



COLLEGE OF AGRICULTURE
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GAP
INITIATIVE  GLOBAL AGRICULTURAL
PRODUCTIVITY REPORT™
AT VIRGINIA TECH



2026 GAP REPORT™

Restarting Growth

The Role of Regenerative Agriculture in Productivity
Growth and Profitability

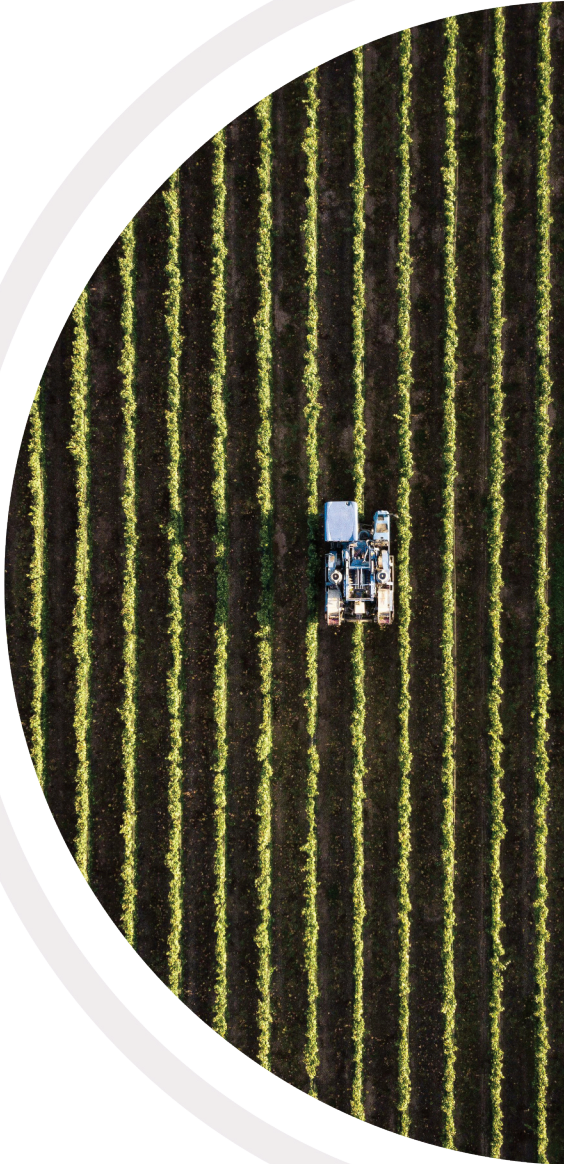


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Managing Editor: Jessica Agnew, Executive Editor: Tom Thompson
Publication Design: Spring Ashby
Peer Reviewer: Ryan Stewart, Professor in the School of Plant and Environmental Sciences Virginia Tech
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REFERENCES & RESOURCES

Access the 2026 GAP Report™ webpage for references and additional resources.

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A NOTE FROM THE DIRECTOR

Global agricultural productivity growth averaged 0.63 percent annually (2015-2024), only 30 percent of its peak in 2001-2010. We need to average over 2 percent a year to meet the demands on our agri-food systems, keep families in farming, support thriving rural communities, protect environmental integrity, and shift the status quo on food and nutrition security.

There is no shortage of commitment. Farmers, researchers, companies, policymakers, investors, and development organizations are working toward stronger agricultural systems. But progress is constrained by fragmented efforts, misaligned policy and investment, and siloed data. The distance between where we are and where we need to be is a structural signal, not a scorecard.

Over the last two years, we have evolved the GAP Initiative to support our partners in addressing these challenges. Our goal is to serve the global agricultural community with systems intelligence and coordinated action. We believe sustainable productivity growth is a unifying strategy that welcomes multiple ideologies, backgrounds, and disciplines, and is compatible with a wide range of practices, technologies, and policy frameworks.

We chose the regenerative agriculture transition for this report because it is the sector's biggest open bet. Producers, companies, governments, and investors are moving toward regenerative practices. But the evidence is still developing, and outcomes are highly context-specific across production and geographies. A practice that improves returns in one context may perform differently in another.

Coordinating action demands both caution and speed, especially as evidence develops. The 2026 GAP Report™ provides a foundation for decisions already underway: identifying where the evidence is strong, where important gaps remain, and what will be required to translate regenerative practices into measurable productivity growth, profitability, and long-term resilience.



Our commitment, in this report and in our ongoing collaboration with partners, is to ensure the momentum behind regenerative agriculture restarts productivity growth and leaves producers, economies, environments, and societies genuinely better off. Strengthening the questions we ask, sharpening the decisions we make, and keeping producers at the center of our work is integral to the journey.

We welcome you to join us and thank those of you who have already been part of it.

A handwritten signature in black ink, appearing to read 'J. Agnew'.

Dr. Jessica Agnew

Director

Global Agricultural Productivity Initiative
Virginia Tech

Restarting Growth

The Role of Regenerative Agriculture in Productivity Growth and Profitability

Growth in global agricultural total factor productivity (TFP), the ratio of all agricultural outputs to all agricultural inputs, has not merely stalled; it has continued to erode. At a time when volatile input costs, geopolitical supply chain disruptions, and mounting resource constraints have left producers least able to absorb losses, identifying tactics to restart productivity growth is both urgent and economically compelling.

Regenerative agriculture (RA) has drawn growing attention, in part because its practices target the input use and natural capital depletion that the current output growth model largely depends on. Yet the potential contribution of RA practices to TFP growth has, thus far, only been a conceptual claim rather than an empirical finding. No study in the current literature directly measures changes in TFP growth attributable to RA.

The 2026 GAP Report™ takes a first step toward assembling and analyzing the foundational evidence needed to determine whether RA practices can serve as tactics for simultaneously addressing TFP growth stagnation, increasing and

repeatable profit margins, and building long-run system resilience, three objectives historically treated in isolation.

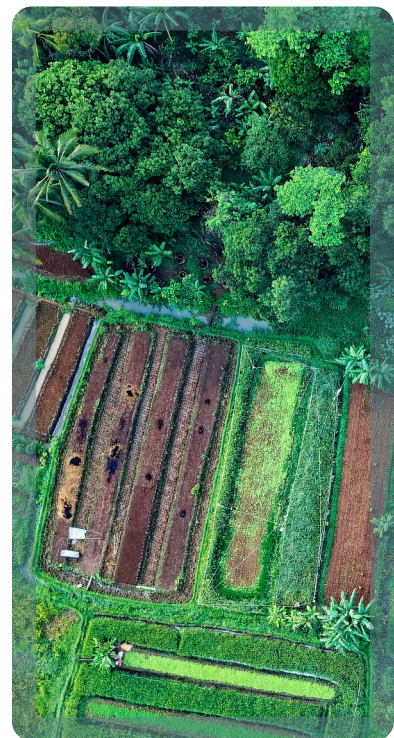
Chapter 1 updates global and regional TFP growth trends. Chapter 2 assesses current RA practice adoption and observed productivity and profitability outcomes. Chapter 3 spotlights TFP growth in the European Union (EU) and the impact of EU policy instruments intended to raise productivity through improved environmental performance. Chapter 4 sets out the R&D, decision-support tools, and policy design needed to translate RA's potential into measurable and sustainable productivity growth at scale.

Key Findings

Global TFP growth has fallen sharply from the 2001-2010 peak of 2.0 percent average annual growth to 0.63 percent during 2015-2024, roughly 30 percent of the peak rate.

Aggregate global agricultural production is shifting back toward an input-driven growth model. Input intensification once again accounts for roughly half of global output growth. Capital growth has been the largest single category of input growth in every decade since the 1990s, leveling off around 3 percent annually in recent decades. At the same time, 2001-2020 was a period of sustained net labor shedding.

TFP growth has been achieved in countries across every income level, not only high-income economies. Among the 15 countries producing the most agricultural output by value, across four income groups, Uganda posted the largest gain, moving from -3.9 percent to 0.8 percent average annual TFP growth between 2001-2010 to 2015-2024. Other relatively large turnarounds occurred in Mozambique and Afghanistan. Progress in upper-middle-income countries was comparatively rare, with only Vietnam posting a TFP gain.



From Evidence to Action:

Five Priorities for a Regenerative Agriculture-Led Restart of TFP Growth

01

BUILD THE MEASUREMENT FOUNDATION

Build harmonized public- and private-sector monitoring, reporting, and verification (MRV) infrastructure that includes stakeholder-tailored metrics, streamlined verification protocols, and publicly available aggregated adoption data. MRV must remain accessible, affordable, and usable so that its benefits accrue to the producers generating regenerative outcomes.

02

CLOSE THE LONG-RUN EVIDENCE GAPS

Long-term, whole-system research trials, co-funded by public agencies, philanthropic capital, and industry, are the missing input for producer-facing decision tools and policy design.

03

DEPLOY LOCALIZED DECISION TOOLS PAIRED WITH EXTENSION INFRASTRUCTURE

Tailor decision tools to scale, production system, context, and commodity, and deliver them alongside extension support that enables agile management and sustained adoption at scale. This integrated delivery can also identify which regenerative practices and tools improve productivity and profitability.

04

DESIGN TRANSITION FINANCE INSTRUMENTS THAT MATCH TRANSITION RISK

Design public, private, and concessional financing instruments that accommodate multi-year capital lock-up, remain portable across tenure arrangements, allow for contextually appropriate adoption of practices and tools, and are calibrated to producers' true costs, including time, upfront investment, and capacity building.

05

SHIFT FROM PRACTICE-BASED TO TARGET-BASED FRAMEWORKS

Create blended, target-based frameworks that incorporate practices, principles, and outcomes to unlock RA's contribution to sustainable productivity growth. Including TFP growth as an outcome indicator alongside adoption and established metrics will support producers in achieving regenerative outcomes alongside economic and system-wide performance goals.

