere-Swallow, Yan, Pragyan Deb, Davide Furceri, Daniel Jimenez, and Jonathan Ostry (2022-March 25). Shipping costs and inflation. IMF Working Paper, https://www.imf.org/en/Publications/WP/Issues/2022/03/25/Shipping-Costs-and-Inflation-515144.

[18] Hauck, Katherine, and Roshni Mehta (2022–April 20). The Economic Cost of China's Lasting Zero Covid Strategy. *Think Global Health*.

[19] D'Odorico, Paolo, Joel Carr, Francesco Laio, Luca Rudolf, and Stefano Vandini (2014–September). Feeding Humanity Through Global Food Trade. *Earth's Future*, Volume 2(9).

rely on food imports primarily to address food insecurity because their own agricultural sectors are unable to produce enough food for domestic consumption. The Global Atlas lists 34 countries in that category, including many that have recently been beset by war or civil conflict, such as Afghanistan, the Central African Republic, Mali, Somalia, and Yemen.[20]

Increases in domestic shipping costs have also affected the food supply chains of many countries around the world. These problems have contributed to the backlog at seaport facilities as the shortage of trucking (and rail in some countries) capacity has slowed the movement of goods from the ports into countries' interiors. These shortages have also increased costs and delays associated with movement of raw commodities and finished food products along the supply chain in landlocked regions as well. The problem of access to sufficient labor to meet internal shipping demands has been building for several years, but was aggravated by COVID-19 and the crisis in Ukraine. The U.S. trucking industry estimated at the end of 2021 that they were facing a shortfall of 80,000 truck drivers, while in China the comparable estimate was 4 million. Japan's trucking workforce has been in a long-term decline due to an aging population. The government of Japan recently announced plans to implement autonomous (driverless) trucking services to alleviate the crunch.[21] The reasons for this problem vary between countries, but it is often the result of drivers' dissatisfaction with the solitary lifestyle and/or low pay compared to other occupations with more agreeable working conditions.

IMPACT OF RUSSIA'S INVASION OF UKRAINE

In late February 2022, the government of Russia launched a multi-prong invasion of Ukraine. This unprovoked action prompted the United States, its NATO partners, and other allied countries in Europe and Asia to impose an escalating array of economic sanctions on Russia and its close ally Belarus.

The conflict has had a devastating effect on the Ukrainian agricultural sector, both in terms of inhibiting farmers' ability to plant their spring crops and to harvest the winter crop (primarily wheat). At the end of the 2022/23 spring planting season, it was estimated that Ukrainian farmers were able to plant about 70 percent of their typical acreage of corn, sunflowers, and spring wheat during this period.[22] The shortfall was due to bomb-damaged fields, lack of access to inputs, and damage to or theft of farm equipment by Russian troops. After the Russian withdrawal from Kyiv, the Ukrainian military deployed troops to check 300,000 hectares of crop land for mines before it could be safely cultivated.[23]

The winter wheat harvest in Ukraine started in June 2022, with a crop of up to 20 million tons expected in the portions of the country still controlled by the Ukrainian government. Another five million tons was set to be harvested in areas under Russian occupation.[24] In the year prior to the invasion, Russia and/or Ukraine ranked among the top three global exporters of wheat, barley, corn, rapeseed and rapeseed oil, sunflower seed and sunflower oil. The Russian Federation also ranked as the world's top exporter of nitrogen fertilizers, the second leading supplier of potassic fertilizers and the

[20] Cargo, Lannessa (2017-December 5). Countries Most Dependent on Others for Food. World Atlas.

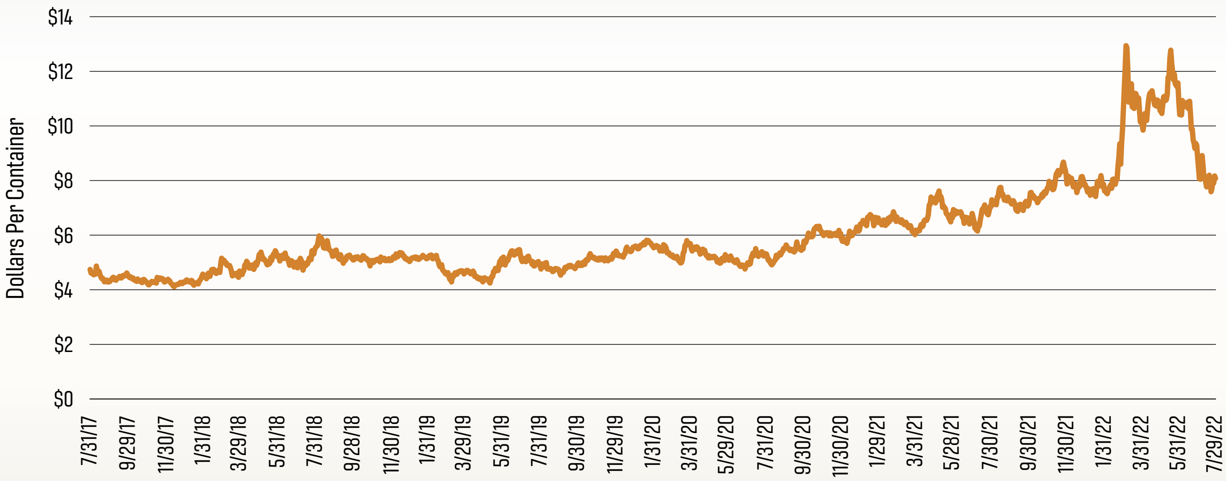
[21] Hope, Graham (2022–March 10). Japan is one step closer to launching driverless vehicles. *IOT World Today*.

[22] Neeley, Todd (2022-May 15). Corteva expects 70 percent of planting in Ukraine." *DTN*.

[23] Kudrytski, Alaaksandr (2022-April 4). Scouring half of Ukraine for mines highlights crop planting pain. *Bloomberg*.

[24] Polityuk, David (2022–May 30). Winter wheat harvest in Ukraine-controlled area seen at 20.1 million tons in 2022. *Successful Farming*.

Figure 3: CBOT SRW Wheat Futures Closing Price, 2017–2022



Source: https:/www.nasdaq.com/market-activity/commodities/zw/historical.

third largest exporter of phosphorus fertilizers. As a direct result of the Russian invasion, Ukraine's agricultural exports had ground almost to a halt for several months, while Russia's grain and fertilizer exports have also been affected due to sanctions.

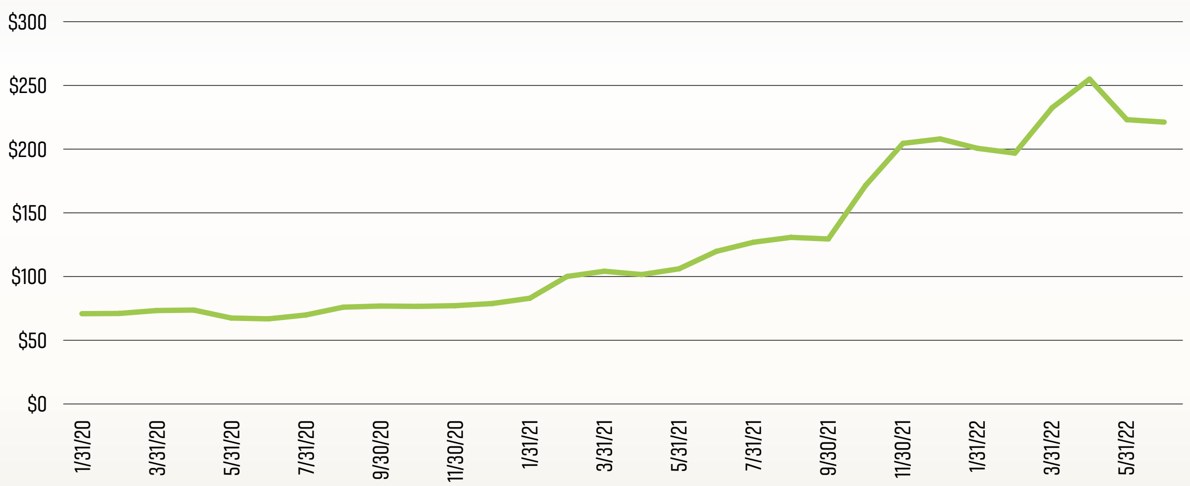
The Russian assault included a marine component, primarily consisting of a blockade imposed on commercial vessels out of Ukraine's ports on the Black Sea. An estimated 22 million tons of grain that had been designated for export was instead sitting in storage or in the holds of ships unable to leave ports such as Odesa. Efforts have been made to export grain via rail or truck, but such routes are unable to carry large volumes, especially since Ukraine's railroad tracks do not match the rail systems of their neighbors to the west. The blockade also imperiled this year's crops, as most grain storage facilities were already largely filled with old crop grain. The newly harvested wheat crop's quality will suffer if farmers are forced to seek temporary storage solutions.

In the first few weeks after the invasion, global grain and oilseed prices soared as fears of an imminent food shortage emerged. Ukraine's primary export customers include low- and middle-income countries in the Middle East and Africa. These countries have been hard pressed to find reasonably priced replacements for the lost imports from Ukraine. The futures price for U.S. wheat rose nearly 50 percent within two weeks of the invasion, but has fallen gradually in the past few months (Figure 3). On July 27th, a deal between Russia and Ukraine to allow resumption of grain shipments through the Black Sea was reached, brokered by the government of Turkey and the United Nations (UN).[25] Through September 22nd, 2022, the Joint Coordination Center, an ad hoc entity created by the UN and the governments of Turkey, Russia, and Ukraine to monitor shipments, reported that 4.3 million tonnes of grain and other agricultural products had been shipped out of Ukraine's Black Sea ports. Shipments were comprised primarily of corn and wheat destined for a variety of countries in Europe, Africa, the Middle

[25] Picheta, Rob, Jomana Karadsheh, Radina Gigova, and Tim Lister (2022–July 23). Kyiv and Moscow agree to resume Ukraine grain exports from Black Sea ports. CNN website https://www.cnn.com/2022/07/22/europe/ukraine-russia-grain-deal-turkey-intl/index.html.

EXPERT ESSAY

Figure 4: Monthly Fertilizer Price Index, 2020–2022



Note: Weighted average of natural phosphate rock, phosphate, potassium, and nitrogenous prices. Based on current US dollars, 2010=100.
Source: World Bank.

East, and Asia.[26] In 2021, Ukraine's agricultural exports had averaged 4 million tonnes per month.[27]

Fertilizer exports from Russia and Belarus were exempted from the sanctions imposed by the United States and EU member countries. However, trade flows in those products have been reduced as a result of the Russian government urging its fertilizer manufacturers to withhold exports immediately after the invasion, as well as complications on completing transactions due to sanctions on most Russian banks.

The price of nitrogen fertilizer spiked at that time, increasing more than 20 percent between February and April of 2022. This followed hefty increases in 2021 due to the shipping bottleneck and Chinese fertilizer export restrictions that started in the fall of 2021[28] (Figure 4). The higher prices have made fertilizer cost-prohibitive for many smallholder farmers in sub-Saharan Africa, resulting in lower crop yields that are likely to persist.[29]

[26] Joint Coordination Centre (2022-September 22). Operational update–22 September 2022–Black Sea Grain Initiative/ Joint Coordination Centre. https://turkiye.un.org/en/200616-operational-update-22-september-2022-black-sea-grain-initiativejoint-coordination-centre.

[27] Welsh, Caitlin, and Emma Dodd (2022-September 13). Rebuilding Ukraine's Agricultural Sector: Emerging Priorities. Center for Strategic and International Studies. https://www.csis.org/analysis/rebuilding-ukraines-agriculture-sector-emerging-priorities.

[28] Baffes, John, and Wee Chian Koh (2022–May 11). Fertilizer prices expected to remain higher for longer. *World Bank Blogs*. https://blogs.worldbank.org/opendata/fertilizer-prices-expected-remain-higher-longer#:~:text=Fertilizer%20prices%20have%20risen%20nearly,and%20export%20restrictions%20(China).

[29] Kaviti, Geoffrey, Chinedu Asada, and Paul Wiseman (2022-April 12). As fertilizer from Russia dwindles, farmers search for solutions. *Christian Science Monitor*.

CONCLUSIONS

The disruptions that these shocks imposed on the global food system over the past two years has demonstrated a lack of resilience within the system. In high-income countries, the combination of the relatively low share of income devoted to food consumption and the financial assistance provided to both agricultural producers and households cushioned the adverse impacts to both ends of the supply chain. However, in low- and middle-income countries, especially those highly dependent on food imports, the consequences of these disruptions have been far more serious. According to testimony provided by the Executive Director of the UN's World Food Program before the Senate Foreign Relations Committee in July 2022, the number of people facing acute hunger around the world rose from 135 million prior to the COVID-19 outbreak in early 2020 to 345 million.[30] These problems will only be aggravated if high fertilizer costs extend into 2023 and beyond, hampering growth of agricultural output, especially in low- and middle-income countries.

Public and private investments are attempting to ease the shipping bottleneck-the Bipartisan Infrastructure Bill signed by President Biden in the spring of 2022 will invest $17 billion in upgrading port facilities over the next few years, and as of July 29, 2022, China's State Shipbuilding Corporation (CSSC) held contracts to build 243 new ships, including liquid natural gas (LNG) tankers and 60 container ships.[31]

As the world begins to recover from these multiple shocks, we need to rethink how the global food supply system functions, so that it serves the interest of all the world's producers and consumers in times of crisis.

[30] Beasley, David (2022–July 20). Written testimony submitted to a hearing of the Senate Committee on Foreign Relations. https://www.foreign.senate.gov/hearings/global-food-security-crisis-and-the-us-response_-immediately-following-the-business-meeting072022.

[31] Van Wyck, Barry (2022–July 29). China's shipbuilding industry is booming, including aircraft carriers, LNG tankers, and container ships. *SupChin.*

PARTNER STORY


Photo: USAID/Kelly Lynch

SUBMITTED BY: **Corteva Agriscience**

INCREASING ACCESS TO HYBRID MAIZE AND WHEAT SEED IN ETHIOPIA

Alliance improves smallholder farmer incomes & resilience

Corteva is collaborating with the United States Agency for International Development (USAID) Feed the Future Ethiopia Alliance program to improve the productivity, incomes, and resilience of smallholder farmers in Ethiopia. The alliance will combine the strengths and capabilities of USAID, ACDI/VOCA, Corteva, John Deere and Hello Tractor. Through the program, Corteva will increase smallholder farmer access to high-yielding and drought-tolerant hybrid wheat and maize seed, and train farmers to adopt climate-adaptive sustainable farming practices. The program will leverage US$4 million in USAID funding and benefit 223,800 smallholder farmers, including 58,000 women, on 104,420 hectares of land.

Corteva has operated in Ethiopia for several years. Through the hard work of a dedicated team of Corteva agronomists, marketers, and researchers, we have become a lead supplier of hybrid seeds and crop protection products to over 1.2 million smallholder farmer customers in Ethiopia. Collaborations such as this alliance improve the market environment and catalyze private sector investment, helping Corteva to grow our business and meet the needs of our customers.

Ethiopia is facing a 4-year drought, the most severe in 40 years, accelerating food insecurity for more than 13 million people. It is essential that smallholder farmers in Ethiopia increase the production of staple grains, such as corn and wheat, to improve food security and increase resilience. The program will strive to enable smallholder farmers to do just this through increasing the adoption of yield-optimized and climate-adaptive hybrid seeds, improving agricultural management practices, increasing agricultural mechanization services to minimize post-harvest losses, improving access to credit, and enhancing market linkages so farmers can sell what they produce, and consumers can buy what they need to feed their families.

Alliance members intend to increase the productivity of targeted smallholder farmers by 70 percent and their incomes by 40 percent. Furthermore, the program will address the enabling environment for local seed production and work with a range of stakeholders to improve policies and address market barriers so that farmers can have an adequate and reliable supply of high-quality seeds in the market.

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

USAID, the United States Agency for International Development is the world's premier international development agency and a catalytic actor driving development results. USAID works to advance U.S. national security and economic prosperity, demonstrates American generosity, and promotes a path to recipient self-reliance and resilience.

ACDI/VOCA, a global development design and delivery partner addresses issues of food security, economic prosperity, and social inclusion through locally driven market solutions.

John Deere, a global leader in agricultural machinery and technology solutions, provides mechanization solutions for emerging farmers through equipment service provision models enabling increased farmer productivity and profitability while reducing manual labor demands of women and emerging farmers.

Hello Tractor, a Kenya-based agricultural technology social enterprise company, focuses on connecting tractor owners and smallholder farmers in sub-Saharan Africa through a farm equipment sharing application.