01



TOTAL FACTOR PRODUCTIVITY GROWTH TRENDS

Demands on our agri-food systems continue to rise, including meeting the nutritional needs of a growing global population; responding to consumption shifts driven by rising incomes; sustaining rural vitality and farming as a way of life; and overcoming the constraints imposed by geopolitical instability, climate variability, and finite land and water.

Many approaches aim to address these demands by focusing on climate mitigation, soil health, water quality, biodiversity, supply chain resilience, food and nutrition security, and rural livelihoods. The broader challenge is to develop an organizing

strategy that works across domains to capacitate agri-food systems to meet rising demands while generating returns for producers, society, the environment, and economies. Sustainable agricultural productivity growth offers both a unifying strategy and a measurable goal, connecting progress across domains to the overall performance of the agri-food system.

Improved efficiency of input and natural resource use is a proven, highly effective strategy for achieving producer, economic, societal, and environmental goals simultaneously (Searchinger et al., 2019). It spares land, lowers costs along the value chain, reduces purchased input use, and eases pressure on water and other natural resources. Total factor productivity (TFP) growth, tracked by the GAP Report™ since 2010, is a system-wide indicator that measures how efficiently agricultural inputs are converted into outputs

TFP growth is driven by technological change, innovation adoption, and improved management practices. Advances in seed varieties, fertilizer efficiency, mechanization, precision agriculture, and data-driven farming techniques, for example, raise the output achievable from a given set of

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inputs. Investment in research and development (R&D) produces the innovations that make efficiency gains possible. At the same time, the pace at which producers adopt new tools and techniques determines how broadly those gains are realized. Extension services, producer education, and knowledge transfer are therefore just as important as the innovations themselves in driving on-farm productivity growth. The policy environment also shapes TFP growth, as government support for agricultural knowledge and innovation systems, infrastructure investment, risk management, and producer access to inputs and markets creates the conditions for new tools and practices to take root and scale.

Accelerating TFP growth to create broader returns to producers, societies, environments, and economies depends on tactics-specific and adoptable tools and practices that raise output relative to inputs. Evidence on the categories of such tactics that reliably deliver accelerated productivity growth alongside other benefits is thinner than the attention paid to the overarching strategy. Identifying those categories and testing them is the work that stands between a shared goal and measurable progress. This report examines regenerative agriculture practices as one candidate category of tactics.

“The distance between where we are and where we need to be is a structural signal, not a scorecard.”

– Dr. Jessica Agnew, Director GAP Initiative



Photo: Corteva

GAP PARTNER STORY

Pioneer: A Century of Innovation

Corteva

A century ago, farmers relied on low-yielding open-pollinated corn, but advances in breeding led to the discovery of hybrid vigor and transformed crop productivity. Henry A. Wallace helped bring the innovation of hybrid corn to farmers by founding the Hi-Bred Corn Company in 1926, which became the Pioneer® seed brand and helped. This became the drive widespread adoption of hybrid corn. Today, Pioneer is Vylor's flagship seed brand, with corn genetics grown in more than 70 countries and a legacy of improving yield, resilience, and food security. As Pioneer enters its next century, innovations such as hybrid wheat show the continued potential of advanced breeding and genetics to help farmers meet growing global food needs.

TOTAL FACTOR PRODUCTIVITY

TFP growth is achieved when producers increase their output of crops, livestock, or aquaculture products using the same amount or less land, labor, capital, fertilizer, and feed. TFP growth also occurs when producers hold output steady while reducing the inputs required to achieve it.

TFP Growth Trends

The Global Agricultural Productivity (GAP) Index, established in 2010, originally set a target annual TFP growth rate of 1.73 percent for 2010-2050, calibrated to the need to roughly double agricultural output to meet the demands of an estimated mid-century global population of approximately 10 billion (solid green line, Figure 1). While UN projections now suggest that global population will reach only 9.7 billion by 2050 (UN DESA, 2024), agricultural demand continues to rise, so the target productivity growth rate remains appropriate.

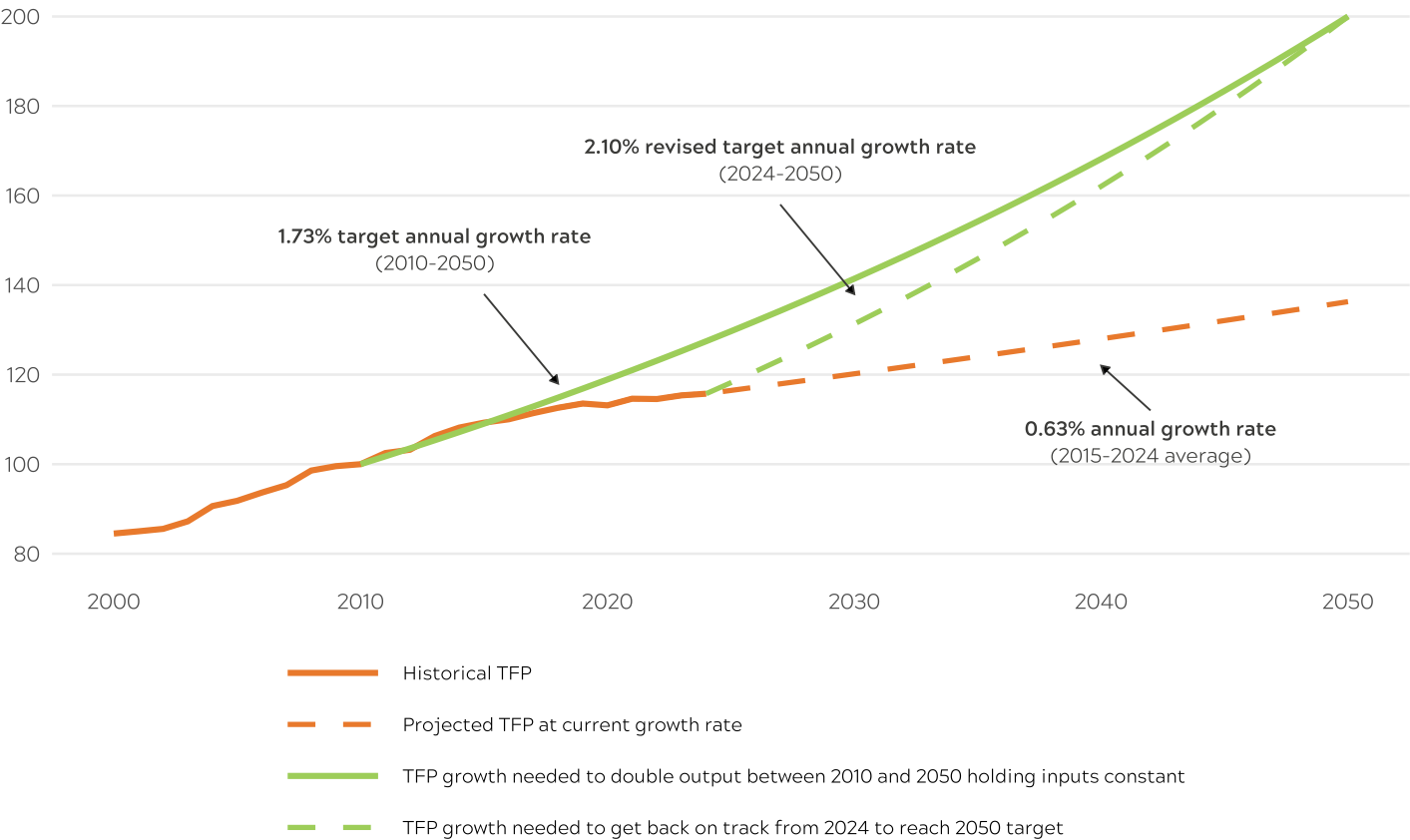
Average annual TFP growth decreased from 0.76 percent during 2014-2023 to 0.63 percent from

2015-2024 (dashed orange line, Figure 1). This widening shortfall raises the required average annual TFP growth rate to 2050 to 2.10 percent per year (dashed green line, Figure 1).

The 2015-2024 average annual TFP growth of 0.63 percent is roughly 30 percent of the peak TFP growth of 2.00 percent observed during 2001-2010, and the lowest rate recorded since the 1970s (Figure 2). The decline from the prior 2014-2023 average of 0.76 percent largely reflects 2014's comparatively strong 1.77 percent TFP growth rolling out of the ten-year window, replaced by near-zero TFP growth of 0.32 percent in 2024.

Figure 1. 2026 Global Agricultural Productivity Index, 2000–2050

The productivity gap is widening.