To learn more about Corteva Agriscience's Agricultural Development collaborations, please contact Jennifer Billings at jennifer.billings@corteva.com or visit corteva.com.

PARTNER STORY

SUBMITTED BY: **Inter-American Institute for Cooperation on Agriculture (IICA)**

FROM THE SOUTHERNMOST RICE REGION IN THE WORLD: INNOVATION GROWS CLIMATE-SMART RICE

New research allows farmers in Chile to grow rice even in drought conditions

Rice is one of the most important staple grains consumed around the world, feeding more than half the world's population. Profitable rice cultures today must survive on less land with less labor and require precise use of inputs such as fertilizer and water. Rice production must become more efficient, environmental-friendly and more equitable, while reducing methane emitted from production practices.

Conventional production requires significant amounts of water. A mega drought that has lasted more than a decade in the central valley of Chile, where the main rice production areas are located, threatens the sector. The rice produced in the 25,000 hectares cultivated in Chile supplies half of the national needs, and there are goals to produce more, but production is threatened by the lack of required water resources.

To respond to these challenges, Chile's national agricultural research institution (INIA) and the Inter-American Institute for Cooperation on Agriculture (IICA) have been working jointly since 2016 on helping the growers of the rice regions of Maule and Ñuble increase productivity by generating innovations in the management of water resources and other elements of rice production.

In the southernmost rice growing region of the world, the sector is now meeting these challenges through participatory research, agronomic innovation, and cooperation. More than 400 miles south of Santiago, Chile, researchers, extensionists and producers are achieving exciting results in the face of climate change and to meet growing market demands.

Over a decade ago, Chilean rice producer Nelso Badilla used traditional rice sowing methods, requiring large amounts of water and fertilizer. But a few years later, with the region facing a historic drought, he switched to a new minimum tillage system and began using practices such as dry sowing, in which rice is planted directly into soil rather than transplanting seedlings into standing water.

Badilla also is part of a participatory research group (PRG) where he works with other innovative rice farmers focusing on more sustainable processes in a project funded by the Regional Government of Ñuble called "Climate-Smart Rice." On his land, with some twenty other rice farmers, he regularly participates in training in genetics, mechanization and monitoring for plant development, as these plants are in their reproductive process during the southern summer.

Of the 57 hectares that he has sown with rice, he has allocated 2,500 square meters to establish an innovation plot where he can try new varieties and practices. There he has attempted an agroecological system that saves up to 50 percent water, called SRI (System of Rice Intensification). The success of SRI depends on the implementation of practices that support the principles that underpin the system. This includes changes in conventional production methods, using precise land leveling, suitable cultivars, good crop establishment, improved water management, and effective and efficient weed and nutrient management. Implementation of SRI will also greatly reduce the methane emissions from rice cultivation through alternate wetting and drying.

The methodology is coordinated by the Agricultural Research Institute (NARI) of Chile and IICA as part of a project supported by the Foundation for Agricultural Innovation (FIA). Grower groups discuss irrigation and temperature, data and measurements, monitor test costs, and analyze daily expenses to predict results. Badilla observed, "We hope to have a variety of rice that matures earlier and uses less water, and what we want to achieve in the future is producing rice in 120 days instead of 150 days; this would considerably relieve the extensive water use that we have today, and tackle climate change."

Karla Cordero, a researcher in the Rice Genetic Improvement Program of Chile's NARI known as "The Rice Queen of Chile", said that they can observe significant differences between the conventional and SRI production. "We have seen that the rice matures a little earlier, so this system would be a very good alternative not only to save water, but also to reduce agrochemical inputs and produce rice as sustainably as possible." She added, "In partnership with IICA, our strategy is to reduce the water used in rice production. Rice is one of the crops with the highest water footprint."

Photo: Fernando Barrera, IICA Extension Specialist, IICA Chile

Fernando Barrera, an extension specialist for IICA in Chile, noted of the SRI process, "The key for success when proposing such a significant transformation is to co-innovate with farmers, learning and adjusting as we go along. We do this through participatory innovation groups, which have proven very important, because farmers participate actively alongside researchers and extension agents to identify problems, design solutions and ïn monitoring and evaluation." Through co-innovation, growers can reduce exposure to risk and uncertainty, and reduce the complexity of learning new practices while consolidating information to promote adoption by dividing new practices into manageable clusters. The SRI process also fosters local variation and adaptation for unique agroecological conditions.

For Cordero, it is highly important that the transfer and development of this new research should not only be done in the experimental fields of research institutes and universities, "but directly on farms, facilitating and expediting the research and the adoption process of these innovations."

The next steps will be to include additional farmers in the participatory processes and share the successes and lessons learned with other rice growers in the hemisphere. IICA has directed and implemented such participatory processes in Chile and other countries of the Americas. Going forward, IICA and its partners will extend low-emissions and sustainable rice in a multi-country program of SRI with the Green Climate Fund. The goal is to ensure climate-resilient rice that reduces water use and methane emissions can become broadly adopted throughout Latin America, the Caribbean and other parts of the rice-growing world.

PARTNER STORY

Photo: Hugh Rutherford/CIP

Beneficiaries of CIP gather vitamin-A rich sweet potato vines in Nsanje, southern Malawi.

SUBMITTED BY: **International Potato Center**

A NUTRITIOUS OPTION FOR COPING WITH THE WHEAT SHORTAGE IN AFRICA

Sweet potato serves as a nutritious alternative crop for wheat in Africa

While the Russia-Ukraine war has had repercussions across the globe, it has been especially problematic for bakeries and households in Africa, a region that imports more than 40 percent of its wheat from Russia and Ukraine. While African countries are extremely dependent on imported wheat, and vulnerable to the vagaries of the international market, a growing number of bakers are taking advantage of a home-grown alternative–orange-fleshed sweet potato puree, which can be substituted for about half the wheat flour in bread or other baked goods.

Root and tuber crops such as sweet potato have long been important staples in sub-Saharan Africa, especially among the rural poor, and because they are grown and consumed locally, they can buffer consumers from global commodity price shocks. The production and use of sweet potato puree, however, is a recent development–part of the CGIAR International Potato Center's (CIP) promotion of that resilient crop to fight hunger and malnutrition.

While most Africans grow and eat white- or yellow-fleshed varieties, orange sweet potato is an excellent source of vitamin A–an essential nutrient for the health and development of pregnant women and children. One small orange sweet potato can supply the daily vitamin-A needs of a young child, reducing their risk of infections, disease, and blindness. The robust root crop grows well on marginal land, with few or no chemical inputs, and produces more calories per hectare than wheat or rice, with less water.

CIP has partnered with national agricultural systems to breed resilient, high-yielding orange sweet potato varieties adapted to local conditions and facilitate the development of seed systems to get quality planting material to almost 7 million farm households during the past decade. The promotion of orange sweet potato puree production and use in baked goods is part of a broader effort to create demand for orange-fleshed varieties, to motivate more farmers to grow them and increase consumption of the nutritious crop.

Scientists found that puree retains its pro-vitamin-A content when baked, so the bread is almost as nutritious as boiled sweet potato. CIP has helped businesses adopt aseptic puree production methods and its researchers developed a procedure to vacuum pack puree, giving it a three-month shelf life without refrigeration. This was vital to facilitate greater consumption, given sweet potato's perishability and the scarcity of refrigeration in rural Africa. At the same time, extension agents train smallholders–who produce 80 percent of the food in Africa–in appropriate agricultural practices and postharvest handling of sweet potato, so they can deliver the quality product that processors demand.

Most consumers like sweet potato bread, and once people understand its nutritional value, they are willing to pay a little more for the "golden bread." The puree can also be used in baby food, doughnuts, and other snacks. Bakers like the puree because its use not only reduces their flour bill but also the amounts of sugar and oil they use in dough, by 70 percent and 30 percent respectively. A growing number of businesses in Africa are producing or using sweet potato puree as an ingredient, and CIP is collaborating with companies in Kenya, Malawi, and Uganda with a goal of increasing puree production to 10,000 tons per year.

Urbanization is advancing rapidly in Africa, where half the population is expected to live in urban areas by 2035, which will create urban food markets worth an estimated USD 500 billion. This includes growing demand for bread and processed foods, which creates opportunities for investors, workers, and farmers. For rural families that form part of the orange-fleshed sweet potato value chain, this can mean more nutritious diets, from the pro-vitamin-A crop they grow to the other varied foods their income enables them to buy.

EXPERT ESSAY

UKRAINE CONFLICT DISRUPTS AGRICULTURAL PRODUCTION AND INTERNATIONAL TRADE

By Amanda Countryman, Associate Professor, Colorado State University and Farm Foundation Agricultural Economics Trade Fellow

ABSTRACT

Ukraine and Russia have become increasingly important suppliers in global agricultural markets, and the war in Ukraine has widespread negative consequences. Lost domestic production in Ukraine and disruptions in international trade threaten global food security and hinder agricultural productivity. War-related damages caused immediate injury to Ukraine's agricultural systems that will have lasting effects on productivity. Western sanctions on Russian goods in tandem with export restrictions imposed by Russia, China, and Least Developed countries in the face of tight agricultural markets further increase commodity prices and volatility that disproportionately affect the world's poor. Increased, transparent international trade is needed to meet global food import demands during this challenging time of turmoil in global agricultural markets.

INTRODUCTION

International trade boosts economic growth, incomes, and productivity. However, disruptions caused by supply chain inefficiencies, conflict, and policy intervention diminish the gains from uninhibited trade. Nations are increasingly interdependent and international trade continues to grow; yet, the connectedness of the world was threatened during COVID-19 related supply chain disturbances, and geopolitical conflict puts substantial pressure on already tight food and agricultural markets. In response to tight supplies, increased commodity prices, and geopolitical tensions, governments implemented trade policies that worsen the affordability and availability of food and agricultural products. In concert, challenges throughout global agricultural systems exacerbate global food insecurity and dampen prospects for agricultural productivity growth.

As the world was moving forward from the consequences of COVID-19, conflict erupted when Russia invaded Ukraine in February 2022. The implications of this conflict are far reaching as both nations are key suppliers of agricultural products, and Russia is a dominant fertilizer source for inputs used around the world. Combined, Russia and Ukraine account for 12 percent of global agricultural exports and 20 percent of fertilizer exports (Glauber and Laborde, 2022). The conflict in Ukraine negatively affects agricultural markets and hinders agricultural productivity given lost domestic production and exports from Ukraine and trade restrictions imposed on Russia and Russian allies that impact grain and oilseed markets and disrupt the global fertilizer industry. Negative consequences are widespread and affect consumers and producers around the world with especially damaging effects on food security in developing nations.

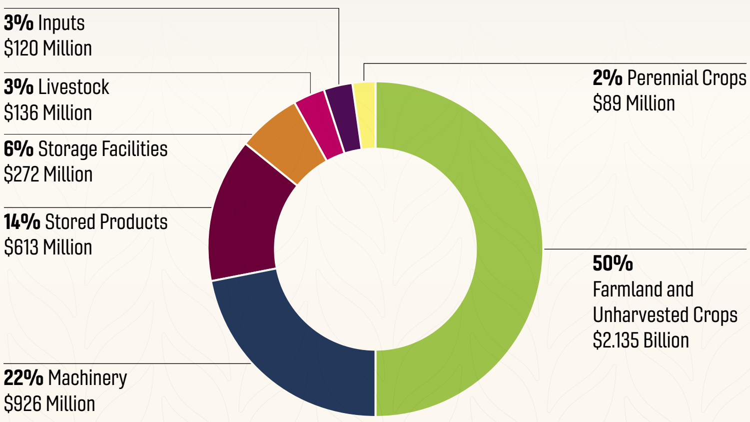
LOST AGRICULTURAL PRODUCTION IN UKRAINE

Agricultural production is central to the economy of Ukraine and is critical for Russia. More than 55 percent of the land in Ukraine is highly fertile, arable land, and agriculture accounts for approximately 20 percent of the Ukrainian economy (USDA FAS, 2022). Agriculture contributes approximately 4 percent to Russia's GDP (World Bank, 2022). Ukraine and Russia have grown in importance for the global agricultural markets during the past three decades with increased agricultural productivity despite noteworthy productivity gaps relative to export competitors. Unfortunately, the onset of Russia's invasion of Ukraine brought destruction to agricultural production in Ukraine that will have short- and long-term consequences for agricultural productivity in the region.

The war in Ukraine is responsible for an estimated $4.3 billion in damages to agricultural systems, equal to nearly 15 percent of Ukraine's agricultural capital stock (Neyter et al. 2022a). Ukrainian agricultural damages account for the destruction of tangible assets and inventories from the invasion and vary across the supply chain as illustrated in Figure 1. Satellite images and photos show devastation across agricultural properties in Ukraine including bombed and burned fields, destroyed capital and equipment, damaged transport systems, and lost livestock. Destruction to farmland and unharvested crops comprise 50 percent of total damages valued at $2.135 billion. Machinery damages equal to $926 million account for 22 percent of total damages. Additional damages are estimated for stored products (14 percent, $613 million), storage facilities (6 percent, $272 million), livestock (3 percent, $136 million), inputs (3 percent, $120 million), and perennial crops (2 percent, $89 million).

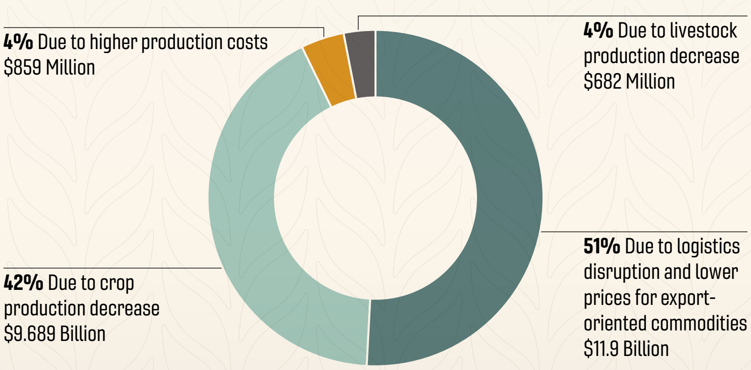
The damages to agricultural supply chains alone do not reflect the extent of losses to the Ukrainian agricultural economy. Figure 3 depicts losses including estimates for lost revenue from decreased production and additional war-related production costs. Ukraine experienced $23.3 billion in total estimated agricultural losses, which is equal to approximately 50 percent of the value of 2021 Ukrainian agricultural output (Neyter et al. 2022b). The biggest losses are attributed to logistics disruptions and lower domestic market prices for export-oriented commodities, totaling an estimated $11.9 billion and accounting for 51 percent of total agricultural losses from the war. Crop losses are nearly $9.7 billion and comprise 42 percent of total estimated losses. The smallest losses are attributed to higher production costs ($859 million, 4 percent) and decreased livestock production ($682 million, 3 percent). While estimates show losses for this year, continued conflict will amplify losses and destruction across Ukraine. Disruptions in agricultural production lead to compounding negative effects on productivity that will persist beyond the time of the invasion. This matters especially in the case of Ukraine given the importance of agriculture for the domestic economy and the need for Ukrainian grains to meet food security needs around the world.

Figure 1: Agricultural Damages in Ukraine from Russian Invasion



Source: Neyter et al. 2022a.

Figure 2: Agricultural Losses by Category in Ukraine from Russian Invasion



Source: Neyter et al. 2022b.

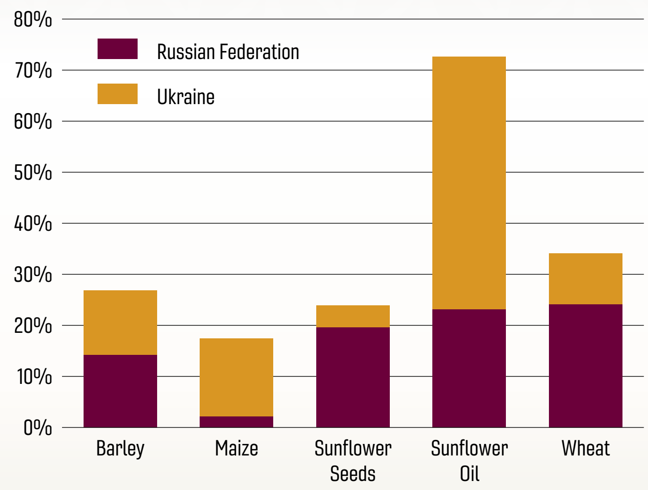
EXPERT ESSAY

TRADE BLOCKADE

Lost trade is another casualty resulting from the conflict in Ukraine. Russia blocked Ukrainian exports and Western countries imposed trade sanctions on Russian goods in response to the invasion. Lost trade of food and agricultural products negatively impact agricultural producers and consumers. Ukraine and Russia are major producers and exporters of grains and vegetable oils as illustrated in Figure 3. Most noteworthy, Ukraine is the largest sunflower oil exporter, supplying nearly 50 percent of global exports while Russia supplies 23 percent of sunflower oil exports. Ukraine is responsible for 15.3 percent of maize exports, 12.6 percent of barley traded, 10 percent of wheat exports, and 4.3 percent of sunflower seeds traded globally. Russia is a major supplier of the same products contributing 24.1 percent of wheat, 23.1 percent of sunflower oil, 19.6 percent of sunflower seeds, and 14.2 percent of barley exports globally (Glauber and Laborde, 2022).