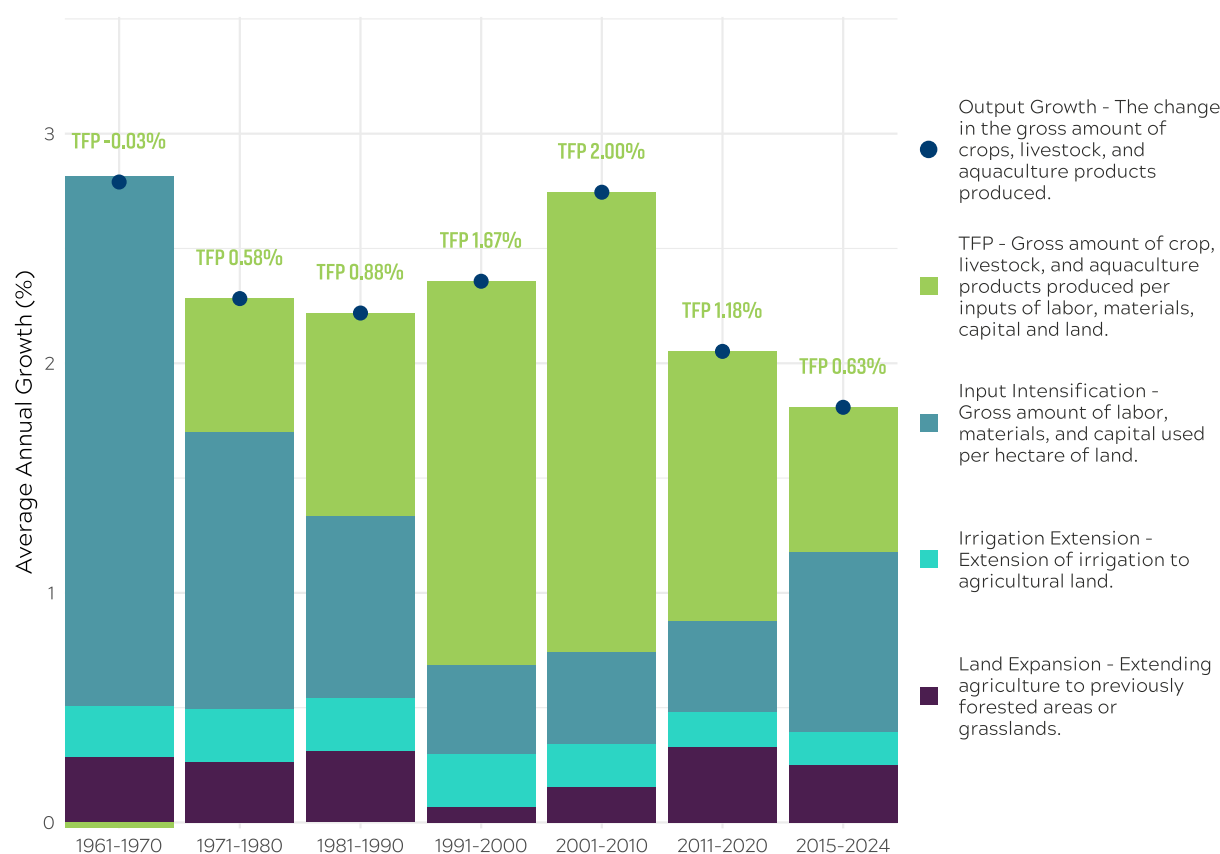


Source: Fuglie, 2026

In the past decade, input intensification has once again become the largest single driver of global agricultural output growth, leaving producers more exposed to input market volatility stemming from factors such as geopolitical tension, extreme weather and climate variability, and disrupted trade and supply chains (OECD/FAO, 2025).

Figure 2. Global Sources of Agricultural Output Growth, 1961–2024

Global output growth is becoming more input-dependent.



Source: Fuglie, 2026

Geopolitical tensions have reached a new high since 2022, compared with relative stability during 2011-2020. Conflict in the Middle East threatens shipping through the Strait of Hormuz, a corridor that carries a large share of the world's fertilizer and natural gas trade. The ongoing conflict in Ukraine continues to strain agricultural export routes through the Black Sea, a region that supplies a substantial share of global grain. At the same time, extreme heat events have grown more

frequent and longer-lasting during the past several decades, increasing the odds of sudden price shocks whenever major exporting regions face extreme weather conditions during critical points in the growing season (Baffes et al., 2025).

Sustainable productivity growth, measured by TFP alongside other proven metrics, gives producers, investors, and policymakers a shared framework for building resilience before the next disruption forces another adjustment.



Photo: Corteva

GAP PARTNER STORY

Boosting Sunflower Productivity in Ethiopia

Corteva

Ethiopia relies heavily on imported edible oil, and demand for sunflower oil is rising. SunGold, a five-year, \$35 million USDA Food for Progress project led by Research Triangle International, in collaboration with Vylor, PepsiCo, and John Deere, is expanding sunflower production, strengthening value chains, and reducing trade barriers. The program aims to shift 43,750 hectares to improved sunflower production and help farmers triple their yields - generating more than \$47 million in new annual income for 90,000 farmers and 78,000 metric tons of sunflower seed each year.

43,750
hectares

90,000
farmers

3X
yields



Photo: IFDC

GAP PARTNER STORY

Building Soil Health and Productivity Across West Africa

International Fertilizer Development Center

Across Burkina Faso, Mali, Niger, and Northern Nigeria, IFDC's Soil Values program supports rural women in strengthening sustainable agriculture through practical training in soil management, climate-smart agriculture, leadership, and organic fertilizer production. Women farmers are adopting practices such as bokashi - a soil amendment obtained by fermenting organic matter - natural pest management, and improved soil fertility management to improve agricultural productivity and improve farm-level productivity in fragile environments. In 2025, the program directly reached 97,966 small-scale food producers and 151,765 hectares of farmland with activities supporting agro-ecological sustainability improvements. Beyond technical skills, Soil Values strengthens women's leadership, confidence, and participation in agricultural decision-making and community development across West Africa.

TFP Growth Trends by Region and Income Group

Global aggregate TFP growth obscures significant regional variation in the pace and composition of output growth. Regional TFP growth averages between 1.79 percent annually in Northeast Asia and 0.39 percent in Sub-Saharan Africa (Figure 3).

Northeast Asia and Central and West Asia and North Africa (CWANA) post the highest TFP growth rates at 1.79 and 1.31 percent, respectively. TFP growth accounts for the majority of their output growth, a markedly different growth model from the global average and most other regions. In contrast, South Asia's output growth, at nearly 3.75 percent annually, is the highest of any region, but TFP growth averages 1.11 percent per year, approximately 30 percent of the output gain. South Asia's TFP growth has declined steeply from its 2001-2010 high, when it averaged 2.85 percent annually. Input intensification in South Asia is

growing at 2.26 percent annually, accounting for roughly 60 percent of the gain in output, twice TFP's share.

Sub-Saharan Africa's (SSA) output growth, at 2.75 percent annually, is the second-highest of any region, but it is driven mostly by land expansion, which grew at 1.81 percent annually, and input intensification, which grew at 0.55 percent annually. TFP grew at an average annual rate of just 0.39 percent, just below Latin America and the Caribbean's (LAC) average annual TFP growth of 0.41 percent. This gap is consistent with the limited access to advanced farming technologies, inputs, and extension infrastructure documented in SSA, constraints that push producers toward expanding agricultural land in order to increase output.

GAP PARTNER STORY

Agroecological Living Labs: Integrating Regenerative Practices to Support Long-Term Farm Productivity

African Agricultural Technology Foundation

Agricultural productivity in Central and Eastern Africa remains constrained by soil degradation, climate variability, persistent yield gaps, and limited adoption of regenerative farming practices. Through the CANALLS project, eight Agroecology Living Labs across Burundi, Cameroon, DRC, and Rwanda are co-creating solutions with over 20,000 farmers and stakeholders, demonstrating that integrated agroecological practices can improve productivity and resilience. Cassava-bean intercropping increased land productivity by 69% in Rwanda, while agroecological coffee management raised yields by 27% in DRC. These results demonstrate that regenerative agriculture and productivity growth are complementary, requiring stronger policies, markets, and farmer-led innovation systems to scale across Africa.

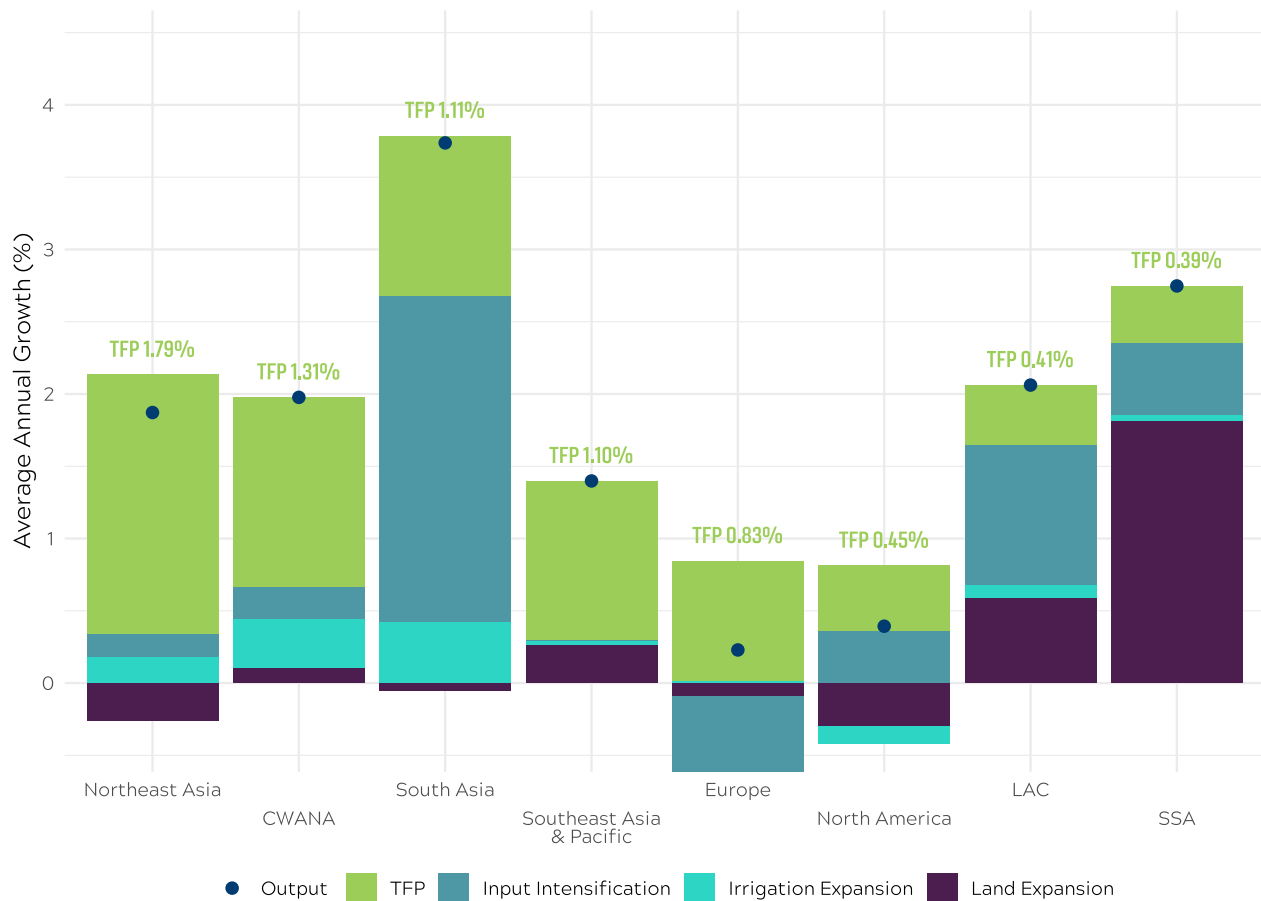


Photo: AATF

THE REGIONAL DIVIDE

Figure 3. Sources of Agricultural Output Growth by Region, 2015–2024

The path to growth looks very different by region.



Source: Fuglie, 2026

Northeast Asia, CWANA, Southeast Asia and the Pacific, and Europe are the only regions where TFP growth substantially outpaces input intensification. The remaining regions rely on input intensification and land expansion to drive the majority of output growth, with TFP growth trailing, a pattern that follows the global aggregate.

As geopolitical instability, volatile input markets, and climate variability pressure the land, water, and purchased inputs that regions rely on, TFP growth is imperative to sustain output growth that depends less on the availability and price stability of those inputs.

“ American agriculture has always led through innovation. By investing in next-generation technologies that improve productivity, efficiency and resilience, we can ensure U.S. farmers remain globally competitive while continuing to reduce emissions through practical, producer-oriented solutions. ”

- Jeremy Harrell, CEO, ClearPath

GAP PARTNER STORY

Advancing Agricultural Innovation for a More Productive and Resilient Future

ClearPath

For decades, American agricultural innovation has helped farmers increase productivity, strengthen resilience and improve efficiency. But U.S. agricultural R&D investment has stagnated while global competitors rapidly expand their innovation capabilities. Technologies such as enhanced-efficiency fertilizers, precision nutrient systems, advanced soil analytics and biochar can help farmers improve yields, reduce input waste, strengthen soil health and lower emissions. Programs like the Agriculture Advanced Research and Development Authority (AgARDA) can help accelerate these breakthroughs by advancing high-risk, high-reward technologies from research to commercial deployment. ClearPath supports market-based policies that strengthen U.S. agricultural competitiveness and ensure farmers have access to practical, productivity-enhancing innovations.



Photo: ClearPath

GAP PARTNER STORY

New Agroclimate App Delivers Real-time Climate and Crop Insights

College of Agriculture and Life Sciences, Virginia Tech

AgroVAP, a free web tool developed by Virginia Tech researchers, gives farmers satellite and weather data to optimize irrigation, fertilization, and harvest timing. Built on Google Earth Engine, the app pulls real-time soil moisture, vegetation health, and 16-day weather forecasts across more than 45 crop types worldwide. By replacing guesswork with precise, field-specific data, AgroVAP helps farmers apply water, fertilizer, and labor more efficiently, producing more from the same inputs rather than expanding resource use. This kind of decision-support technology is a key driver of agricultural productivity growth, turning research-grade data into practical, on-the-ground farming decisions.



Photo: CALS

Top TFP Growth Improvers By Income Group

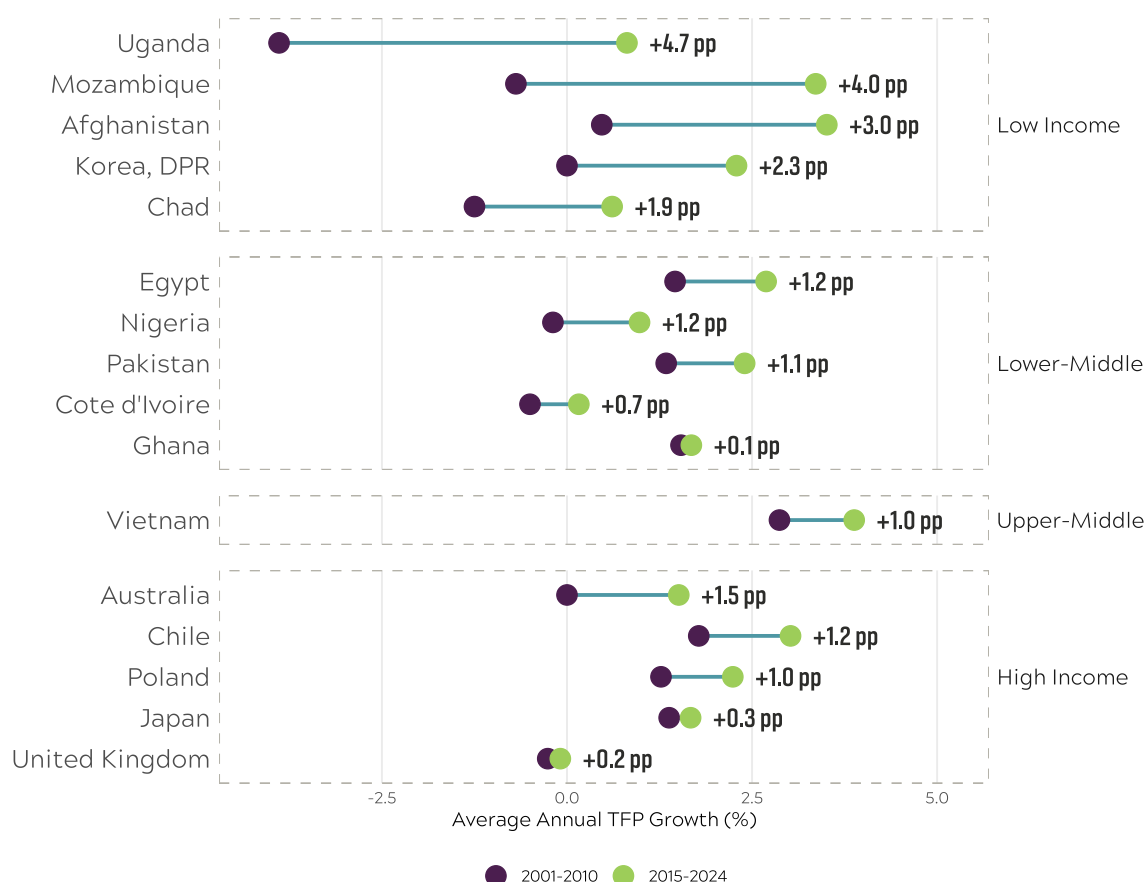
Among the 15 largest agricultural producers in each income group, according to output value, only a minority increased TFP growth between 2001-2010 and 2015-2024. Among these improvers, gains varied sharply, from just 0.1 to 4.7 percentage points (Figure 4).

Among low-income countries, the top improvers were led by Uganda, which moved from -3.9 percent to 0.8 percent average annual TFP growth, a swing of 4.7 percentage points. Similar-magnitude turnarounds were achieved in Mozambique and

Afghanistan. Lower-middle-income country improvements were led by Egypt and Nigeria, posting more modest but still meaningful TFP gains of 1.2 percentage points. Among upper-middle-income countries, only Vietnam posted an improvement, with the remaining 14 of the 15 largest producers recording declines in TFP growth during the same period. High-income improvers included Australia, which moved from essentially flat average annual TFP growth to 1.6 percent, alongside Chile and Poland.

Figure 4. TFP Growth Improvers Among the Largest Agricultural Producers, By Income Group

Countries across all income groups have reversed the slowdown.



Source: Fuglie, 2026

Note: This figure shows only the 15 largest agricultural producers within each income group (ranked by average agricultural output value, 2015-2024); countries with smaller production bases are excluded, as percentage-based TFP growth figures can remain highly volatile for them even after decade-averaging.

Among these top 15, only countries where average annual TFP growth increased between 2001-2010 and 2015-2024 are shown (up to five per income group).

EXTENSION, TRADE LIBERALIZATION, AND R&D INVESTMENTS: A POTENT PRODUCTIVITY GROWTH TRIO

While the pace and drivers of these gains vary across countries, the leading improver in each income group offers insight into the policy and market levers associated with sustained TFP growth.

Low Income: Extension Systems and Information

Access. Uganda's extension system expanded substantially between 2003 and 2011 through the National Agricultural Advisory Services (NAADS) program. Launched in 2001, its share of the agricultural budget grew from 10 percent in 2003-04 to nearly 50 percent by 2010-11 (Kasirye, 2013). Expanding mobile phone access during this period has been linked to increased adoption of agricultural inputs and improved seed technology by increasing farmers' access to information (Gupta et al., 2020; Kaila and Tarp, 2019). Because independent evaluations of NAADS have generally found limited or inconsistent effects on yields, the likely mechanism behind Uganda's TFP growth was through reduced input use - either through improved inputs or optimized application.

Lower-Middle Income: Trade Liberalization. Egypt's TFP growth acceleration over the past decade was driven mostly by input reduction (OECD, 2026). This may have been facilitated by a major 2016 currency liberalization aimed at improving export competitiveness, after which Egypt's high-value horticultural exports grew rapidly, rising to more than half of total agri-food exports by 2022-24 (World Bank, 2019; OECD, 2026). Trade liberalization and agricultural productivity growth have broader linkages, plausibly through competitive pressure, capital formation, and technology transfer from trading partners (Teweldemedhin and Schalkwyk, 2010; Otgun et al., 2025).