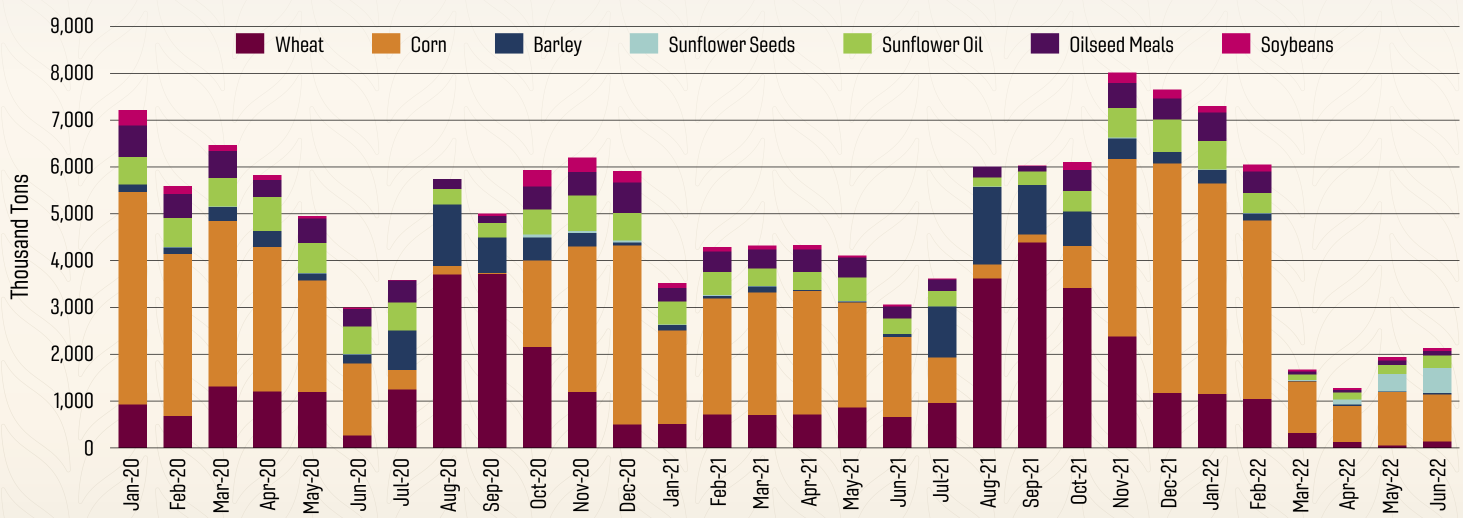
The dramatic drop in exports from Ukraine after the invasion is illustrated when comparing grains and oil export quantities shown in Figure 4 (Martyshev and Myslytska 2022). The threefold decrease in exports beginning in March 2022 was caused by Russian occupation of ports and the fact that only roughly half of western rail stations in Ukraine have been actively used. Rail transport in the west is plagued with logistics challenges including inconsistencies in rail width between the Ukraine and the EU and agricultural products must compete with nonagricultural products for transport, especially iron ore. While there was a UN-backed agreement to allow Ukrainian agricultural exports from three key ports beginning in August, 2022, annual shipments are well below previous year export levels. Decreased exports fuel challenges for food security given developing country dependence on Ukrainian grain.

Figure 3: Ukraine and Russia Export Shares Volume



Source: Glauber, J. and D. Laborde. "How will Russia's invasion of Ukraine affect global food security." IFPRI Blog Post. February 28, 2022.

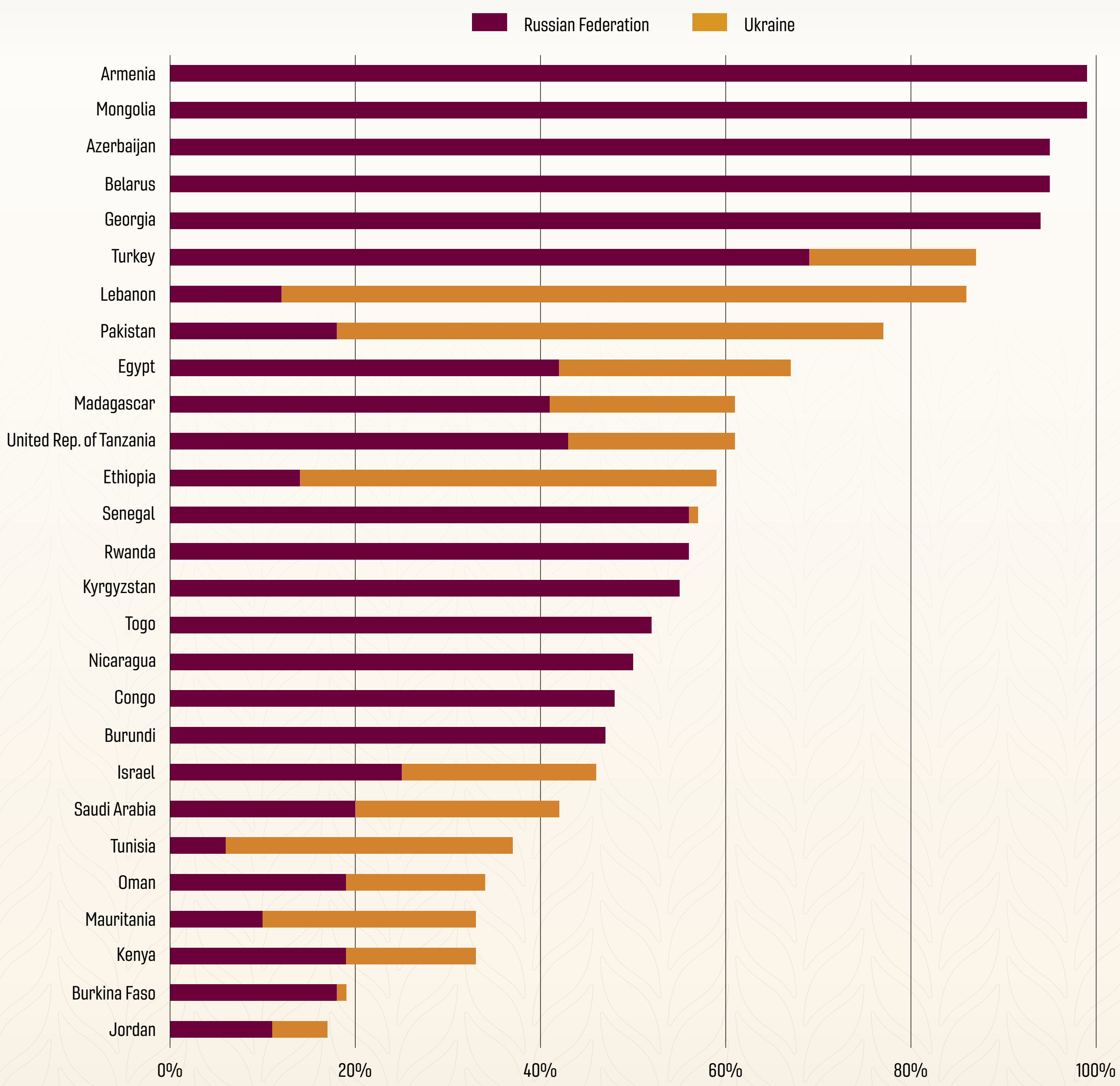
Figure 4: Key Ukrainian Agricultural Exports



Source: Martyshev and Myslytska 2022.

Exports from Ukraine and Russia are central to import bills in Least Developed Countries (LDC) in the Middle East, Africa, and other regions. Together, Ukraine and Russia provide 12 percent of calories traded globally (Glauber and Laborde, 2022). Figure 5 provides an example of wheat import dependency across net importing countries in 2021 (UN COMTRADE, 2022). Several countries rely on Russia and Ukraine to supply more than 80 percent of wheat imports, and the Food and Agriculture Organization notes that twenty-five LDCs source at least half of wheat imports from Russia and Ukraine (FAO, 2022b). Not only were Ukrainian exports stalled due to Russian occupation of ports and destruction of commodities, but Russia also sold stolen Ukrainian grain to other countries in need before ports were reopened in August, essentially weaponizing food. Continued export challenges are expected as the conflict ensues.

Figure 5: Wheat Import Dependency, Net Importers, 2021 (%)



Source: UN Comtrade.

TRADE POLICY PROBLEMS

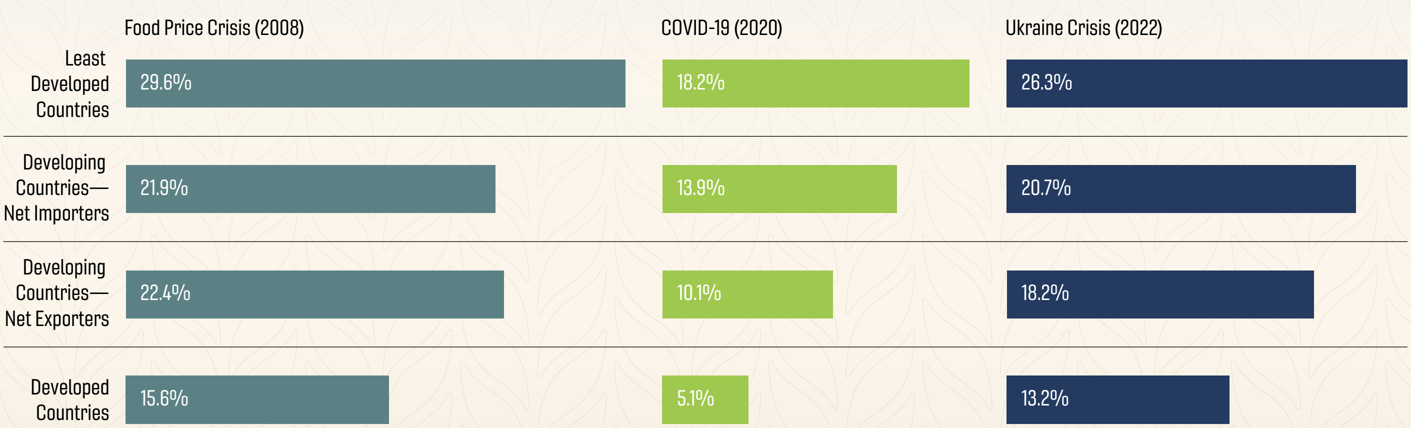
Stifled agricultural commodity exports from Ukraine exacerbate food insecurity in LDCs; yet trade restrictions imposed for various reasons across countries contributed to worsening food market conditions in the wake of COVID-19 and beyond. Many countries turn to export restrictions on food products during times of high prices and limited supply in attempts to shield domestic markets from global commodity market volatility. Unfortunately, the use of export restrictions across countries causes higher world prices and greater global market volatility. Figure 6 demonstrates the share of imported calories affected by export restrictions during the 2008 Food Price Crisis, COVID-19, and the Ukraine Crisis. In all cases, LDCs are the most negatively affected, and export restrictions intensified global food insecurity by distorting markets (Glauber et al., 2022). Currently, 26 percent of LDC calorie imports of food, feed and energy face restrictions imposed by exporters compared to 13.2 percent for developed country imports. This clearly demonstrates the disproportionate negative impacts export restrictions have on low-income countries.

Ukraine, Russia, and other countries imposed restrictions on agricultural exports that deteriorate food and fertilizer trade. The Ukrainian government mandated export licensing for key food products including wheat, corn, sunflower oil, and other commodities in March 2022, after the invasion. However, export licensing was cancelled in July 2022 in anticipation of the new wheat crop (Martyshev and Myslytska 2022). Restrictions on Russian agricultural trade are two-sided, including Russian-imposed export restrictions and Western sanctions on Russian goods. Russia restricted fertilizer exports in December 2021 through 2022, which was a major disruption to the highly concentrated global fertilizer market given the importance of Russian supplies. Russia was the largest exporter of nitrogenous fertilizers and the second largest exporter of both phosphate and potash in 2019. The fertilizer market faces further challenges with trade policy that restricts exports from key suppliers. China was the largest phosphate supplier and the second largest exporter of nitrogenous fertilizers in 2019 and imposed fertilizer export restrictions in 2021 (Hebebrand and Laborde, 2022). Decreased fertilizer exports cause higher world prices and is of grave concern given LDC reliance on import sourcing of agricultural inputs.

SKY HIGH PRICES

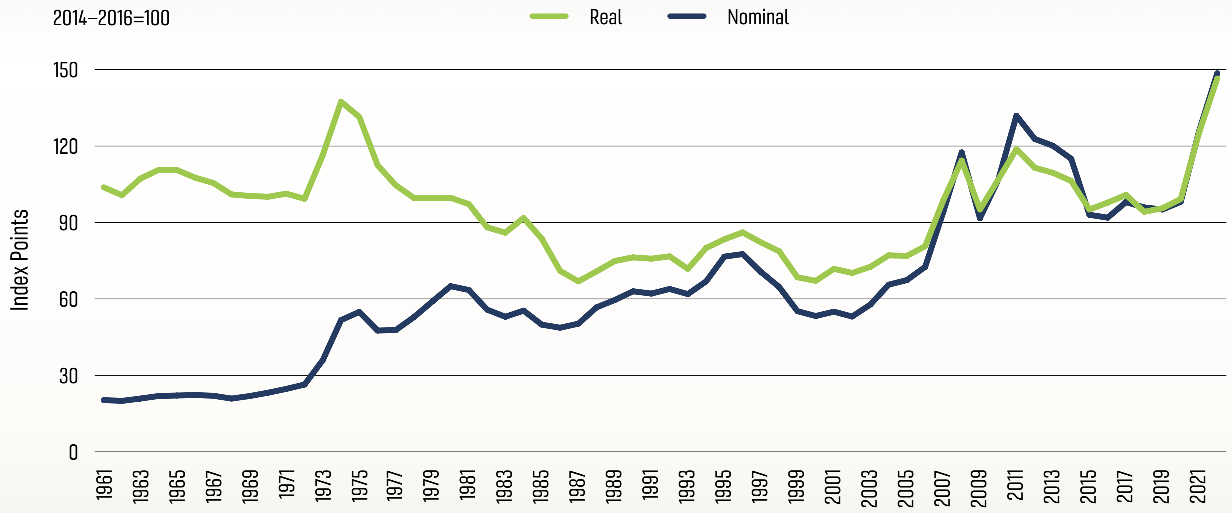
Global agricultural prices were high, and supplies were tight before the war in Ukraine given disruptions from COVID-19 and other market dynamics including decreased world supplies from drought. War and policy related negative impacts on supply chains puts additional pressure on

Figure 6: Share of Imported Calories Impacted by Export Restrictions by Economic Group



Source: Glauber et al, 2022.

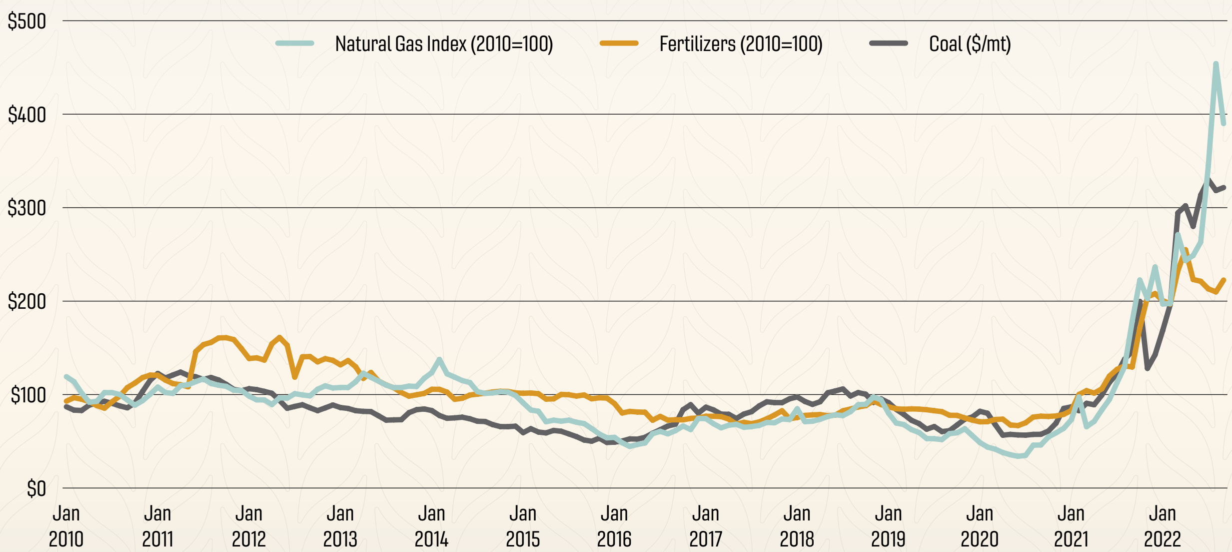
Figure 7: FAO Food Price Index in Nominal and Real Terms



Source: Food and Agriculture Organization of the United Nations, 2022b.

agricultural input and output prices. Figure 7 illustrates real and nominal food price indices over time (Food and Agriculture Organization, 2022a) and Figure 8 describes agricultural input price indices (World Bank, 2022). Both food and input prices have increased exponentially since 2020 (Baffes and Temaj, 2022). Concurrently, price volatility increased. Cotton, wheat, soybeans, coffee, and maize are the agricultural product markets with the highest volatility over the past year (International Food Policy Research Institute, 2022). The perfect storm of tight supplies, high prices, and amplified market volatility will have negative consequences for global food security and agricultural productivity, especially in LDCs.

Figure 8: Agriculture Input Price Indices



Source: World Bank Commodity Price Data, 2022.

EXPERT ESSAY

IMPLICATIONS FOR AGRICULTURE

The conflict in Ukraine has far-reaching negative consequences for consumers and small and large agricultural producers around the world. Lost agricultural production and trade, trade policy interventions, in tandem with high agricultural prices and market volatility contribute to concerns related to global food security and agricultural productivity. Short run damages to agriculture in Ukraine equal $4.3 billion. However, the full extent of the short- and long-term damages to agricultural systems in Ukraine depend on the duration of the war. Furthermore, continued export shortfalls of Ukrainian agricultural commodities and Russian fertilizer will exacerbate global food concerns. Lost fertilizer trade causes immediate productivity losses and potential for long-term detriment to total factor productivity in LDCs that rely on imports for production inputs. While a swift end to the conflict is unlikely, robust international trade structures provide an avenue to meet current world import demand. Country collaboration to avoid policy measures that restrict trade will help minimize widespread negative impacts from the crisis in Ukraine.

References

Baffes, J. and K. Temaj. "Food Prices Continued their Two-Year-Long Upward Trajectory." World Bank Blogs. May 25, 2022. https://blogs.worldbank.org/opendata/food-prices-continued-their-two-year-long-upward-trajectory.

Food and Agriculture Organization of the United Nations. "The Importance of Ukraine and the Russian Federation for Global Agricultural Markets and the Risks Associated with the War in Ukraine. June 10, 2022. https://www.fao.org/3/cb9013en/cb9013en.pdf.

Food and Agriculture Organization of the United Nations. World Food Situation. August 5, 2022. https://www.fao.org/worldfoodsituation/foodpricesindex/en/.

Glauber, J. and D. Laborde. "How will Russia's invasion of Ukraine affect global food security." IFPRI Blog Post. February 28, 2022. https://www.ifpri.org/blog/how-will-russias-invasion-ukraine-affect-global-food-security.

Glauber, G., D. Laborde, A. Mamun, E. Olivetti, and V. Pineiro. "MC12: How to Make the WTO Relevant in the Middle of a Food Price Crisis." IFPRI Blog Post. June 11, 2022. https://www.ifpri.org/blog/mc12-how-make-wto-relevant-middle-food-price-crisis.

Hebebrand, C. and D. Laborde. "High fertilizer prices contribute to rising global food security concerns." IFPRI Blog Post. April 25, 2022. https://www.ifpri.org/blog/high-fertilizer-prices-contribute-rising-global-food-security-concerns.

International Food Policy Research Institute. Food Security Portal. August 10, 2022. https://www.foodsecurityportal.org/.

Martyshev, P. and A. Myslytska. "Is Ukrainian Wheat Easily Replaced? Global Trade Flows Review." Center for Food and Land Use Research, Kyiv School of Economics. August 2, 2022. https://kse.ua/wp-content/uploads/2022/08/Is-Ukrainian-wheat-easily-replaced_-Global-trade-flows-review.pdf.

Neyter, R., H. Stolnikovych, and O. Nivievskyi. "Agricultural War Damages Review, Ukraine Rapid Damage Assessment." Center for Food and Land Use Research, Kyiv School of Economics. June 8, 2022. https://kse.ua/wp-content/uploads/2022/06/Damages_report_issue1-1.pdf.

Neyter, R., H. Stolnikovych, and O. Nivievskyi. "Agricultural War Losses Review, Ukraine Rapid Loss Assessment." Center for Food and Land Use Research, Kyiv School of Economics. June 9, 2022. https://kse.ua/wp-content/uploads/2022/06/Losses_report_issue1.pdf.

United Nations COMTRADE Database. 2022. https://comtrade.un.org/.

World Bank Commodity Price Data. 2022. https://www.worldbank.org/en/research/commodity-markets.

USDA Foreign Agricultural Service. "Ukraine Agricultural Production and Trade." April 2022. https://www.fas.usda.gov/sites/default/files/2022-04/Ukraine-Factsheet-April2022.pdf.

World Bank Data. Agriculture, forestry, and fishing, value added (% of GDP) - Russian Federation. August 2022. https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=RU.

CONTRIBUTOR STORY


Photo: Rocio Quiroz / CIMMYT

SUBMITTED BY: **CIMMYT**

RECOMMENDATIONS FOR TRANSFORMING THE FOOD SYSTEMS OF A CRISIS-STRICKEN WORLD

The ongoing crisis in Ukraine has placed major strains on global food security. Food system transformation is the key to adapting to shifts in global food supply.

Agriculture and food production are of the utmost importance to peace and prosperity. Throughout history, the rise and fall of civilizations has been greatly determined by their food systems' resilience. The capacity to produce, store, distribute and commercialize food has been and, indeed, continues to be the stepping stone to economic growth, and a source of political clout globally.

The Food Security Crisis in Ukraine

The crisis in Ukraine has abruptly reminded the world that food systems are interdependent and vulnerable to market shocks like the one triggered, in this case, by conflict. The international development sector's response capacity has been put to the test due to the disruptions of food exports from two breadbasket countries that together account for 34 percent of the wheat traded globally.

Severe supply chain disruptions could be catastrophic for North Africa and the Middle East. First in countries that are already in crisis, such as Tunisia and Yemen, but also in Lebanon and Egypt. Even relatively stable countries such as Morocco and Turkey could suffer the consequences of scarcity and high food prices. The World Food Programme (WFP) warned that acute hunger could grow by 17 percent globally if the conflict in Ukraine continues unabated, and that African countries would be most severely affected.

The war in Ukraine and associated trade sanctions on Russia have had, and are likely to continue to have, significant impacts on global wheat and maize. The food security impacts of the current crisis are likely to reverberate over months, if not years, and to be most deeply felt by vulnerable communities in low- and middle-income countries. In this challenging environment, the world must urgently invest in agricultural capacity and resilience.

A Blueprint for Food Systems Transformation

Transforming food systems requires shifting the focus of food production from efficiency to resilience, and from competition for resources to balance and inclusion. This transformation must rely on solid, science-informed solutions, policy recommendations and proven methodologies that can help avert the global food security crisis that looms. In the short term, efforts must focus on boosting local food production in both low and high productivity areas to buffer the negative effects of higher energy and commodity prices and of supply chain bottlenecks. At the same time, vulnerable communities and countries should be prepared to substitute wheat flour for flour obtained from other crops like millet or chickpeas.

To increase resilience in the medium term there should be a targeted expansion of agricultural production within agro-ecological boundaries. For example, there is potential for wheat production in Eastern and sub-Saharan Africa, but farmers will need comprehensive technical support to grow wheat profitably and sustainably. In parallel, governments and/or farmer associations should invest in crop monitoring and early warning systems that greatly contribute to mitigate agricultural risks associated with climate change and to known and emerging pests and diseases.

Ultimately, the world needs to invest heavily in research and capacity development for agricultural resilience to combat malnutrition and overcome the recurring threat of food insecurity driven by climate change and conflict. Research and development of more sustainable farming practices and technologies will help farmers adapt agriculture to climate change and cut greenhouse gas emissions of agricultural activities that greatly contribute to global warming. It is also urgent to address the gender and youth disparities in agriculture and rural communities to accelerate the transition to more resilient and sustainable agri-food systems.

There is no time to waste in this decisive decade for the United Nations 2030 Agenda of Sustainable Development Goals. The immediate and long-term responses to the unfolding crisis will have a great impact on future generations that will undoubtedly hold their predecessors accountable for the actions of today. Hopefully, by the end of the century, people will look back in awe to the 2020s and commend the decisions made by those who rose to the challenge.

CHAPTER 3: REVERSING COURSE

POLICY AND INVESTMENT PRIORITIES FOR PRODUCTIVITY GROWTH

The current downward trajectory of agricultural productivity growth must be reversed. Climate change, conflict, and extreme weather events add multiple layers of difficulty and complexity to an already challenging task. Governments, the private sector, research institutions, international development organizations, and civil society groups need to work collaboratively to create an enabling environment for agricultural innovation, services, and knowledge to take root. In addition, small-scale producers must focus on urgent and vigorous action to accelerate productivity growth, improve food security, increase incomes, and strengthen sustainability and resilience.

The GAP Report's six policy and investment priorities for productivity growth are data-driven solutions with proven results. Additional information is available at globalagriculturalproductivity.org.

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

CONTRIBUTOR STORY

SUBMITTED BY: **CIMMYT**

NEW OPTIONS FOR AVERTING A GLOBAL FOOD EMERGENCY

New policies provide support and resist shocks in order to maintain food supplies

Background

The food price spike of 2005-2008 sparked civil unrest in dozens of countries, including across the Middle East, where the Arab Spring soon followed. While the circumstances today differ, food prices are once again spiking. Russia and Ukraine together account for 34 percent of the world's wheat exports, so high prices are linked to an actual supply disruption of a staple grain. More than 2.5 billion people worldwide consume wheat-based products, so the effects of these disruptions could mean significant hunger and possibly civil unrest. Potential hunger hotspots include nations already in crisis, such as Yemen, Sudan, and Ethiopia, but also Egypt, which is highly dependent on wheat imports from Russia and Ukraine.

Policy Options

The world is mobilizing emergency food aid to ensure the survival of the most vulnerable populations. Given the possibility of a prolonged global crisis, improved global food production is also urgent. According to a new CIMMYT paper in the July 19, 2022 issue of *Nature Food*, governments, international organizations, and humanitarian groups need strategies to **mitigate the immediate crisis, stabilize production** in the mid-term, and **build resilience** in the long-term to climate change and food shocks.

MITIGATE THE IMMEDIATE CRISIS.

The first priority, according to the authors, is to address today's growing food emergency through immediate steps to increase food production, such as:

- **Intensify existing wheat production** through improvements in the distribution, productivity, and management of land, seeds, and plants. In many cases, these improvements can be made within a single planting season. Governments and organizations should consider:
  - Temporary, targeted subsidies for inputs, machinery, and services in low-productivity areas.
  - Direct economic incentives in high-productivity areas.
  - Soil fertility management practices that decrease total demand for fertilizer.
- **Ensure grain access** through coordinated and multilateral policies that help to:
  - Conserve or prioritize grain stocks for human consumption.
  - Avoid further trade restrictions and promote transparency about productivity and exports.
  - Support minimum and stable prices for wheat and other grains.
- **Explore flour blends,** which can partially offset high wheat flour prices and reduce dependence on imported cereals.
  - Partially substitute lower-cost, nutrient-rich or drought-tolerant cereals such as legumes, cassava, sorghum, and millet for wheat.
  - Test consumer acceptance and product quality.

STABILIZE THE WHEAT SUPPLY.

In the **medium term,** the authors emphasized the need to increase the local, regional, and global resilience of the wheat supply. Strategies include:

- **Expand production** in areas that are agro-ecologically suitable and have existing infrastructure, value chains, and farmer support mechanisms. This can be facilitated by:
  - Strategic and tactical planning with multi-sector stakeholders in specific agri-food systems.
  - Using knowledge and innovation mechanisms tailored for rural agricultural systems.
- **Encourage wheat self-sufficiency.** Countries such as Ethiopia and Sudan have real potential to meet their own needs without relying heavily on imports by:
  - Shifting policies to encourage public and private investments, including price supports for agricultural inputs and outputs.
  - Expanding use of improved varieties and practices through better seed systems and agricultural services, such as credit, logistics, education, and communications.
  - Targeting interventions based on better data and analysis of smallholder vulnerability.
- **Provide comprehensive technical support** to farmers for better returns on tactical investments, such as:
  - Mechanization and grain storage.
  - Crop management, such as sowing seeds in rows or integration with legume crops and livestock systems.
  - More targeted use of fertilizer or improved pest control.
  - Highly productive, disease-resistant wheat varieties.
- **Improve monitoring.** There is an opportunity today to use new technologies, such as satellites, remote sensing, and machine learning to give farmers unprecedented visibility and foresight, enabling better interventions in everything from pest and disease management to productivity improvements.

PROMOTE RESILIENCE.

The current situation will not be the last food shock in the 21st century; indeed, climate change all but guarantees a rising frequency of challenging conditions. To avoid lurching from crisis to crisis, with enormous human suffering and economic losses, governments, organizations, and farmers must adopt **long-term measures** to encourage resilience.

- **Enhance agroecosystem diversity.** To protect agricultural productivity, governments, organizations, and farmers must avoid agricultural expansion that further degrades biodiversity, carbon sequestration, and other ecosystem services by:
  - Analyzing and navigating tradeoffs among sufficient wheat production, climate change mitigation, more resilient agroecosystems, and sustainable management of biodiversity and natural resources.
  - Investing in conservation-based agricultural technologies.
- **Resolve gender disparities.** To minimize the disproportionate effect of food insecurity on women, governments and organizations should:
  - Adopt gender-responsive design and monitoring of solutions to ensure that food price spikes and policy and programmatic responses do not negatively affect women.
  - Address women's barriers to entry into growing wheat markets.
- **Invest in agri-food transformation.** Meet the extensive knowledge and technology needs across production systems, value chains, and monitoring systems by:
  - Investing in climate-resilient crop varieties and low-carbon mechanization and farm management as well as the science of effective policy interventions.
  - Focusing on pre- and post-harvest loss reduction while improving food system efficiency and resilience.

EXPERT ESSAY

CAN DIGITAL SERVICES FOR AGRICULTURE CONTRIBUTE TO RESILIENT TFP GROWTH IN SUB-SAHARAN AFRICA?

By Jessica Agnew, Ph.D., Associate Director of CALS Global in the College of Agriculture and Life Sciences at Virginia Tech, Harrison Byrnes, Data Analyst, AgUnity, Okeyo Mwai, Principal Scientist, Global Livestock Genetics–Live Gene Research Program, International Livestock Research Institute

INTRODUCTION

In sub-Saharan Africa (SSA), agricultural output held a steady rate of growth between the 1980s and 2000s, with a slowing in the past decade. Increased output resulted primarily from introducing new land into agricultural production with marginal contributions from uptakes of technologies such as use of improved seed varieties and agronomic practices. However, land expansion is not likely to be a viable approach for growing the agriculture sector in the long-term. Tim Njagi, Research Fellow at Tegemeo Institute in Kenya, emphasized this in his remarks at the *Accelerating Agricultural Productivity Growth in East Africa: Agenda for urgent action* event held in Nairobi in June 2022. “We can no longer rely on land expansion as a means of growing agricultural output, climate change has made land less productive”, Njagi said. Investments in agricultural research and development to create new technologies and attractive returns for private sector investors will be essential for SSA to drive output growth through improved total factor productivity (TFP).[1] Further, increasing TFP in SSA can make a critical contribution to global agricultural productivity growth, which is desperately needed as growth slows among industrialized countries.

Digital services for agriculture (DSAs) have demonstrated success in improving agricultural productivity in an industrialized country context. Defined as “a solution that uses digital equipment and devices such as mobile phones, computers, satellites, and sensors to solve problems in agriculture,”[2] DSAs have been widely touted as the next great opportunity for the transformation of African agriculture. Today there are more than 437 DSAs on the market in SSA, with Nigeria and Kenya tied for the top number of offerings (around 90). Digitization can contribute to TFP growth

[1] Fuglie, K., M. Gautam, A. Goyal, and W.F. Maloney. 2020. *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*. World Bank, Washington DC.