Upper-Middle Income: Extension and Trade

Liberalization. Vietnam's agricultural productivity gains stand on the foundations of a formal extension system dating to 1993 (Truong, 2022), reinforced by a 2000 policy shift toward higher-value export crops that made the country a top global exporter of cashew nuts, pepper, coffee, and rubber by 2010 (Sakata, 2023). A 2008 World Bank-supported extension program focusing on technology training and adoption further lifted participating farmers'

yields by 17 percent (World Bank Group, 2016). As with Egypt, this trade shift coincides with a broader pattern linking increased trade activity to agricultural productivity growth (Teweldemedhin and Schalkwyk, 2010; Otgun et al., 2025).

High Income: R&D Investment and Technology

Adoption. Australia's apparent TFP growth acceleration is complicated by timing. The 2001-2010 baseline coincides with the Millennium Drought, a severe multi-year drought documented as having significantly suppressed agricultural productivity growth during that period (Chambers, Pieralli, and Sheng, 2020; Lu and Hedley, 2004). Alongside recovery from drought conditions, agricultural R&D funding in Australia surpassed AUD 3 billion in 2024-25, with private-sector investment growing at 4.2 percent annually since 2005-06 compared to 1.4 percent for public funding (DAFF, 2025). Technology adoption has also expanded substantially over recent decades: no-till or reduced-tillage practices reached 73 to 96 percent of Australian cropland as of 2009 (Kirkegaard et al., 2014). Related soil-health practices, including stubble retention and optimized fertilizer use, have seen widespread but pragmatic uptake, reflecting farmers' tendency to adapt conservation agriculture principles to local conditions rather than apply them rigidly (Kirkegaard et al., 2014). With drought frequency and duration increasing globally (UN, 2022; Zhang, 2026), Australia's experience illustrates a broader case for sustained agricultural R&D investment as a tool for maintaining productivity growth through recurring climate stress, rather than only recovering from it after the fact.

While these country cases illustrate the potential for sustained TFP growth and reversing lagging trends, they tend to be the exception rather than the rule. The path each of these countries has taken, whether through extension investment, R&D funding, or recovery paired with technology adoption, shows what deliberate investment can deliver.

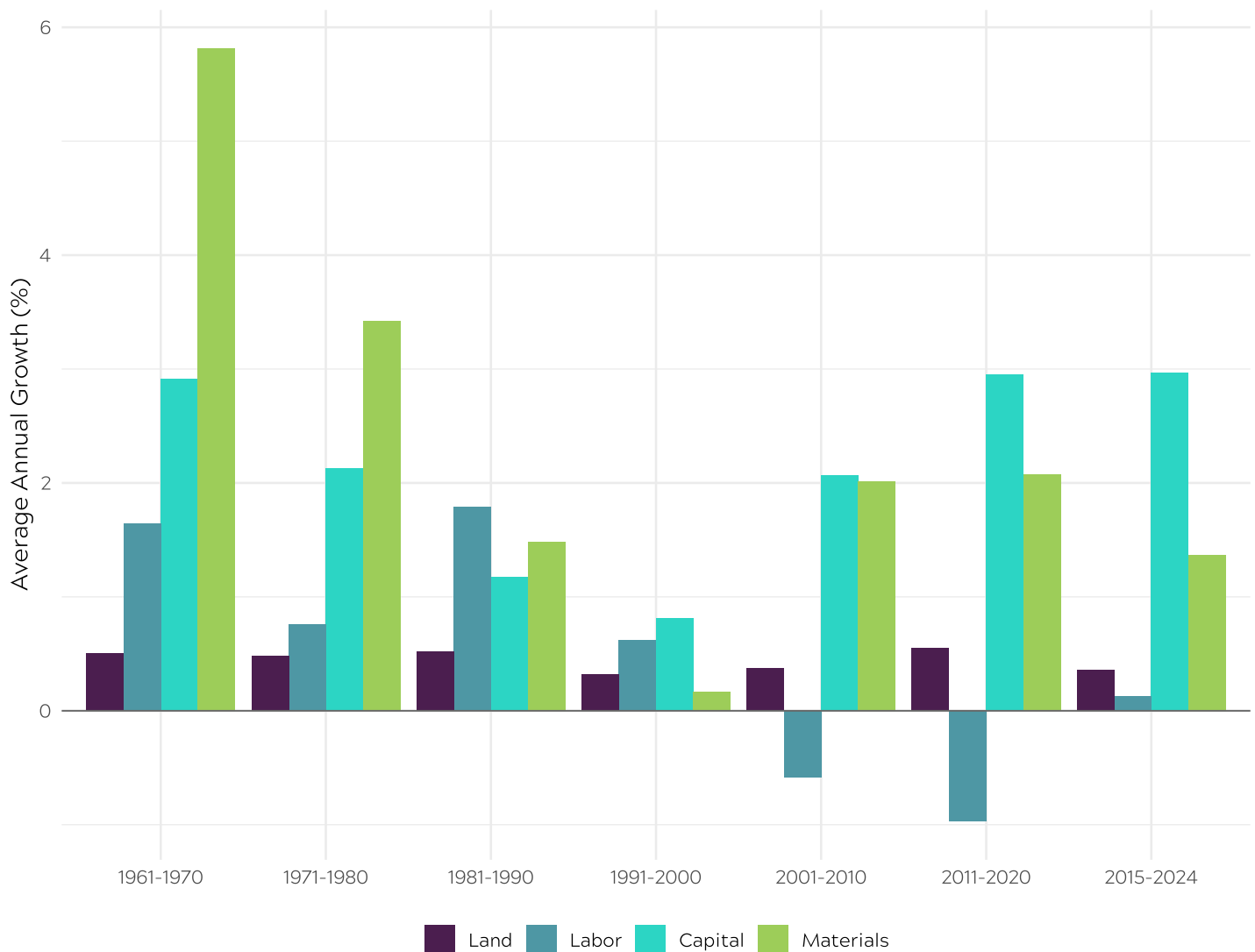
The Shifting Composition of Input Growth

Input intensification's growing role in output growth has been accompanied by a marked shift in the composition of inputs during the past six decades, with global agriculture becoming increasingly capital-intensive and less labor-intensive (Figure 5). Materials use—including fertilizer, pesticides, and feed—grew nearly 6 percent annually in the 1960s before slowing to

around 2 percent since the early 2000s. Capital growth accelerated from the 1990s and has been the largest single category of input growth in every decade since, reaching around 3 percent annually in recent decades. Meanwhile, labor use growth turned negative in 2001-2010 and declined further through 2011-2020, before edging back into positive territory in the past decade.

Figure 5. Global Average Annual Growth in Input and Resource Use by Decade

Agriculture is becoming more capital-intensive.



Source: Fuglie, 2026

This shift reflects growing use of machinery, equipment, and other capital assets to sustain output as the marginal returns to conventional productivity-enhancing inputs, such as fertilizer and improved genetics, have leveled off (Agnew and Nakelse, 2025; Alston and Pardey, 2014; Pardey

et al., 2012). Larger operations are often best positioned to absorb these higher capital requirements, as greater purchasing volumes can lower per-unit input costs and strengthen negotiating leverage, contributing to ongoing farm consolidation (Langemeier and Boehlje, 2017).

Driving output growth through input intensification rather than efficiency gains has economic and environmental implications.

→ **Economic Risk Exposure:** Input and capital costs are largely committed before the season begins and have proven markedly less flexible than output prices, which can fall sharply within the season, leaving producers with limited ability to pass rising costs through to buyers (Loy and Biram, 2024).

→ **Environmental Degradation:** Excess fertilizer and agrochemical use intensifies pressure on soils, watersheds, and ecosystems, eroding the natural capital agriculture depends on.



Photo: SAA

GAP PARTNER STORY

Permagardening: Small Plots, Big Gains for Nutrition, Income, and Resilience

Sasakawa Africa Association

In Ethiopia, Sasakawa Africa Association's permagardening approach demonstrates how regenerative practices can increase productivity on even the smallest plots. By combining crop diversification, composting, water conservation, and year-round production, households improved resource-use efficiency while strengthening food security and incomes. A 2025 assessment found that participating households achieved higher profits, greater dietary diversity, and stronger adoption of improved production practices than non-participants. Nearly all beneficiaries planned to continue using the approach, highlighting its practicality and scalability. The results show how low-cost, knowledge-intensive innovations can help smallholder farmers increase productivity, resilience, and household wellbeing in resource-constrained environments.

Alongside capital, purchased inputs, particularly fertilizer, play a central role in all three major production systems. Crop systems are the primary direct consumers of synthetic fertilizers, livestock production relies heavily on fertilizer-intensive feed crops, and aquaculture carries similar embedded input costs through formulated feeds and, in some systems, direct pond fertilization.

Global demand for the three primary fertilizer nutrients (nitrogen, phosphorus, and potassium) reached a record 200 million tonnes in 2020, with nitrogen alone accounting for more than half. Despite a decline in 2022 driven by price spikes, demand has since recovered toward 2020 levels (IFA, 2024).

This record demand reflects a rational response to real agronomic needs. In many soils and farming contexts, synthetic fertilizers remain the most reliable and cost-effective tool available. The concern is not fertilizer use but the share of output growth that depends on purchased inputs rather than on efficiency. When input costs are high and volatile, and supply chain disruptions abound, high input use translates directly into margin pressure that producers have limited ability to absorb. When input use expands faster than output, both financial risk exposure and environmental footprint grow. One promising avenue for addressing both simultaneously is a closer examination of input use itself, and the role natural capital stocks can play in reducing reliance on it. **Regenerative agriculture practices enter here as a candidate set of tactics for reaching the target 2.10 percent average annual TFP growth.**



Photo: Mosaic

GAP PARTNER STORY

From Commitment to Scale: Advancing Sustainable Productivity on 100 Million Acres

Mosaic

The Mosaic Company is advancing sustainable productivity growth by improving nutrient use efficiency (NUE), a key lever for producing more food with fewer resources. Through its goal of implementing soil health and conservation practices on more than 100 million acres by 2030, Mosaic is helping farmers strengthen productivity while improving resource stewardship and reducing costs. Central to this effort is adoption of the 4R nutrient stewardship framework and enhanced-efficiency fertilizer technologies that improve nutrient availability, uptake, and utilization. Combined with conservation practices such as reduced tillage and cover crops, these innovations help farmers maintain or increase yields, improve soil health, and build more resilient production systems at scale.

02



REGENERATIVE AGRICULTURE: PRODUCTIVITY & PROFITABILITY

The case for RA as a potential category of tactics to restart productivity growth rests on three distinct channels by which specific practices can move the TFP ratio: input reduction, output improvement through biological and ecological processes, and output stabilization under climate-related stress. This chapter assesses practices within each channel across crop, livestock, and aquaculture systems and their effects on the TFP ratio and implications for producer profitability. Long-run system resilience is assessed through the time horizon on which each channel operates. Input reduction can register within a season or two, while natural capital accumulation and output stabilization build over years.

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No universally accepted definition of regenerative agriculture exists. Across the peer-reviewed and practitioner literature, it is variously defined by its *outcomes*, such as improved soil health, biodiversity, watershed function, and ecosystem services; by its *principles*, including minimizing disturbance, maximizing biological diversity, and integrating livestock; or by its *practices*, such as cover cropping, reduced tillage, and rotational grazing. Definitions also vary across sectors. This lack of definitional unity complicates cross-study comparisons, adoption measurement, and policy design.

For this report, RA is defined as a set of contextually appropriate farming and management practices and tools oriented toward improving soil and ecosystem health as a primary goal, with enhanced biodiversity, watershed function, and resilience as downstream benefits. Which practices qualify depends on local soil, climate, and production system conditions. This definition aligns practices, principles, and outcomes, centering ecosystem health as the mechanism through which broader gains are achieved.

REGENERATIVE AGRICULTURE'S CONNECTION TO TFP GROWTH

CHANNEL 1: INPUT REDUCTION

The most immediate and measurable way regenerative practices affect TFP growth is by reducing input use. Across crop, livestock, and aquaculture systems, evaluations of regenerative practices consistently show that output levels can be maintained or improved while purchased inputs and costs are reduced. The efficiency gain derived from input reduction tends to materialize earlier than output changes or natural capital improvements. The mechanism differs by sector, but the logic is the same: fewer purchased inputs for the same or greater output directly raise TFP.

CROP SYSTEMS

Nitrogen use is the highest-leverage target.



More than half of all nitrogen applied worldwide is lost to the environment rather than taken up by crops (You et al., 2025). Optimized combinations of nutrient, crop, and soil management can substantially close that gap, translating directly into lower input costs without sacrificing output (You et al., 2023). Other crop-based RA practices also reduce material input use. For example, no-till eliminates tillage passes and diversified rotations reduce agrochemical expenditure. Input savings compound over time to close the gap with conventional production economics (Volsi et al., 2022).

50%+

of nitrogen applied worldwide is lost to the environment

LIVESTOCK SYSTEMS

Feed is the biggest opportunity.



Input reduction is realized primarily through feed, which is typically the largest variable cost in livestock operations (USDA ERS, 2022). Adaptive multi-paddock grazing with faster rotations and lower stocking rates improves pasture utilization. It reduces supplementary feed demand (Day et al., 2024a), while manure and compost from integrated crop-livestock systems close nutrient loops that would otherwise require purchased fertilizer, reducing external input dependency across the whole farm (Ran et al., 2026).

AQUACULTURE SYSTEMS

Waste can become a resource.



Feed dominates production costs in fed systems, making feed efficiency the primary lever for input reduction (FAO, 2024). Biofloc technology and integrated multi-trophic aquaculture (IMTA) both convert waste into feed or biomass, reducing net input requirements across the system (Khanjani et al., 2022). Species selection also reduces input use. Low-trophic species, including bivalves and seaweeds, require no external feed or fertilizer inputs, insulating them from the feed-cost volatility that pressures fed systems (Barrett et al., 2022).

CHANNEL 2: OUTPUT IMPROVEMENT THROUGH BIOLOGICAL AND ECOLOGICAL PROCESSES

The second channel moves TFP by improving outputs through biological and ecological processes. Across crop, livestock, and aquaculture systems, the consistent finding is that practices that regenerate natural capital by improving soil and ecosystem health support output levels at least comparable to those achieved through other production approaches, with potential for increasing yields over time. However, gains often accrue slowly and are rarely captured in short-term trials or single-season economic analyses.



CROP SYSTEMS Build soil capital.

Soil organic carbon (SOC) is the primary form of natural capital. Increasing SOC supports higher and more consistent yields by improving soil structure, water infiltration and storage, nutrient cycling, and biological activity. Unlike purchased inputs, SOC is not subject to geopolitical supply disruption or price volatility (Dominati et al., 2010; Lal, 2004; Murphy, 2015; Oldfield et al., 2019).



LIVESTOCK SYSTEMS Build stronger pastures.

Natural capital within livestock systems is realized through pasture and rangeland health. Well-managed grazing systems accumulate SOC, support higher stocking densities, and build forage quality and quantity, reducing supplementary feed dependency over time. A global meta-analysis of 64 studies found that rotational grazing improved soil carbon and bulk density, while continuous grazing significantly reduced soil organic carbon, the carbon-to-nitrogen ratio, and total nitrogen relative to ungrazed land (Byrnes et al., 2018). In a review of 21 studies on grazing management, 5 found that showed higher net returns under intensive, rotational-style grazing compared to continuous grazing. This was driven by the higher stocking densities that more frequent paddock rotation allows, with larger operations benefiting most (Day et al., 2024b).



AQUACULTURE SYSTEMS Build healthier aquatic ecosystems.

Natural capital takes the form of water quality, sediment health, and the biological communities that regulate nutrient cycling. Non-fed bivalve and seaweed systems generate measurable nitrogen removal through bioextraction at harvest, along with increased abundance of targeted fish species relative to reference habitats (Barrett et al., 2022).

This channel operates slowly in all land and water production systems. Realizing its potential requires sustained practice adoption over a longer time horizon than most farm-level financial models accommodate. Across all three systems, existing markets rarely compensate for natural capital co-benefits, meaning standard farm-level financial analysis underrepresents the full output of these

systems (Grabowski et al., 2012). Most farm-level analyses are built around one- to five-year planning windows with break-even thresholds calibrated to normal-year yields, neither of which captures soil capital gains that accrue over decades. Patient capital, transition financing, and monitoring infrastructure are the investment priorities this channel points to most clearly.

CHANNEL 3: OUTPUT STABILIZATION UNDER CLIMATE STRESS

The third channel is less directly observable than the first two and the hardest to quantify, but may prove increasingly important as climate stress and variable weather patterns intensify. The productivity losses associated with extreme weather events are measurable and cumulative (Zhang, 2026). Drought frequency and duration, for example, have increased 29 percent since 2000 (UNCCD, 2022). The resulting output variance increasingly drags on agricultural TFP growth. Regenerative practices may partially offset the effects of drought and other climatic variability across all three production systems.



CROP SYSTEMS

Buffer yields through healthier soils.

Soils with higher SOC retain more water and buffer yield loss under drought and heat stress (Kane et al., 2021). The resilience benefit is distinct from average output improvement and tends to be largest under moderate, rather than extreme, water stress conditions. The largest gains accrue to soils with lower starting SOC, given diminishing marginal returns as SOC accumulates (King et al., 2026).



LIVESTOCK SYSTEMS

Stabilize output through productive pasture.

Well-managed pasture provides a structural buffer against output losses that accompany drought and rainfall variability. Systems with stronger natural capital metrics have shown greater output stability over time, suggesting that ecological condition functions as a form of resilience that standard metrics do not fully capture (Heagney et al., 2026; Muleke et al., 2026). Well-managed productive pasture also reduces dependence on purchased feed, buffering producers against price volatility that results when climate stress drives poor harvests in feed crop systems.



AQUACULTURE SYSTEMS

Diversify to spread climate risk.

Integrated and diversified systems demonstrate greater income stability under climate stress than monoculture alternatives, since crop, livestock, and fish/feed prices are not perfectly correlated and diversification spreads exposure across distinct stressors (Troell et al., 2014). Non-fed and low-trophic systems are structurally less exposed to climate-driven feed crop price volatility, providing resilience through input independence rather than ecological buffering alone (Boylard and Lara, 2024; Krause et al., 2022).

Despite its significance across all three sectors, output stability under stress remains a largely uncounted TFP growth channel. Farm-level economic models and most agronomic trials are not designed to capture output variance

reduction as a distinct benefit. The gap between what regenerative practices can deliver biophysically and what standard analyses measure reflects, in part, this accounting blind spot (Nicolau et al., 2026).

A NOTE ON RA OUTCOMES AND TFP GROWTH

The TFP growth connection to RA practices rests on clear channels and substantial practice-level evidence. Still, no study in the current literature directly measures TFP growth change attributable to regenerative practice adoption. The argument rests on the properties of TFP growth and on cumulative practice-specific findings rather than on direct measurement. The literature also does not establish that regenerative practices consistently improve productivity or profitability across contexts. **Outcomes vary significantly by practice type, soil conditions, climate, tenure arrangements, market access, and adoption duration, and for many practices and regions the evidence is too thin, too short-term, or too context-specific to support broad generalized recommendations yet.**

“Since I began practicing regenerative agriculture, I've seen life return to the soil and rediscovered the joy of being a farmer.”