[2] Kieti, J., T.M. Waema, E. B. Ndemo, T. K. Omwansa, and H. Baumüller. 2021. “Sources of value creation in aggregator platforms for digital services in agriculture - insights from likely users in Kenya.” *Digital Business* 1. http://dx.doi.org/10.1016/j.digbus.2021.100007.

by increasing access to information,[3,4] diffusing innovations to last-mile agricultural communities,[5] increasing value chain functionality,[6] and creating positive feedback loops in human capital development.[7]

Despite proliferation in the market and growing interest in using digital solutions, DSAs have not yet generated returns to TFP growth in the SSA context due to underutilization, lack of product 'stickiness', and challenges in reaching scale. Of the 437 DSAs on the market, only 3 percent have passed the 1 million user mark, and of these only an average of 30 percent of users are active.[8] There are three tenets that actors in the innovation ecosystem must address to achieve the scale and success required for digitization to contribute to trending and resilient TFP growth–(1) DSAs must create adequate value for the user; (2) supporting infrastructure must be consistent and reliable; and (3) there must an adequate and integrated enabling environment for digitizing agriculture. We discuss each of these tenets and explore an example of a blockchain-powered DSA that considers these aspects in their digital service design, business model, and advocacy.

Access to Information

Digital records can help farmers to make more informed decisions in production planning. Digital extension services can reach farmers that have historically had challenges in receiving evidence-based production training. Digital information can be a significant enabler of inclusivity, especially enabling women and youth to such information.

Access to Innovation

Digital marketplaces can help to accelerate dissemination of TFP-enhancing innovations to producers that are in the last-mile agricultural communities. ICTs can be used to inform producers of produce prices and new innovations and how to use the latter.

Access to Efficient Value Chains

Having access to value chains that can absorb agricultural output can help to reduce post-harvest loss. Digital solutions can not only help to improve value chain efficiency but also ensure that smallholders have access to them.

Access to Support

Producers and value chain actors that have their basic needs met, feel that their efforts are valued by the market, and are socially supported are likely to be more productive. Digital services for agriculture can also provide complementary services that will increase the relative productivity of human capital.

---

3 Deichman, U., A. Goyal, and D. Mishra. 2016. *Will digital technologies transform agriculture in developing countries?* World Bank, Washington, DC. http://hdl.handle.net/10986/24507.

4 Marwa, M.E., J. Mburu, R.E.J. Oburu, O. Mwai, S. Kahumbu. 2020. *Impact of ICT Based Extension Services on Dairy Production and Household Welfare: The Case of iCow Service in Kenya*. Journal of Agricultural Science 12(3).

5 iBid.

6 Agnew, J., R. P. Hall, J. Mwangi, N. Kristofikova, and D. Sumner. 2022. *The Impact of Blockchain Technology on Food Insecurity Through African Indigenous Vegetables in Western Kenya*. Virginia Tech, VA.

7 iBid.

8 Baskaran-Makanju, S., S. Hoo, C. Mitchell, J. Larson, S. Unnikrishnan, S. Vasudevan, and Y. Zrikem. 2021. *The Digital Agriculture Revolution Will Take More Than Innovation*. Accessed August 21, 2022. https://www.bcg.com/en-cn/publications/2021/digital-agriculture-and-development.

EXPERT ESSAY

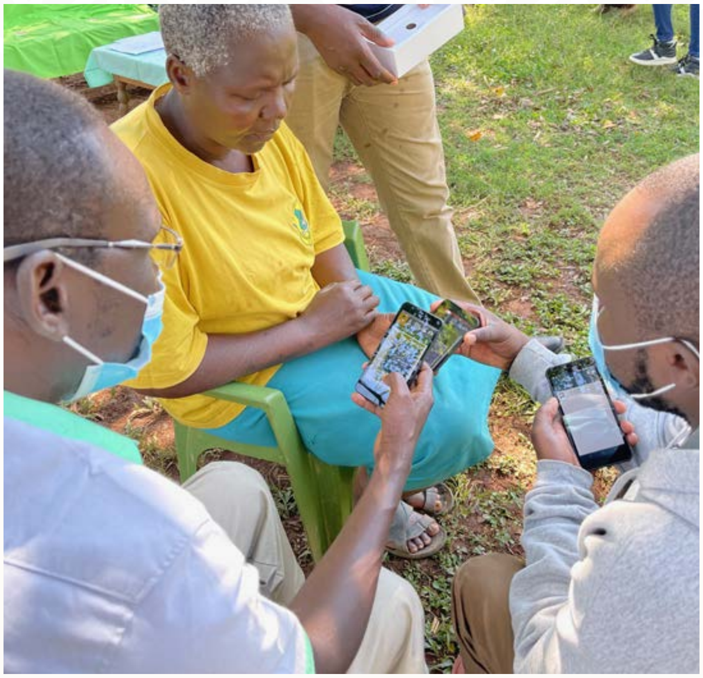


Photo: Jessica Agnew

DSAs MUST CREATE ADEQUATE VALUE FOR THE USER.

For DSAs to significantly and sustainably contribute to TFP growth, the user must be interested in and able to use the service and it must generate sufficient value so as to produce stickiness–frequent and sustained use over time. For smallholder farmers with constrained and seasonally fluctuating income, affordability and timing of payment schemes are a central value driver. Digital platforms (of which DSAs are a subset) that aggregate complementary services along with other features such as online and offline functionality, quality and reliability, and increased social support are more likely to create higher value and stickiness than those that offer single solutions. Value propositions that include rewarding loyalty, upholding trust, reduce information asymmetry, and offer customizable services are likely to be more successful at helping smallholder farmers overcome the multiple types of challenges they face. According to likely users of DSAs in Kenya, this will help to overcome underutilization and barriers to scale.[9]

SUPPORTING INFRASTRUCTURE MUST BE CONSISTENT AND RELIABLE.

One of the most commonly cited reasons for the underutilization of DSAs in the SSA context is the lack of connectivity. Kenya demonstrates, however, that improving ICT service delivery is only one part of the supporting infrastructure required for sustained use of DSAs. Service providers must consider how they will support the transfer of digital skills to a population with limited familiarity with advanced digital technologies. According to one potential DSA user, service providers should offer "tutorials and quick lessons; building confidence to farmers by visiting their farms and advis(ing) accordingly."[10] In the initial stages, translation of the tutorial into local languages may be necessary.

Working in tandem with the public sector, extension models could be evolved to incorporate training on emerging DSAs and transfer digital literacy. Reskilling extension agents, including providing them with evidence of impact and success, will help to accelerate the adoption of DSAs in SSA as extension systems play a critical role in transferring technologies, information, and skills to farmers. Innovatively packaged DSAs can provide critical insights on the barriers to adoption and key value drivers to service providers, policymakers, and other key stakeholders in the innovation ecosystem.[11] By building out community engaged higher education, universities can also be a key player in disseminating training and evidence of DSAs' contribution to improved agricultural

---

[9] Kieti, J., T.M. Waema, E. B. Ndemo, T. K. Omwansa, and H. Baumüller. 2021. "Sources of value creation in aggregator platforms for digital services in agriculture - insights from likely users in Kenya." *Digital Business* 1. http://dx.doi.org/10.1016/j.digbus.2021.100007.

[10] Kieti, J., T.M. Waema, E. B. Ndemo, T. K. Omwansa, and H. Baumüller. 2021. "Sources of value creation in aggregator platforms for digital services in agriculture - insights from likely users in Kenya." *Digital Business* 1. http://dx.doi.org/10.1016/j.digbus.2021.100007.

[11] Jiménez, D., D. Guerna, B. Ortiz-Crespo, K. Davis, and J.A.A. Salazar. 2021. *Extension agents grow new skills to cultivate a better future for CGIAR impacts*. Accessed on: August 21, 2022. https://alliancebioversityciat.org/stories/extension-agents-grow-new-skills-cultivate-better-future-cgiar-impacts.

productivity and profitability. Partnerships between tech companies, research institutions, and universities have demonstrated that working in collaboration to disseminate training and evidence generation leads to increased adoption and ability to overcome challenges to DSA adoption in Western Kenya.[12,13]

THERE MUST BE AN ADEQUATE AND INTEGRATED ENABLING ENVIRONMENT FOR DIGITIZING AGRICULTURE.

The innovative value proposition of DSAs alone will not be sufficient to create agricultural transformation. The proliferation of standalone DSAs has resulted in a fragmented digital innovation ecosystem, that has led to underutilization and impeded scale up of adoption.[14] Policies that prioritize the right of its citizenry to access digital agricultural extension, like those in Kenya, help to provide the enabling environment needed for innovation dissemination. Policies that consider data security and authenticity will also be required in order to ensure consumer confidence in DSAs that use their data and offer insights in return. Other policies that are needed to create a healthy enabling environment for DSAs to reach adequate and sustained scale include those that will incentivize adequate growth-stage capital, lead to the development of robust and scalable business models (not just products), and support the infrastructure for robust digital stacks.[15] This type of enabling environment will allow stakeholders across sectors to leverage economies of digital scale that can be leveraged to produce TFP that is resilient to shocks and leads to long-term trending growth.

BLOCKCHAIN TECHNOLOGY IMPROVES PRODUCTIVITY THROUGH BETTER VALUE CHAIN FUNCTIONALITY

In Western Kenya, African indigenous vegetables (AIVs) support livelihoods through their nutrient packed leaves and by offering short growing cycles and high demand that can be used to supplement incomes, especially for women. In May 2021, a select number of AIV value chain actors received phones containing the AgUnity platform. AgUnity, an Australian tech start-up, develops and deploys low cost, blockchain based technology solutions to build efficient digital supply chains, from farmer to consumer. A study conducted by Virginia Tech and Egerton University showed that the reliable digital transacting and record keeping features of the blockchain-powered platform led to improved value chain functionality–transaction costs were reduced, value chain actors cooperated, quality increased, incomes increased and yields increased.[16]

So, what does this have to do with agricultural productivity? Through improved value chain functionality, increased productivity was observed among the participating smallholder producers. This primarily resulted in reduced post-harvest loss–increased total output with the same amount of inputs. Because AgUnity's blockchain-powered app ensures that all transaction details are

[12] Agnew, J., R. P. Hall, J. Mwangi, N. Kristofikova, and D. Sumner. 2022. *The Impact of Blockchain Technology on Food Insecurity Through African Indigenous Vegetables in Western Kenya*. Virginia Tech, VA. http://hdl.handle.net/10919/110444.

[13] Marwa, M.E., J. Mburu, R.E.J. Oburu, O. Mwai, S. Kahumbu. 2020. *Impact of ICT Based Extension Services on Dairy Production and Household Welfare: The Case of iCow Service in Kenya*. Journal of Agricultural Science 12(3).

[14] Kieti, J., T.M. Waema, E. B. Ndemo, T. K. Omwansa, and H. Baumüller. 2021. "Sources of value creation in aggregator platforms for digital services in agriculture - insights from likely users in Kenya." *Digital Business* 1. http://dx.doi.org/10.1016/j.digbus.2021.100007.

[15] Baskaran-Makanju, S., S. Hoo, C. Mitchell, J. Larson, S. Unnikrishnan, S. Vasudevan, and Y. Zrikem. 2021. *The Digital Agriculture Revolution Will Take More Than Innovation*. Accessed August 21, 2022. https://www.bcg.com/en-cn/publications/2021/digital-agriculture-and-development.

[16] Agnew, J., R. P. Hall, J. Mwangi, N. Kristofikova, and D. Sumner. 2022. *The Impact of Blockchain Technology on Food Insecurity Through African Indigenous Vegetables in Western Kenya*. Virginia Tech, VA. http://hdl.handle.net/10919/110444.

Photo: Jessica Agnew

reliable and transparently recorded, producers, traders, and retailer users prefer to transact with other users of the application because of the increased trust the system provides. Producers stopped harvesting prior to finding a buyer and would only harvest what the buyers were looking for. Traders only ordered the varieties demanded by the retailer and consumer from the producer. The blockchain-based record keeping functionality of the platform also helped inform producers about the varieties and quantities that were demanded and they worked collaboratively to change production cycles to better meet market demand.[17]

The AgUnity platform offers value generation features that are likely to produce stickiness among consumers–it creates network effects, reduces information asymmetry, and reduces search cost. However, perhaps even more critically, it is designed to be a DSA aggregator, eventually offering complementary services (i.e., weather information, extension advisory services, marketplace) in one user-friendly location that could create a multiplier effect on TFP growth. The AgUnity platform is also designed to allow the user autonomy over their data sharing. Working collaboratively with stakeholders across the agricultural sector, a data sharing scheme can be designed to support smallholder producers even more effectively.

[17] iBid.

ACCELERATING AGRICULTURAL PRODUCTIVITY GROWTH IN EAST AFRICA: AN AGENDA FOR URGENT ACTION

By Jessica Agnew, Associate Director of CALS Global in the College of Agriculture and Life Sciences at Virginia Tech

TFP Growth in East Africa reached its peak between 1991 and 2000. Since then, it has declined, reaching negative growth between 2011 and 2020. Irrigation extension has changed little over the past six decades, while input intensification growth has surged since 1991. Land expansion continues to be the primary driver of agricultural output growth; however, during the last decade, there has been a cooling off in the region's output growth rate.

On June 23, 2022, the Global Agricultural Productivity Initiative at Virginia Tech held a multi-sectoral event in Nairobi, Kenya, to discuss the need and potential pathways for increasing agricultural productivity, especially among smallholder farmers, in East Africa. Leaders and experts from the public sector, industry, academia, research institutes, NGOs, and farmer organizations participated in panel discussions and an interactive workshop to discuss the way forward.

In his keynote address, Tim Njagi, Research Fellow at Egerton University's Tegemeo Institute in Nairobi, emphasized that "for sustainable growth, Kenya and the region ***must*** rely on increasing productivity on available land." He outlined the importance of investment in agricultural research and development given demonstrated success in addressing emergent challenges such as the adverse effects of climate change and weather variability, increased pest and disease outbreaks, lack of household resilience to production shocks, and limited value addition and agro-processing scalability.

"We have the potential. We have the people. We have the land. Africa can become a supplier of global food needs, which will contribute to resilient food and nutrition security on a global scale."

— Dr. Canisius Kanangire, Executive Director, AATF

Photo: Erica Corder, 2022

The event's fireside chat with Dr. Canisius Kanangire, Executive Director of the African Agricultural Technology Foundation (AATF), and Dr. Jason Grant, W.G. Wysor Professor of Agriculture at Virginia Tech, explored the potential of technology and trade to contribute to productivity growth in East Africa. Dr. Kanangire highlighted access to finance as a significant challenge to smallholder producer productivity growth. "Farmers are trapped in that inability to access the available technologies," he remarked. Further, he emphasized that access to technologies has not been inclusive in the region, favoring male, middle-aged, medium to large-scale producers. As a result, women and youth have not had equal opportunities to adopt new technologies because of numerous and interacting structural barriers.

Three working groups convened in the collaborative workshop portion of the agenda to discuss urgent action items for accelerating productivity growth in Kenya. The key recommendations are summarized below.

KEY RECOMMENDATIONS

Key Technologies and Innovations for Accelerating Productivity Growth

- Prioritize improved inputs.
- Technologies and innovations that consider the environmental contexts and constraints are imperative for adapting to climate change and reducing investment risk.

Priorities for Improving Access to Finance, Markets and Information, Transportation, Storage, and ICT

- The affordability of information and communication technology must be improved; digital literacy will rapidly follow.
- Partnerships between academia, scientists, and the private sector must be harnessed to reduce the cost and time it takes to reach scale.

Barriers Preventing Smallholders from Accessing Productivity Enhancing Solutions

- Affordability and availability of productivity-enhancing solutions
- Policies and policy setting environments

Recommended Actions for Policymakers and Legislators to Create a More Robust Enabling Environment for Productivity Growth

- Strengthen existing policies. This will require a review, evaluation, and participatory development process that includes county governments and other governance stakeholders.
- Create policies that are evidence-informed and data-driven. Policymakers are looking for trustworthy sources of data and evidence, accompanied by solid recommendations backed by science and demonstrated return on policy change.

What Actions, Policies, and Investments, Can Be Taken in the Next 12 to 36 Months to Accelerate TFP Growth in the Region?