– Martin Simeon Wanser, GAAS associate farmer

GAP PARTNER STORY

The Next Generation of Farmers Is Rebuilding Productivity from the Ground Up

Farm Foundation

Farm Foundation’s FarmPath program received 671 applications from individuals in 48 states in its first year. The program more than doubled its initial goal of 300 participants. Of those, 502 producers joined the FarmPath community. Applicants consistently expressed interest in soil health, diversified crop systems, rotational grazing, conservation practices, and reduced input dependence as strategies to improve long-term profitability and operational resilience. Application data indicates many emerging producers increasingly view regenerative agriculture as connected to productivity and essential to building efficient, economically viable farming systems in changing economic and environmental conditions.



Photo: Farm Foundation

SELECT REGENERATIVE PRACTICES AT A GLANCE

SYSTEM	WHY IT'S REGENERATIVE	TFP GROWTH CHANNEL(S)
Crops		
Cover crops	May fix atmospheric nitrogen conditional on species, reducing reliance on synthetic fertilizers. Can suppress weeds.	INPUT ↓
No-till / reduced tillage	Cuts fuel, labor, and capital costs; builds soil organic matter, improving water retention and drought resilience.	OUTPUT ↑ INPUT ↓
Precision N management	Matches nitrogen supply to crop demand, reducing over-application without yield penalty.	INPUT ↓
Livestock		
Adaptive multi-paddock grazing	Improves pasture utilization and biomass; reduces supplementary feed dependency.	OUTPUT ↑ INPUT ↓
Silvopasture	Fodder species can reach economic viability without carbon payments; sequestration potential opens carbon market revenue.	OUTPUT ↑ INPUT ↓
Integrated crop-livestock	Builds soil carbon without yield loss in cropping phases; reduces purchased input dependency and improves income stability.	OUTPUT ↑ OUTPUT ↔
Poultry-vegetable rotation	Manure enriches soil nitrogen for subsequent crops, reducing fertilizer inputs while improving vegetable yields.	OUTPUT ↑
Aquaculture		
Circular aquaculture	Converts waste into productive inputs through methods like biofloc systems and feed reformulation, reducing production costs and dependence on external feed.	INPUT ↓ OUTPUT ↑
Integrated multi-trophic aquaculture	Waste from fed species becomes feed or biomass for extractive species, improving productivity and reducing effluent.	INPUT ↓ OUTPUT ↑

Where RA Practices Stand Today: Adoption Rates, Geographic Patterns, and the Data Gap

The potential for RA practices to serve as tactics to restart desperately needed productivity growth, secure profitability, and ensure long-run system resilience depends entirely on scale. Regenerative practices that improve input efficiency, build natural capital, and stabilize output under stress can only create system-wide impact if they reach enough producers. Current adoption rates are far below that threshold.

Conservation agriculture (CA), the combination of minimum or no-till, retained crop residue, and diversified rotations, is one subset of RA practices for which consistent global adoption data exist. CA was used on approximately 205 million hectares, or 14.7 percent of global cropland, in 2018/19, up from 7.5 percent a decade earlier (Kassam et al., 2022). Even so, the underlying rate of change is slow. Depending on the practice, it could take decades to reach majority adoption in key production regions. For example, adoption of tillage reduction practices

increases by roughly one percentage point a year in some contexts. Similar trends are seen in the adoption of winter cover cropping (McGill et al., 2026). Moreover, the measurement infrastructure needed to track adoption reliably does not yet exist at the scale required, and estimates from different data sources disagree significantly (McGill et al., 2026).

The 2025 GAP Report™ identifies closing adoption gaps as one of four core strategies for restarting TFP growth, noting that where proven tools exist but have not yet reached most producers, the latent productivity growth potential is substantial. **The diagnostic that follows provides a first step in closing the adoption gap by assessing where the evidence is strong, where it is weak, and what would need to be true for RA to be achieved at a scale that would meaningfully contribute to TFP growth and producer profitability.**

GAP PARTNER STORY

Brewing Sustainability: Community Leading Regenerative Coffee Farming in Karnataka

S M Sehgal Foundation

Karnataka is referred to as the “Coffee Capital of India,” contributing nearly 70% of the country’s coffee production. At the heart of this sector are women farmers who are increasingly adopting regenerative farming practices that promote ecological sustainability and strengthen rural livelihoods. The S M Sehgal Foundation is supporting women farmer groups in this transition by building awareness and capacity in soil health improvement, biodiversity enhancement through plantation of native tree species, water conservation, balanced use of fertilisers, and greater utilisation of bio-resources. The experience demonstrates how adoption of regenerative practices can support sustainable productivity growth, enabling farmers to produce more value from their land while conserving the resources needed for future production.



Photo: SMS

GAP PARTNER STORY

Measuring Innovation at Scale: Why Evidence Drives Productivity

HarvestPlus

Agricultural innovation drives productivity growth only when proven technologies achieve widespread adoption, yet measuring adoption at scale remains a major challenge. Using biofortification as a case study, HarvestPlus and its partners demonstrate how credible, standardized, and cost-effective measurement systems generate the evidence needed to inform policy, strengthen investment decisions, and accelerate scaling. A new methodology developed by the International Food Policy Research Institute's HarvestPlus program, in collaboration with GroundWork and the Alliance of Bioversity and CIAT, estimates the reach of biofortified crops across agricultural value chains. Applied to 2025 program data, it estimates that more than 650 million people were consuming biofortified foods across 13 countries.



Photo: HarvestPlus

The strongest evidence is not for a practice alone, but for the right practice in the right context.

GAP PARTNER STORY

Redefining Regenerative Agriculture for the Tropics: A Farmer-Led Framework Built for Scale

The Nature Conservancy

In Brazil's tropics, decades of input intensification have stalled productivity and tied farmers to volatile global supply chains. TNC Brazil partnered with GAAS (a producer association with more than 400 members) to formalize a definition of and approach for Regenerative Agriculture for the Tropics and a producer-grounded MRV system built for scale. The approach replaces chemical dependency with biological process management: cover crops, biological inputs, remineralizers, and composting. Results from anchor farms include up to 15% productivity gains, near 50% lower costs, margins up to 300% higher, 75% less synthetic chemicals, and reduced yield variability. In the tropics, regenerative practices are a demonstrable tactic for increasing productivity alongside profitability.



Photo: TNC

REGENERATIVE AGRICULTURE IN CROPPING SYSTEMS

The crop practices with the strongest productivity growth and profitability potential operate primarily through the input reduction channel, with soil capital and yield stabilization benefits possible but

slower to materialize and more context-dependent. Cover cropping, reduced tillage, and nitrogen optimization have the deepest evidence base of the crop practices reviewed.

EVIDENCE SUMMARY

● ● ● Strong

● ● ● Mixed

● ● ● Limited

	NO-TILL Reduced and zero tillage	NITROGEN OPTIMIZATION Precision and biological N management	COVER CROPS Cover cropping and species selection
TFP CHANNEL	Input Reduction Output Improvement	Input Reduction	Input Reduction
KEY CONDITION	Regional profitability is variable; mechanization required in smallholder contexts.	Gains are context-specific; local calibration required to avoid underperformance.	Species choice and termination timing are decisive; high risk if poorly matched to local context.
EVIDENCE STRENGTH			
Input reduction	● ● ●	● ● ●	● ● ●
Output improvement	● ● ●	● ● ●	● ● ●
Output stabilization	● ● ●	● ● ●	● ● ●

Note: Strong – evidence is consistent across multiple study designs, regions, and farm types; the direction of the effect is clear and well-characterized. Mixed – evidence exists but outcomes vary significantly by species, timing, soil type, climate, or management quality; the effect is documented under some conditions but is not reliably predictable across contexts. Limited – the evidence base is too thin, too short-term, or too geographically narrow to support a general claim; the mechanism may be theoretically plausible but has not been documented at scale under real production conditions.

Reduced and no-till: Productivity, profitability, and risk

No-till is one of the most-documented regenerative cropping practices. Input cost and yield effects stand out as two of the strongest mechanisms for productivity growth, though the evidence on both is more mixed than often portrayed. Profitability associated with adopting reduced tillage is well documented but uneven across soil properties and climates. In smallholder contexts, affordable herbicide availability is a prerequisite rather than a complement to adoption (Dahlin and Rusinamhodzi, 2019).

Eliminating tillage passes directly reduces fuel, labor, and capital costs. Russell (2022) found that across four representative Texas cotton farms, no-till scenarios tended to produce a higher projected five-year net present value (NPV) than other regenerative scenarios tested, especially when paired with the gradual sale of tillage equipment. In the Northern Plains and Coastal Bend farm models, however, the conventional baseline outperformed all regenerative scenarios based on NPV (Russell, 2022). A meta-analysis of temperate arable systems found that reduced and no-till adoption increased SOC without reducing yield during cropping years, but when the authors re-ran their analysis excluding lower-quality studies, this effect did not hold up (Jordon et al., 2022).

The drought-resilience picture is similarly contested rather than settled. One review cites a case where no-till farmers in western Iowa saw notably higher corn yields than conventional-tillage farmers during the 2012 drought. Still, it immediately tempers this with a meta-analysis finding that crop rotation, residue management, and no-till had no significant effect on yield stability compared to conventional tillage. Organically managed fields also showed lower relative yield stability, an open question that needs further research (Rehberger et al., 2023).