- Achieve consensus on the critical evidence gaps, mobilize investment to fill them (not only financial but could include a commitment of partners to deploy through interventions and programming), and create partnerships in the enabling environment to scale proven innovations and solutions.
- Develop compelling regulatory and legal frameworks to ensure the implementation of existing policies and policy changes.

What Would Change in East Africa if a Sustainable Rate of TFP Growth Could Be Achieved?

- Livelihoods would be improved. Basic needs would be met.
- An economic multiplier effect would activate, leading to prosperity and regional resilience.

A full list of recommendations and endnotes for this article are available at globalagriculturalproductivity.org. Correspondence for Jessica Agnew may be sent to: jlagnew@vt.edu.

PARTNER STORY

Photo: HarvestPlus

SUBMITTED BY: **HarvestPlus**

IN ZAMBIA, STRENGTHENING FOOD AND NUTRITION SECURITY FOR REFUGEES AND HOST COMMUNITIES

A HarvestPlus partnership in Zambia is supporting refugees and their host communities with humanitarian supplies of vitamin A-enriched orange sweet potato (OSP) and the means to grow it themselves for improved food and nutrition security. Smallholder farmers in the refugee settlements will also benefit from the opportunity to sell their OSP vines on the market, providing an important livelihood boost.

The collaboration between HarvestPlus, the UN Refugee Agency (UNHCR), Sylva Foods Solutions Limited and other partners started in November 2021 as part of an 18-month Government of Canada-funded "Integrated Food Systems" project that is providing urgent food, nutrition, and livelihood support to vulnerable communities in the wake of the COVID-19 pandemic.

Zambia hosts refugees from DR Congo, Angola, Burundi, Rwanda and more countries in three UNHCR settlements in Meheba, Mayukwayukwa, and Mantapala, located in the western and northern parts of the country. HarvestPlus is delivering essential training in nutrition and agronomy to 1,300 lead farmers in the settlements, to support UNHCR in their comprehensive multi-stakeholder approach to providing essential public health, livelihood, and social services, including much-needed nutrition, food, and income security. The trained lead farmers will pass on their learned skills to their many follower farmers within the settlement areas.

A 2021 UNHCR survey indicated that the average rates of stunting among children in the refugee settlements range from 17-53 percent, indicating chronic malnutrition and exposure to poor living conditions in early life. Average anemia prevalence in the three settlements ranges from 41-74 percent in children and 43-49 percent in women. Biofortification is a proven strategy for improving children's and women's nutrition and health; eating OSP regularly can improve and maintain the immune system and reduce child morbidity.

As part of this project, HarvestPlus and its partners are strengthening the production, processing, and consumption of biofortified OSP and iron beans among vulnerable households, many of them women-headed.

Aggregation centers are being established and expanded in collaboration with the Ministry of Agriculture for participating smallholder farmers to store their biofortified produce and preserve its freshness prior to processing; this helps build a ready off-taker market. In select districts, the project is facilitating linkages with Sylva Foods (a woman-led and managed food processing business) and other processors to increase smallholder farmer entrepreneurial activities and expand the reach of OSP-based products.

The collaboration will continue until June 2024, ensuring these and other critical activities are implemented and sustained, providing lasting beneficial impacts to refugees and their host communities, as well as many other vulnerable Zambian households.

Photo: Daugherty Water for Food Global Institute, University of Nebraska

SUBMITTED BY: **Daugherty Water for Food Global Institute, University of Nebraska**

SYNERGISTIC TOOLS BOOST CROP PRODUCTION AND REDUCE NEGATIVE ENVIRONMENTAL IMPACTS

The Daugherty Water for Food Global Institute is working to create innovative tools to help farmers make decisions on their farm

Climate change and unpredictable seasonality can make it difficult for farmers to make important business decisions on crop management. For example, one common inefficiency of crop management is in irrigation, which is largely based on weather forecasts. When water is imprecisely applied, it can contribute to profit loss, nitrogen leaching and yield gaps.

Researchers at the Daugherty Water for Food Global Institute (DWFI) and their partners are working to solve these problems through a powerful synergy of tools to help growers around the world achieve the required critical food production goals, while overcoming environmental challenges and keeping farms profitable.

The Dashboard for Agricultural Water Use and Nutrient Management

The Dashboard for Agricultural Water Use and Nutrient Management (DAWN) project aims to provide farmers a powerful, predictive decision-making support tool to sustain food and energy crop production. DAWN is supported by the United States Department of Agriculture-National Institute of Food and Agriculture and is a collaborative effort among several universities and organizations.

DAWN combines modeling previously developed by DWFI and its Director of Research, Christopher Neale–the Spatial EvapoTranspiration Modeling Interface (SETMI) and Global Daily Evapo-Transpiration (GloDET) tools. Both SETMI and GloDET are tools for measuring evapotranspiration (ET)–or, the process by which water evaporates from the soil and simultaneously transpires from plants and enters the atmosphere. SETMI utilizes remote sensing via satellites to estimate evapotranspiration and predict rainfall and irrigation needs, while GloDET is the data set of evapotranspiration used in assessing water budgets, water productivity, plant stress and drought.

Through DAWN, collaborators hope to provide a more accurate set of seasonal forecasts one-to-nine months in advance, as well as one-to-six-day short-term forecasts during the growing season. These more reliable forecasts can translate into concrete decision-support tools useful for growers to optimize crop productivity while minimizing environmental impacts.

The DAWN project also aims to make this technology easy to use by providing recommended actions with an irrigation scheduling tool based on tailored input. It will also help farmers manage risk by giving planning scenarios that allow producers to explore how crops will fare under different conditions. Altogether, this will provide crucial information to producers in understanding the costs and benefits of different management strategies, help to close water usage gaps and make significant advances in advancing food security.

Parallel 41 Flux Network ground truths satellite data

DWFI uses its Parallel 41 Flux Network–a series of eddy covariance flux towers across the central United States–to determine movement of water vapor and other gasses in crop fields. The variance in this movement and the composition of the air helps measure ET more exactly and ground truth the satellite data in GloDET. Accurate and timely ET data is necessary for assessing water budgets, water productivity, plant stress and drought–ultimately helping growers precisely apply the amount of water that crops need, when they need it, to achieve the best possible yields. The Irrigation Innovation Consortium provides additional funding to expand the network of towers.

Measuring greenhouse gasses through the network

The Parallel 41 Flux Network and SETMI also provide an opportunity to measure greenhouse gas emissions in corn production fields supplying the ethanol industry–a protocol that eventually could be used with other crops in other countries. DWFI and University of Nebraska researchers were awarded a $3 million grant from the U.S. Department of Energy and another half-million dollars of matching funds to add gas analyzers to the flux towers to measure carbon dioxide, nitrous oxide and methane fluxes in the air and underground.

These technologies, combined with extensive soil and plant sampling for nutrients, carbon and nitrogen, allow researchers to estimate a complete carbon balance that can then be fed into lifecycle analysis models. These, in turn, provide data that shows how successful different production systems are at minimizing harmful effects of nitrous oxide emissions as well as efficiency in fixing carbon, which can provide a profit incentive in the form of carbon credits to the farmers in future carbon markets.

The combination of greenhouse gas measuring technology and modeling will lead to an increase in overall profitability as farmers adopt more efficient production systems in fixing carbon and management approaches to reduce emissions. Widespread adoption of efficient production systems is important, because mass producer adoption gives us the best chance to significantly and sustainably improve water productivity, food production and environmental quality in Nebraska and other states. Furthermore, once the technology is completed, tested and perfected, it can be applied to production agriculture in other parts of the U.S. and the world.

PARTNER STORY


Photo: International Potato Center

SUBMITTED BY: **International Potato Center**

CLIMATE-SMART POTATOES AND SWEET POTATOES BOOST RESILIENCE IN THE TROPICS

New potato varieties maintain climate resilience and improve farmer conditions

Potatoes and sweet potatoes have played important roles in nourishing burgeoning populations in Africa and Asia, and their attributes ensure their contribution to food and nutrition security as climate change challenges farmers' ability to feed their own families and consumers.

Both potatoes and sweet potatoes produce more calories per hectare than rice or wheat, and with less water. Early maturing varieties that are ready to harvest when grains are still green produce precious food in what rural Africans call "the hunger months", and enable Asian farmers to sustainably intensify food production in grain-based systems by adding an extra crop in otherwise fallow months. But their greatest attribute in the long run may well be resilience.

Plant breeders have traditionally aimed for high yields and disease resistance, but nutritional value and climate resilience have also become priorities in the past decade. The sweet potato has great potential for heat tolerance, as a mass screening of the crop's biodiversity in northern Peru demonstrated. Scientists assessed the performance of 1,973 sweet potato accessions from the International Potato Center (CIP) genebank in the coastal desert during the southern summer, when mid-day temperatures can top 40 °C. They identified 132 that produced good harvests and could thus be used to breed heat-tolerant varieties for tropical countries.

CIP has partnered with breeding programs across the globe in tapping potato and sweet potato biodiversity for the development of robust, productive and nutritious varieties, improving the livelihoods of about 10 million farming families to date. This has resulted in almost two dozen drought- and heat-tolerant sweet potato varieties being released in Mozambique since 2010, several of which have been shared with other African countries.

Though the potato is mainly a cool-climate crop, breeders have managed to develop heat- and drought-tolerant varieties that are also disease resistant and early maturing, which means they produce food even when the rainy season ends early. The development of these varieties has been laborious and slow, which is a problem given the recent pace of climate change. The good news is that technologies such as gene editing can accelerate breeding of more climate-smart varieties with characteristics that men and women consumers want, or the nutritional content young mothers and children need. In the meantime, a growing cadre of climate-smart varieties are already helping small-scale farmers across the tropics–where 40 percent of the global population lives–rise to the challenges of climate change:

- Several heat- and salt-tolerant potato and sweet potato varieties have been introduced in the southern delta districts of Bangladesh, where cyclones have flooded coastal zones, leaving saline soil that reduced productivity on 40 percent of arable land. A kilo of sweet potato costs half as much as a kilo of rice in Bangladesh, making it a vital food for vulnerable families, including about 42,000 Rohingya refugees.
- The drought-tolerant Unica potato variety, originally released in Peru, is now grown on three continents. It has enabled potato farming in areas where the crop was never grown before, such as the lowlands of Kenya's Taita-Taveta County. Yields are comparable to other varieties on less than a third of the rainfall.
- Heat-tolerant potato variety Kufri Lima allows farmers in Central India to plant that winter crop a month earlier than normal, which means they harvest when potatoes are scarce and prices are high and could open the door to potato farming in new areas.
- Drought-tolerant Irene, a nutritious sweet potato variety widely grown in Mozambique, has been shared with five other African countries in recent years. It has helped families in drought-prone northern Kenya diversify their diets and incomes and will be distributed in rural communities of southern Madagascar to help them recover from two years of severe drought.

Photo: International Potato Center

PARTNER STORY

SUBMITTED BY: **S M Sehgal Foundation and Mosaic India Pvt. Ltd.**

Photo: Sehgal Foundation

PROMOTING SUSTAINABLE AGRICULTURE PRACTICES AMONG SMALLHOLDER FARMERS

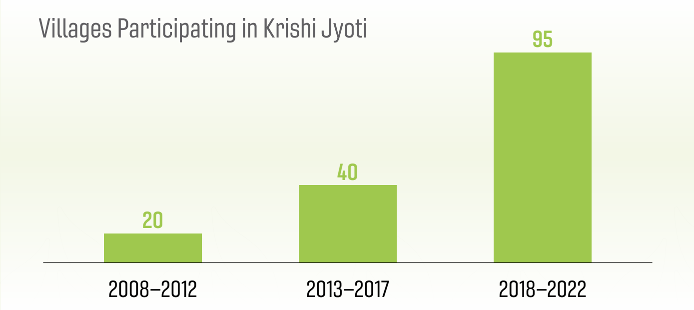
A case of Mosaic India Pvt. Ltd. & S M Sehgal Foundation partnership

A large percentage of India's population is still dependent on agriculture as their primary source of income, many of whom are small-scale farmers. The crucial development challenge for India is to ensure farmers are adequately compensated, contribute to the country's growth, all while increasing their resilience towards the many challenges facing agriculture, including climate change.

The Seghal Foundation's agricultural development program works to raise farm productivity while building resilience to climate change challenges faced by small and marginal farmers. In order to help farmers sustainably produce more, the team focuses on improving water efficiency in agriculture by promoting micro irrigation techniques and building check dams to replenish the groundwater table. Projects actively engage women farmers and improve school infrastructure to contribute to holistic improvements in the community environment. Female empowerment and education are critical to the vitality of agricultural communities.

To scale reach and impact on the agriculture sector, the *Krishi Jyoti (enlightened agriculture)* project was initiated through a partnership between the S. M. Sehgal Foundation and Mosaic India Pvt. Ltd. The project aims to help farmers in India move out of poverty and achieve greater food security in the Uttar Pradesh, Haryana, and Rajasthan states of India. It focuses on reaching out to traditional agrarian communities that struggle with low productivity to encourage farmers to adopt new technologies that will improve on-farm efficiency and improve their livelihoods.

The project began in two villages in 2008. As of July 2022, it has directly impacted the lives of 150,501 families in 155 villages across three states. It emphasizes the importance of promoting sustainable agriculture practices among smallholder farmers in rural hinterlands. These approaches can be replicated into other low productivity areas. Figure 1 shows the increase in villages covered in the project with time.



The solutions offered through the project address multiple dimensions of rural society, including agricultural development (soil health, balanced crop nutrition, and agriculture advice); water management (augmentation and conservation); and education (school transformation and upgrades).

Farmers are given a package of practices (PoP) on crops such as cotton, wheat, mustard, onion, paddy rice, and tomato. The PoP includes soil testing, micronutrients, and various farm supports and field days. A total of 37,080 demonstrations have been given as part of this project. The capacity building of the farmers, including women farmers, is done through on and off farm training, field days, and specialized training. The average increase in crop production observed was 16 to 26 percent.

Crop	Production Increase (%)
Mustard	18%
Wheat	16%
Paddy	18%
Onion	22%
Millet	26%

Water-efficient irrigation practices such as laser leveling, drip irrigation, and mini sprinklers were promoted on 1,493-acres of land, which conserved approximately 291-million-liters of water annually. Seventeen check dams have been built with a total annual water storage capacity of 66.8 million liters of water.

Farm Mechanization

The Krishi Jyoti project also introduced farm mechanization to small scale farmers participating in the project to increase the ease of farming, incomes, and total farm productivity. Under the project, eight seed drill machines were provided to eight farmers. The farmers rented out the machines to neighboring farmers at a subsidized rate. Farmers in these villages still follow a broadcast method for wheat sowing. The machine owners rented out machines to 256 farmers in the first season and saved approximately 150,000 INR (1,820 USD) in a single crop season; and in total saved 5,120 kg of seed worth INR 122,880 (1,500 USD). The individual farmers saved 20 kg seed/acre (480 INR, 6 USD). The use of a seed drill also helped spread seed at uniform distances, leading to uniform germination, fewer diseases, optimum utilization of nutrients, an 8 to 10 percent increase in crop yield, and provided an additional income of INR 4,400 (53 USD) per acre.

In another location, ten wheat harvesting machines (reapers) were provided to save costs and allow for timely harvesting. A total of 270 acres of wheat were harvested using reapers. The average cost of manual harvesting is about INR 3,200 (39 USD) per acre, whereas harvesting with a reaper costs only INR 1,120 (14 USD) per acre, resulting in a net savings of INR 2,080 (25 USD) per acre and an 80 percent savings in harvesting time.

Kitchen/Nutri Gardens

Besides focusing on enhancing total farm production, the Krishi Jyoti project also works to enhance nutrition of farm families by supporting the planting of kitchen gardens.

Malnutrition is a concern in rural India, especially among smallholder and marginal farmer families. Improving household food security with balanced, accessible and acceptable foods can counteract nutritional deficiencies and improve health. To improve dietary quality, the project promotes kitchen gardens, which creates diverse food choices while also saving money. Farm families, particularly women, are trained in kitchen gardening by being provided demonstrations.

Seven hundred kitchen gardens, 900 square feet each, have been established in 20 villages. The households have been provided with seeds for seasonal vegetables, saplings of papaya, lemon and guava, and fencing material to protect plants from animals.

The kitchen gardens have provided more vegetables and fruits to the village families. Before Krishi Jyoti, only a few vegetables were available (mainly bottle gourd, sponge guard, okra, pumpkin, lobia bean). After the intervention an additional five types of vegetables and two fruits were available. Money saved from growing vegetables per household was approximately INR 3804 (46 USD). Four hundred and thirty one of 700 women farmers had sold surplus vegetables in the market and earned an average annual INR 1540 (19 USD).

The project also supports improving the learning environment in government schools in the project villages, wherein basic infrastructure such as toilets for boys and girls, a safe drinking water system, playgrounds, and smart classes were developed. A total of 7,551 schoolchildren have benefited from this program so far.

Impact and Sustainability

By providing training, access to inputs, and improved access to diverse foods, the project has led to an improvement of agricultural productivity of 20 to 30 percent. This has resulted in a 15-20 percent increase in farmers' income.

A Village Development Committee (VDC) was formed within each village. The VDC oversees all aspects of the project. The members participate in regular training offered by agricultural experts. A community contribution is collected by villagers and is deposited in the name of VDC. These fees are used for maintaining infrastructure in the long term. The school management committees (SMCs) are responsible for management and upkeep of school infrastructure.

The uniqueness of *Krishi Jyoti* lies in the replicability of the model; it can be easily replicated anywhere in the country to help farmers achieve greater economic independence. The project's intention is to impart vital knowledge to farmers. Krishi Jyoti involves whole communities, is inclusive and participative in its approach, and does not go to villages unless the involvement and participation is total.

PARTNER STORY

SUBMITTED BY: **John Deere**

TESTING IRRIGATION TECH: KANSAS FARMS DEMONSTRATE WATER SAVINGS

Photo: John Deere

Autonomous Pivot soil moisture sensing and mobile drip irrigation are just two of the many technologies being tested by Ryan Goering and his father Eugene.

Earlier this year, the John Deere publication *The Furrow* reported on new irrigation technology coming out of Kansas. A recent survey of irrigated growers in Kansas found nearly all thought it was important to conserve water, but also believed they were already doing all they could. Seventeen of those irrigators are now involved in an educational effort to prove them wrong.

The Kansas Water Office launched the effort in 2016 with these Water Technology Farms charged with testing–and demonstrating–the latest in irrigation management and technology. The farms are comparing various types of center-pivot irrigation nozzles, soil moisture sampling methods, irrigation scheduling approaches, using aerial imagery and more. Information about each farm and the most recent Growing Season Report are available at www.kwo.ks.gov.

Concerns over water quantity and quality spurred father and son partners Eugene and Ryan Goering to enroll their farm near Moundridge, Kansas. "We want to conserve water and optimize efficiency as much as possible and help other farmers see what tools can best benefit them," says Ryan. The Goerings have experimented with precision mobile drip irrigation and other technologies. "We've experimented with 80 percent and 90 percent of the rated application rate and have seen no difference in yield so we're confident we could cut back at least 10 percent of water use and maybe more with the PMDI technology," says Ryan.

Ryan adds that they've also been able to reduce the system's pressure which slashes pumping costs. However, he admits that weather conditions can have a major impact, which highlights the benefit of the soil moisture sensing tools that he and other growers are testing. These include monitoring plant stress by measuring stalk diameter, ground penetrating radar to estimate soil moisture, and standard soil moisture probes. "We've found that using some type of soil moisture sensing technology really helps save water and input costs," says Zion Roth, who's involved with the Tech Farm his family operates near Garden City, Kansas.

Soil moisture probes also played a role on Steve Compton's Circle C Tech Farm near Healy, Kansas. "We wanted to determine if cover crops could be another way to save moisture and irrigation water, so we used probes in side-by-side plots and found they could. We were losing moisture to evaporation from bare soil even during the winter," he says.

THE SUSTAINABILITY OF A NEW TRAJECTORY

THE CALL TO ACTION FOR SUSTAINABLE PRODUCTIVITY GROWTH: CREATING ACCESS FOR EVERY FARMER TO EVERY TOOL

By Jessica Agnew

The challenges posed to the agricultural sector during the past decade underscore a need to develop solutions, innovations, partnerships, and accessibility for sustainable growth in total factor productivity (TFP). According to Elise Golan, Director for Sustainable Development in the Office of the Chief Economist at the USDA, sustainability refers to productivity growth that advances social and economic development objectives by ensuring that all people have access to safe and nutritious food that is produced in a way that protects the natural environment of current and future generations. Creating sustainable growth requires more than a one-size fits all approach. It demands place-based strategies and innovations, appropriate to the geographic, social, and economic context, that are accessible to all farmers around the world.

In her opening remarks in Part 2 of the *Accelerating Agricultural Productivity Growth for a Sustainable, Resilient World* event on October 4, Golan pointed out that historically, the major driver of sustainable productivity growth has been innovation in technological and managerial solutions, nature-based solutions, new institutional arrangements, infrastructures, and knowledge.

Industry, civil society, and the public sector have invested in creating place-based strategies and innovations that will help farmers to tackle mounting challenges to their productivity, sustainability, and profitability. The USDA-convened *Sustainable Productivity Growth Coalition Showcase at the Accelerating Agricultural Productivity Growth for a Sustainable, Resilient World* event highlighted innovations, solutions, and strategies from around the world that can help improve TFP sustainably (Box 1).

Concrete actions to increase sustainable productivity growth for food security, resource conservation, and climate change mitigation.

Food and Agriculture Organization of the United Nations—Climate Resilient Cropping Systems

Landscape and farm system approaches have been developed to increase yields, incomes, and standards of living of farming households in the long-term.

RESULTS Reduced fertilizer usage, reduced irrigation requirement during main season, increased irrigation in the dry season using saved water, increase in crop yields through climate smart agronomy and mechanization.

Agriculture and Agri-Food Canada—Living Labs: A New Approach to Canadian Agricultural Innovation

Living Labs brings together farmers, scientists, and other partnerships to co-develop solutions for farmers using a user-centered approach. Farmers help to refine the solutions so they are more likely to be adopted in the long-term.

RESULTS Canadian farmers have access to technologies that help to adapt to climate change, reduce water contamination, improve soil and water conservation, and maximize habitat capacity and biodiversity.

BASF—Drones in Agriculture: Smallholder rice cultivation in Ecuador and Colombia

Drone technology is being used to enable precise spraying of rice fields to optimize the use of farm inputs and reduce labor in Ecuador and Colombia.

RESULTS 120 farmers trained on application technology, 50 farmers trained on responsible and efficient use of inputs, 90 percent lower water use in crop protection product (CPP) application.

Foundation for Food and Agriculture Research—The Greener Cattle Initiative

This public-private partnership was designed to support the development of commercial solutions that can reduce enteric methane emissions from dairy and beef cattle. It uses a participant driven structure to facilitate variety in implemented projects (e.g., production systems, geographies).

RESULTS Discoveries in nutrition, microbiome, physiology, genetics, and management, meta-analyses and improved life cycle assessments, improved whole-farm models, and improved estimates of climate impact.

Australian Centre for International Agricultural Research—Protected Cropping Systems in the Pacific

This project supports local champions to build capacity across input supply, production, and allied sectors through locally developed training to create farming system integration with environmental considerations, social and cultural awareness, and impact on diet and health.

RESULTS Increased income for farmers, improved business management and marketing skills, improved dietary diversity of participating households, and adoption of integrated pest management to reduce pesticide use.

CropLife Canada—Genetically Modified Crops and Carbon Sequestration in the Canadian Prairies

Conducted research on the relationship between farmer adoption of herbicide tolerant cropping systems (beginning in 1995) and soil carbon sequestration from reductions in tillage and summer fallow.

RESULTS Conservation tillage and elimination of summer fallow both lead to increased soil carbon. There has been significant adoption of these practices with the use of glyphosate and HT canola, and yield and profitability has increased.

International Fertilizer Development Center—Transfer Efficient Agricultural Technologies Through Market Systems

The TEAMS Initiative in Mozambique uses a hybrid market systems approach, women centered-programming, and climate change adaptation and resilience strategies to provide smallholder farmers with innovative, time-saving technologies that are appropriate for fragile and conflict-dominated contexts.

RESULTS Adoption of climate smart agricultural practices, strengthened and inclusive market systems, increased incomes, crop diversification, and resilience to shocks and stresses, increased food security.

British Department for Environment, Food, and Rural Affairs—Farming Innovation Programme

Designed to improve agricultural productivity, environmental sustainability, and resilience in England's farming sector, funding is awarded under the Farming Innovation Programme on a competitive basis.

RESULTS Promotes collaboration between farmers and researchers, projected to increase sustainable productivity by 15 percent by 2050, encourages job creation, facilitates the creation of new commercial products, services, and patents, and abatement of 4.9 mega tonnes of CO_2 equivalent by 2050. Projects to come out of the Farming Innovation Programme include PigProGrAm, DETECT-PEST, and Muddy Machines.

International Maize and Wheat Improvement Center (CIMMYT)—Climate Smart Nutrient Management in Smallholder Systems

This project has worked in three areas in India (Haryana, Bihar, Punjab) on rice and wheat trials using nutrient expert (NE) based fertilizer management. The evaluation measured greenhouse gas emission savings.

RESULTS Greenhouse gas emission savings of 2.5 percent in rice and 20 percent in wheat by using NE fertilizer management. If this could be achieved in the whole country, this would translate into greenhouse gas savings of 5.2 Mt CO_2 from rice and 4.6 Mt CO_2 from wheat.

During the panel in the first part of the event, Canisius Kanangire, executive director of the African Agricultural Technology Foundation, remarked on the lack of access that smallholders have, especially those on the African continent, to these place-based strategies and innovations for improving TFP. The efforts to increase smallholder access to technologies and markets has ramped up over the past decade in many countries around the world. Yet there remains an urgent and immense need to more rapidly scale the access of every farmer to every tool for improving productivity to reverse the negative TFP growth trends.

So what can we do to accelerate sustainable productivity growth?

Champion agricultural productivity in all places and spaces where agricultural decisions are being made. The policy recommendations outlined in Chapter 3 provide examples for decision makers, industry, and civil society to catalyze investment in the creation and dissemination of solutions, knowledge, and strategies. A unified effort to champion these recommendations where multilateral and national-level decisions are made will help to move the needle on their achievement.

Catalyze more effective knowledge sharing. One of the major contributors to low levels of innovation uptake by farmers, growers, and businesses is due to a lack of effective knowledge sharing and capital risk. Multi-sectoral efforts such as the SPG Coalition and the GAP Initiative provide a platform for sharing independent research on the impact of turnkey solutions that could improve productivity and profitability in the sector. At the *Accelerating Agricultural Productivity Growth for a Sustainable, Resilient World* event there were more than 250 online participants from 50 countries. The SPG Coalition already has more than 102 members. Other platforms for effective knowledge sharing should be identified and prioritized.

Activate unconventional partnerships. As the Director for Sustainable Development, Golan recommends mobilizing uncommon and unexplored collaborations. This can mobilize solutions throughout the food system by combining international expertise and indigenous knowledge on how to increase the uptake and adoption of productivity-enhancing solutions.

Mobilize increased productivity in research, development, and commercialization. In a recent article, Alston and Pardey found that research productivity and research effort on wheat have led to an acceleration in the annual flow of new varieties and increase in productivity since 1990 (Alston & Pardey, 2022). Applying the same principles of increased productivity of agricultural production, increasing the productivity of research, development, and commercialization of TFP solutions can accelerate the annual flow of innovation into the sector and reverse the downward trajectory of TFP growth.

Leverage financing through mechanisms designed for the agricultural sector. A major challenge in scaling up access to sustainable productivity-enhancing solutions has been limited availability and applicability of financial products for the agricultural sector. This is especially the case in Africa. The USAID-funded *Kenya Investment Mechanism (KIM)*, a $250-million project under the *Prosper Africa* initiative, has leveraged more than $500 million in investment for key sectors in Kenya's economy by providing incentives to the financial sector for designing products that are tailored for agri-businesses. KIM builds the capacity of financial institutions and business advisory service providers to provide working capital to agribusinesses and smallholder producers. Access to affordable finance is a persistent challenge for smallholders to access technologies that can radically transform their production and productivity. Innovative projects like the *Kenya Investment Mechanism* can help to catalyze affordable finance in a way that makes sense for agricultural stakeholders.

Link businesses with aligned missions to reduce sector fragmentation. Another challenge to accelerating access to and uptake of sustainable technologies is the fragmentation of agribusiness markets in many low- and middle-income countries. BASF Agricultural Solutions' Head of Public Affairs for North America, Sarah Brown, emphasized the urgent need to develop business models with clear linkages between local providers of technologies, services, inputs, etc. with producers in her presentation at the *Accelerating Agricultural Productivity Growth for a Sustainable, Resilient World* event.

These are guiding actions that we can take to align our efforts to ensure that **every farmer** has access to **every tool** for creating sustainable productivity growth. However, extreme weather events, conflict, and other global shocks will continue to threaten our progress in achieving the TFP growth we need to sustainably meet the global demand for agricultural products. Therefore, we must be iteratively designing strategies for overcoming challenges to sustainable productivity growth and ensuring that producers have the access they need to contribute to meeting our TFP growth goal in a way that achieves environmental, economic, and social sustainability.

PARTNER STORY

Photo: Smithfield Foods

SUBMITTED BY: **Smithfield Foods**

FEED EFFICIENCY TECHNOLOGY: FEEDING THE RIGHT ANIMALS THE RIGHT FEED

The science of raising hogs for improved agricultural productivity.

Smithfield Foods is continually researching methods to produce high-quality, high-protein products that improve agricultural productivity, require fewer resources and have a smaller environmental footprint. Due to efforts like Smithfield's feed efficiency program, in which animal feed is engineered to maximize nutrition and meat production, the hogs Smithfield raises today require fewer resources to raise than they once did.

Genetic Improvement

Smithfield targets genetic characteristics in its livestock that enable animals to be raised more efficiently. For example, improvements in feed efficiency can increase the rate of calorie conversion, leading to a quicker achievement of market weight and, therefore, requiring less resources over time. This also decreases overall waste and improves manure management.

The swine genome became available in 2009 and has advanced marker-assisted selection. Geneticists at Smithfield use DNA microarrays known as Single Nucleotide polymorphisms (SNPs) to help identify specific markers in the swine genome that contribute to economically important traits, such as feed efficiency. It typically takes three to four years for genetic potential to be realized in the livestock on Smithfield farms.

Feed, Form and Shape

The modification of feed form has shown an improvement in the average daily gain (ADG) of Smithfield hogs. In comparison to diets fed in meal form (>600 microns), diets fed in pellet form (300-400 microns) at the nursery, growing, and finishing stages of development have yielded a 4 to 8 percent increase in ADG. The improvements are due to enhanced palatability, reduced waste and the potential for improved nutrient utilization due to the heat treatment of the ingredients. Cereal grains can be ground finely and included in a pelleted diet, offering further improvement to feed efficiency compared to a meal diet containing large particles.

Ingredients for Success: Feed Additives

The use of feed additives can contribute to both the profitability and sustainability of swine production. Most feed additives target animal welfare, environmental sustainability and increasing profitability. A few examples include enzymes such as phytase and xylanase and acidifying prebiotics. Smithfield carefully researches and evaluates these additives.

Phytase makes phosphorus in the hog's diet more freely available for digestion. The improved availability of organic phosphorus decreases the quantity of inorganic phosphorus needed to meet the pig's protein requirement. Additionally, improved utilization of phosphorus reduces the nutrient's presence in the resulting manure.

Xylanase breaks down natural fibers in a pig's diet and produces many beneficial "prebiotic" fractions. Smithfield researchers have documented that the prebiotic alters the microbial balance in the digestive tract and can potentially reduce the need for antibiotics to treat gut-level disease challenges.

Dietary addition of organic acids such as lactic acid (think fermented dairy products) can help transition piglets to adult diets. Weaned piglets better digest their diets and help prevent digestive-level challenges after lactic acid is added to their diets. This can improve piglet welfare at weaning, minimizing gut level health issues.

Smithfield's Role in Improving Productivity

As the largest producer of hogs in the United States, even incremental improvements in feed efficiency can decrease overall waste and improve manure management, leading to improvements in sustainability and productivity.

PARTNER STORY

SUBMITTED BY: **Smithfield Foods**

CONSERVATION PRACTICES IN HOG PRODUCTION

Environmental stewardship informs Smithfield's approach to increasing agricultural productivity

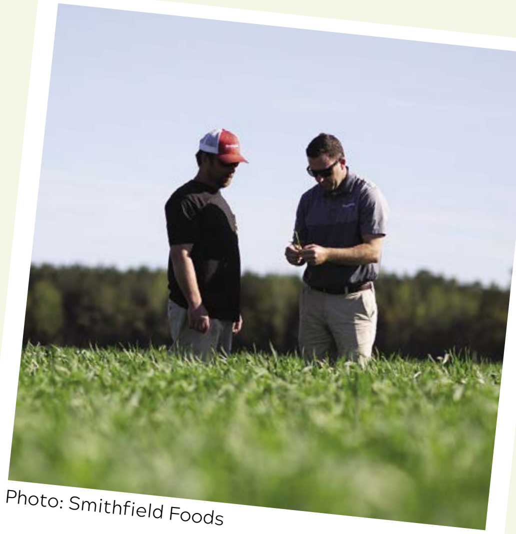


Photo: Smithfield Foods

Environmental stewardship is one of the core focus areas of the Smithfield sustainability strategy, seeking bold and innovative ways to do good for the environment. The promotion of conservation practices in hog production is central in its stewardship approach.

Supporting Climate-Smart Crop Production for Animal Feed

Smithfield has created a reduced-cost seed program to encourage farmers to grow non-GMO soybeans between crop seasons to enhance soil health and nutrients. The winter wheat program provides discounted seed to farmers, increasing locally grown, cost-effective access to wheat for hog feed. Smithfield has also expanded its storage capability to enable the company to purchase grain early in the harvest season at its peak quality. This arrangement is mutually beneficial for Smithfield and its farmers, who receive higher prices for their crops and do not have to worry about crop loss during hurricane season.

Reduce, Reuse, and Recycle

Smithfield recycles hog manure produced on company-owned farms using anaerobic lagoons to store and treat the manure, then apply it as fertilizer to grow crops such as corn, soybeans and certain grasses. This practice uses environmentally sound methods that follow local agricultural best practices and adhere to all regulatory requirements.

Smithfield's Monarch Bioenergy partnership with Roeslein Alternative Energy and TPG Rise Climate captures methane from hog manure on nearly all of its company-owned finishing farms in northern Missouri and converts it into clean energy, generating carbon-negative renewable natural gas (RNG) at a rate of approximately 800,000 dekatherms annually. Its Align Renewable Natural Gas joint venture with Dominion Energy is also producing RNG from a network of 26 of its contract hog farms in Utah. Building on this success, Smithfield is developing similar projects in North Carolina, Arizona and Virginia.

Through a partnership with Anuvia™ Plant Nutrients, Smithfield is producing sustainable fertilizer from renewable biological materials from hog farm manure treatment systems. Fertilizer produced through this partnership utilizes remnant solids that accumulate at the bottom of Smithfield's anaerobic lagoons and basins, which store and treat hog manure on farms. This results in commercial-grade fertilizer that is higher in nutrient concentration than the organic materials in their original form. The fertilizer produced allows farmers to better manage nutrient ratios and use less fertilizer overall. Because Anuvia's products contain organic matter, their nutrient release is more controlled, resulting in reduced greenhouse gas emissions. Smithfield is continuing to explore other methods to recycle manure and benefit the environment.

Butterfly Benefits

Over the last century, the biodiversity of native prairie lands has been lost, and many of the remaining grasslands have been invaded by non-native grasses not suitable for butterflies and other pollinators. Monarch butterfly populations have dropped approximately 95 percent since the 1980s and are in danger of being listed as a threatened species.

The Monarch Butterfly Habitat Exchange is a partnership between Smithfield Foods, Environmental Defense Fund and Roeslein Alternative Energy to restore 1.5 million acres of prime breeding and nectaring habitat along butterfly migration routes. In 2018, we contributed funding to plant native milkweed and wildflower species, which are monarch-friendly, on 1,000 acres of land near our hog farms in northern Missouri.

Prairies also serve to help hold water and nitrogen in the soil and reduce potential waste. If harvested at the proper time, prairies create biomass for methane generation, used to produce biogas. Smithfield is working to identify new conservation opportunities to continue its industry leadership in environmental responsibility.

PARTNER STORY

SUBMITTED BY: **The Mosaic Company**

Photo: USDA

THE ANSWER TO FEEDING THE WORLD IS RIGHT UNDER OUR FEET

Agricultural productivity is rooted in science and relies on the collaboration of interdisciplinary science to develop innovative solutions for our world's food security problems.

The Mosaic Company has taken the spirit of collaboration to heart when it comes to creating new soil fertility products and resources that improve agricultural productivity.

In the past year, Mosaic has partnered with BioConsortium, AgBiome, and Sound Agriculture, as well as acquired Plant Response. All partnerships and business ventures will work to develop soil biome technology to unleash the potential of soil microorganisms.

Partnering for soil health

Beneath our feet there is a world of diversity among micro and macro organisms. The active ability of soil to decompose organic material relies on the presence and health of these organisms composed of bacteria, insects, fungi, and animals. The term "soil health," is described by the USDA "as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans."

Over years of cultivation, the health of soil can decline due to intensive tillage, overgrazing, and deforestation. Soils with a weakened biome are less able to mobilize nutrients from organic matter including, but not limited to, nitrogen, carbon, and phosphorus. Feeding and supporting communities of microbes in the soil biome will support a more resilient agricultural system, build healthier soils, and improve efficiencies of crop nutrients.

With less available nitrogen and phosphorus in the soil, producers are required to apply more inorganic nutrients to provide their crops with the minerals and compounds needed to grow. The Mosaic Company is working to create products that improve the soil's ability to recycle nutrients from organic matter.

We are all in this together: Support for the 4Rs

Agricultural productivity is not only about the tools offered to farmers but also the implementation of the tools. The Mosaic Company is a long-term supporter for the 4R Nutrient Stewardship, a science-based framework to utilize the Right nutrient Source, at the Right Rate, at the Right Time, and in the Right Place.

The improper use of fertilizer can cause nutrient losses through surface and subsurface runoff and leaching, and volatilization losses to the air resulting in nutrient deficiencies for crops and impacts to the environment. A 4R framework may include soil testing regimes to confirm what the next crop's nutrient demand will be or precisely placing fertilizer at the seed where it is most needed. Both these methods minimize the loss of nutrients and maximize the use of resources.

The 4R program empowers producers and industry advocates to collaborate and educate others on how to more efficiently use fertilizer inputs. Implementation of 4R Nutrient Stewardship practices enabled an Illinois farmer to decrease costs per acre between $16.49 and $25.31 while also reducing greenhouse gas emissions (CO_2e) by 34.7 percent from 9.4 CO_2e per bushel to 6.14 CO_2e per bushel. 4R Nutrient Stewardship principles allow farmers to spend less money to grow their crops while reducing environmental impact.

SUBMITTED BY: **Bayer Crop Science**

Photo: Ann Steensland

SOLUTIONS FOR PRESSING FOOD SYSTEM CHALLENGES

Ensuring smallholder farmers' access to all tools will help accelerate agricultural productivity growth.

Author: Nassib Mugwanya

From extreme weather conditions to growing malnutrition, smallholder farming is as risky as it is vital. Smallholders play a significant role in producing food in low- and middle-income countries, especially in Africa and Asia. However, agricultural productivity in smallholder farming systems has been severely declining for the past decade. According to recent data, smallholder farming regions globally are struggling, with the annual average Total Factor Productivity (TFP) growth rate down by 52 percent from 2011-2020 compared to the previous decade.

Bayer Crop Science is providing smallholder farmers with access to agronomic education and unique products and partnerships leading to improved incomes and better lives. Several solutions have been developed by Bayer that can significantly improve agricultural productivity and, thereby, food and nutrition security in developing nations. These range from biotechnology to crop protection and digital farming solutions.

On a recent farm tour to sub-Saharan Africa, Mark Edge, Bayer Crop Science Director of Partnerships for Seeds & Traits Business Development for LMICs, met with Afiya, a smallholder farmer with a two-acre plot of land that is predominantly rain-fed. Afiya noted that relying solely on rain fed agriculture is becoming increasingly difficult due to the unpredictable patterns of rain seasons in recent times. However, Afiya shared a secret approach to farming with other smallholders–seeds. More specifically, reliable, drought-resilient maize seeds. These seeds were developed to also be insect-pest resistant, like how cowpea and cotton were developed to repel pod borers and bollworms from feeding on those crops. Afiya chooses biotech seeds according to the attributes needed to suit the conditions of her small plot, mitigating risks that compromise her harvest.

Seeds: A Gateway to Sustainable Practices

Biotech finetunes seeds through processes such as molecular breeding, genetic modification (GM or GMO) and gene editing, to make crops more resilient. This reduces risks globally affecting crop yield and quality by improving the crop's ability to grow and to protect itself against damage. Processes involve breeding compatible plants to accelerate their natural tendency towards strengthening selected traits or editing the genetic code that makes a crop susceptible to environmental influences.

Careful seed choices also mean Afiya, and other smallholders like her in Asia, India and Africa, can unlock the potential for further sustainable practices. By planting herbicide-tolerant maize, Afiya does not need to disrupt the earth for weeding, which promotes a healthier topsoil and enabling a fertile growing ground for her crop. Fertile soil more readily sequesters carbon and offsets emissions thus reducing the carbon footprint of Afiya's farm. Healthy soil also retains moisture, meaning less water is needed to irrigate. Through seeds and sustainable practices, Afiya saves time and uses less crop protection to minimize the environmental impact on nature surrounding her plot. With biotech seeds, Afiya can rely on more predictable harvest outcomes while working sustainably to minimize the effect of farming practices on wildlife and soil.

- Hybrid rice varieties to withstand flooding and drought.
- Smart corn system for withstanding severe weather conditions.
- Precise in-season management of fertilizer and crop protection needs.
- GM maize for insect resistance and drought tolerance.

Collective Action to Accelerate Productivity Growth

Accelerating agricultural productivity growth for smallholders will not only require a substantial investment in developing and availing all tools, such as biotechnology to smallholders, but also partnerships. As part of the commitment by Bayer to empower 100 million farmers in low- and middle-income countries by 2030, we are taking a farmer-centric partnership approach with several private and public organizations. Notable partnerships include the TELA maize project aimed at helping smallholders in Africa to improve their incomes and food security through growing insect-resistant and drought-tolerant maize varieties. This partnership brings key sector players such as grower associations, the Africa Agricultural Technology Foundation (AATF), and public agricultural research systems.

Another partnership is with Cereal Growers Association in Kenya–a non-profit organization that addresses food challenges from a variety of angles. This partnership tackles farmer access to quality drought- and disease-tolerant maize seeds among other solutions to foster food security. Partnering with these organizations, and many others, is critical in helping increase farmers' access to the latest technologies that can improve their agricultural productivity.

However, improving agricultural productivity growth will not only come from making all tools accessible to farmers. Climate resilience and environmental sustainability are equally critical for improving agricultural productivity in smallholder farming systems. Additionally, addressing gender inequalities, improving rural infrastructure, as well as smallholder access to finance and markets is important if gains from agricultural productivity are to be sustained. Finally, regulatory hurdles surrounding important productivity solutions such as biotechnology remain a key challenge. Regulation to provide the framework for reliable seeds to become the norm is an enabling factor for sustainable farming throughout smallholder regions. After 25 years of breeding and genetically engineered seeds, the scope and benefits of biotech are clear. Scientific methods, risk assessment and stewardship measures are vigorous, yet the need for regulatory harmonization in key smallholder markets precedes widespread adoption of these innovations. In the meantime, Bayer scientists continue to invest in the research to improve seeds and foster partnerships to alleviate challenges of cultivating to feed communities, and support more resilient food systems.

> As it stands, many of these tools cannot be accessed by farmers because of the lack of enabling policy environments in countries where smallholder farming systems are dominant.

REFERENCES

Aragón, F. M., Oteiza, F. and Rud. J.P. (2021). "Climate change and agriculture: subsistence farmers' response to extreme heat." *American Economic Journal: Economic Policy*, 13(1): 1-35.

Alston, J., and P.G. Pardey. 2022. "Are Ideas *Really* Getting Harder to Find." *Staff Paper Series P22-06*. University of Minnesota. 10.22004/ag.econ.320517.

Caballero, R.J, Hammour, M.L., et al. (1994). "The Cleansing Effect of Recessions." *American Economic Review*, 84(5): 1350-1368.

Carleton, T.A., and Hsiang, S.M. (2016). "Social and economic impacts of climate." *Science*, 353(6304).

Christiaensen, Luc, Lionel Demery, and Jesper Kuhl. (2011). "The (evolving) role of agriculture in poverty reduction–An empirical perspective." *Journal of Development Economics*, 96(2): 239-254.

Damania, R., Desbureaux, S., and Zaveri, E. (2020). "Does rainfall matter for economic growth? Evidence from global sub-national data (1990-2014)." *Journal of Environmental Economics and Management*, 102, p. 102335.

Food Security Information Network. (2022). *2022 Global Report of Food Crises* (No. 6). https://www.wfp.org/publications/global-report-food-crises-2022#:~:text=The%202022%20Global%20Report%20on,economic%20shocks%2C%20and%20weather%20extremes.

Fuglie, K., Gautam, M., Goyal, A., & Maloney, W. F. (2020). *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*. World Bank Group.

Fuglie, K., & Nelson, K. P. Agricultural and food research and development expenditures in the United States. USDA-ERS. Accessed at https://www.ers.usda.gov/data-products/agricultural-and-food-research-and-development-expenditures-in-the-united-states/.

Fuglie, K., & Rada, N. E. (2013). Resources, policies, and agricultural productivity in sub-Saharan Africa. *U.S. Department of Agriculture, Economic Research Service*, ERR-145.

Fuglie, K., & Steensland, A. (2022, January). *Strengthening the climate for sustainable agricultural productivity growth* [PowerPoint slides].

Fuglie, K. O., Wang, S. L., Ball, V. E., & C.A.B. International (Eds.). (2012). *Productivity growth in agriculture: an international perspective*. CABI.

Hallegatte, S., Hourcade, J. and Dumas, P. (2007). "Why economic dynamics matter in assessing climate change damages: illustration on extreme events." *Ecological Economics*, 62(2): 330-340.

Hallegatte, S., and Rozenberg, J. (2017). "Climate change through a poverty lens" *Nature Climate Change*, 7(4): 250-256.

Jayne, T.S, Fox, L., Fuglie, K., and Adelaja, A. (2021). "Agricultural productivity growth, resilience, and economic transformation in sub-Saharan Africa: Implications for USAID." Bureau for International Food and Agricultural Development.

Johnston, B.F., and Mellor, J.W. (1961). "The role of agriculture in economic development." *The American Economic Review*, 51(4): 566-593.

Lesk, C., Rowhani, P., and Ramankutty, N. (2016). "Influence of extreme weather disasters on global crop production." *Nature*, 529(7584): 84-87.

Liang, X.Z., Wu, Y., Chambers, R.G., Schmoldt, D.L., Gao, W., Liu, C., Liu, Y., Sun, C., and Kennedy, J.A. (2017). "Determining climate effects on US total agricultural productivity." *Proceedings of the National Academy of Sciences*, 114(12): E2285-E2292.

Lobell, D.B., Schlenker, W. and Costa-Roberts, J. (2011). "Climate trends and global crop production since 1980." *Science*, 333(6042): 616-620.

OECD, FAO. (2022). *OECD-FAO Agricultural Outlook 2022-2031* https://doi.org/10.1787/f1b0b29c-en.

Schlenker, W. and Roberts, M.J. (2009). "Nonlinear temperature effects indicate severe damages to US crop yields under climate change." *Proceedings of the National Academy of Sciences*, 106(37): 15594-15598.

USDA Economic Research Service. (2022). *USDA ERS – International Agricultural Productivity*. https://www.ers.usda.gov/data-products/international-agricultural-productivity/.

Wheeler, T., & von Braun, J. (2013). Climate Change Impacts on Global Food Security. *Science, 341*(6145), 508-513. https://doi.org/10.1126/science.1239402.

ACKNOWLEDGEMENTS

The GAP Report would not be possible without the efforts and expertise of many partners and friends. Thank you to Keith Fuglie, senior economist at the USDA Economic Research Service, for providing the total factor productivity data and assistance with interpretation and analysis. Tessa Naughton-Rockwell and Megan Pollock, Virginia Tech students and GAP Initiative interns, provided invaluable assistance on multiple fronts. Erica Corder provided communications support. Graphic design and artwork by Chris Dinsmore of Dinsmore Designs. Website design and maintenance by Ironistic. Event and video production services for the "Accelerating Agricultural Productivity Growth for a Sustainable, Resilient World" event, which included the GAP Report launch, were provided by the National Press Club. We also express our deep appreciation to those individuals at partner and contributor organizations who submitted stories for the GAP Report.

The Global Agricultural Productivity Report (GAP Report) draws on expertise from the private sector, international aid agencies, civil society organizations, conservation and nutrition groups, universities, and research institutions.

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

SUPPORTING PARTNERS

CONSULTATIVE PARTNERS

EXPLORE ADDITIONAL RESOURCES AT

GLOBALAGRICULTURALPRODUCTIVITY.ORG