Nitrogen optimization and nutrient management

Nitrogen management is the highest-leverage, nearest-term entry point into the input reduction

channel for crop systems. Adoption of precision N management varies sharply by context, reflecting fundamental differences in soil testing capacity and extension services. In the United States, approximately 30 to 60 percent of large-scale producers use soil or plant nitrogen testing to set application rates. Within the European Union, adoption ranges widely, from about 23 percent in Denmark to about 80 percent in France. Adoption in China and India ranges from 25 to 59 percent, while Mexico's rate is under 2 percent (Cai, Zhao, and Yan, 2025).

Global nitrogen recovery efficiency averages just 48 percent. Less than half of applied nitrogen is recovered in aboveground crop biomass relative to the unfertilized baseline, with the remainder subject to a mix of soil retention, immobilization, and loss pathways. Optimal combinations of nutrient, crop, and soil management could raise that figure from 48 percent to roughly 67 percent (You et al., 2023, 2025). Nebraska research provides on-the-ground evidence that sensor-based nitrogen management cut application rates by an average of 33 lb N/acre (37 kg N/ha) across more than 80 site-years. Meanwhile, a satellite-guided approach saved 56 lb N/acre (63 kg N/ha) with a roughly \$24/acre (\$60/ha) profit gain, both while maintaining yields (Balboa et al., 2025). Precision tools may address the types and quantities of nutrients needed, but soil health governs how efficiently crops use the nutrients available to them (Joshi et al., 2026). Broader adoption of precision application tools alongside other regenerative strategies could plausibly translate into measurable TFP growth.

Enhancing soil health could increase global crop yield by 7.8 million tonnes and reduce nitrogen surplus by 8.1 million tonnes by 2050 (Xu et al., 2025). In Tanzania, active soil carbon strongly predicts maize yield response to nitrogen. This matters because the profitability of fertilizer use for smallholders drops sharply as farmgate price ratios worsen. Raising soil carbon may be an optimal intervention to make fertilizer use economically viable in some smallholder contexts (Chamberlin, Jayne and Snapp, 2021).

Cover cropping: Yield effects, soil organic carbon, and farm economics

Cover crops can potentially reduce the need for synthetic inputs through nitrogen fixation, but they are one of the riskier regenerative practices to get wrong. Species choice is the most consequential decision: legumes fix atmospheric nitrogen biologically and can boost subsequent corn yields by more than 50 percent without added fertilizer. Meanwhile, grasses and brassica cover crops require additional N to match yields from a fallow field (Juneja et al., 2026).

Yield benefits tend to build over time, particularly on soils starting from lower SOC (Vendig et al., 2023). However, yield gains alone do not translate into positive near-term net income once practice

costs are accounted for (Maples et al., 2026). If those yield gains are sustained, it implies TFP growth potential; however, this remains a theoretical extension of the underlying findings rather than a demonstrated result to date.

The economics reinforce how much the details matter. Cover crops produced the lowest returns and highest financial risk of any regenerative practice evaluated in Texas cotton production, requiring yield increases of 4.8 to 12 percent to match conventional net present value (Russell, 2022). The input reduction channel is the most plausible near-term TFP growth route. Still, it is conditional on species selection and local calibration in ways that generalized recommendations cannot substitute for.

GAP PARTNER STORY

From Rice Straw to Mountain Mulch: How a Potato Innovation Traveled from India to Peru

The International Potato Center

Potato Zero Till Mulching is transforming potato production by turning agricultural residues into a valuable resource. Developed by the International Potato Center (CIP) and India's Indian Council of Agricultural Research, the practice uses rice straw that was previously burned after harvest as mulch for potatoes grown with minimal soil disturbance. The approach eliminates the need to burn residues, reduces labor and input costs, conserves soil moisture, and builds soil organic matter. Inspired by its success in India, CIP adapted the system for Peru's Andes, where farmers use locally available mulch materials such as grasses and pine needles. The result is higher yields, healthier soils, more efficient use of inputs, and more sustainable potato production.



Photo: CIP

OP-ED: JOHN DEERE

FEEDING AND FUELING THE FUTURE: PRODUCTIVITY GROWTH MAKES BOTH POSSIBLE

For decades, discussions about agriculture's future have often been framed as a choice: should farmers grow crops to feed people or produce renewable fuels? As global demand for food, feed, fiber, and energy continues to rise, this "food versus fuel" debate suggests that agriculture faces a zero-sum equation. The reality on today's farms tells a different story.

Agricultural productivity growth has enabled farmers to produce more while using fewer resources per unit of output. Technology, innovation, and data-driven decision making continue to expand what is possible from every acre. Rather than forcing a choice between competing demands, productivity growth allows farmers to meet a broader set of societal needs simultaneously. Modern agriculture operates in an increasingly complex environment. Farmers must navigate economic uncertainty, weather variability, labor challenges, regulatory pressures, and evolving consumer expectations. At the same time, they are expected to produce abundant food, support growing renewable energy markets, and do so while conserving natural resources. Meeting these expectations requires more than additional inputs—it requires smarter management and better tools.

Precision agriculture technologies are transforming how farmers use critical resources. Advanced planting systems help place seeds at the proper depth, spacing, and speed to maximize yield potential and manage tight windows. And precision application systems like John Deere See & Spray™ allow farmers to apply crop protection products only where and when they are needed. These technologies help improve productivity while reducing unnecessary inputs, creating benefits for both farm profitability and environmental stewardship.

Digital technologies like John Deere Operations Center™ are helping farmers make more informed decisions throughout the growing season. Access to real-time field data, machine information, and agronomic insights enables farmers to better understand variability within their operations and respond accordingly. Instead of managing fields uniformly, farmers can leverage their data to make targeted decisions that improve efficiency, reduce waste, and optimize outcomes.

Renewable fuel markets represent an important opportunity for farmers and rural communities. Strong and reliable demand for crops provides economic incentives that support continued investment in innovation and productivity-enhancing practices. At the same time, advances in agricultural technology help ensure that expanding renewable fuel production does not require farmers to choose between feeding people and supporting energy needs.

The key to this progress is continual innovation. From connected machinery and precision technologies to advanced analytics and automation, new tools are enabling farmers to do more with less. These innovations help farmers improve yields, reduce overlap in field operations, conserve resources, and make better decisions across their operations. As adoption expands, the benefits extend beyond individual farms to entire agricultural systems. The future of agriculture depends on maintaining this momentum. Continued investment in research, innovation, and technologies that improve productivity will be essential to meeting the world's growing needs. Policies that encourage innovation, support farmer access to new technologies, and promote market opportunities can help ensure that productivity growth continues.

LIVESTOCK AND MIXED SYSTEMS

Across the three livestock practices reviewed here—adaptive multi-paddock grazing, crop-livestock integration and silvopasture, and poultry in silvopasture and crop rotation—the evidence for plausible TFP growth contributions exists, but the pathway to realizing it depends heavily on conditions outside the practice itself. Incentive

structures also play a key role. When carbon markets are inaccessible, land tenure is insecure, producer time horizons are too short to capture long-run returns, or premium market infrastructure is underdeveloped, the gap between biophysical potential and measured productivity growth is wider.

EVIDENCE SUMMARY

● ● ● Strong

● ● ● Mixed

● ● ● Limited

	GRAZING MANAGEMENT Adaptive multi-paddock grazing	INTEGRATED SYSTEMS Crop-livestock integration and silvopasture	POULTRY INTEGRATION Poultry in silvopasture and crop rotation
TFP CHANNEL	Input Reduction Output Improvement	Input Reduction Output Improvement Output Stabilization	Output Improvement
KEY CONDITION	Stocking rate, not rotation complexity, drives outcomes; ecological and financial optima diverge without carbon pricing.	Payback periods of decades for timber systems; grass-phase income gaps require policy support or blended revenue streams.	Economic viability requires premium market access in high income country contexts; cost structures cannot generate returns at commodity scale.
EVIDENCE STRENGTH			
Input reduction	● ● ●	● ● ●	● ● ●
Output improvement	● ● ●	● ● ●	● ● ●
Output stabilization	● ● ●	● ● ●	● ● ●



Adaptive multi-paddock and rotational grazing

Adaptive multi-paddock (AMP) grazing can improve pasture output and reduce the need for supplementary feed. Field comparisons in the southeastern United States found AMP systems produced 46 percent higher standing crop biomass and supported 2.38 times higher stocking density than continuous grazing (Johnson et al., 2022). Gains from AMP-style grazing varied across Australian sheep farms studied, with pasture production increasing by up to 35 percent under variable grazing at the highest-rainfall site but by smaller margins at the lower-rainfall sites (Muleke et al., 2026). Reduced need for supplementary feed offers the most reliable near-term productivity growth (Muleke et al., 2026).

Yet the practices that maximize ecological outcomes are not always the most profitable. In the Australian example, the grazing regimes that produced the highest SOC accrual were not the same ones that generated the highest gross margins. In the United States, the most financially successful AMP systems were characterized by faster rotations, shorter rest periods, and lower stocking rates. Operational efficiency rather than ecological complexity is the primary economic lever. However, in some scenarios, a baseline-and-credit carbon pricing mechanism helped make the most ecologically beneficial systems financially competitive, pointing to a genuine trade-off that management alone cannot resolve (Muleke et al., 2026).

“ When I fed my cow with Azolla, milk production increased from two liters to five liters per day, and the quality improved significantly.

– Musabyimana Maliya, smallholder farmer, Rwanda

”

GAP PARTNER STORY

Climate-Smart Feed Transforms Livestock Farming in Rwanda

Heifer International

In Rwanda, Heifer International has partnered with smallholder livestock farmers to turn a feed crisis into a productivity growth opportunity with Azolla, a fast-growing, protein-rich aquatic plant.

Azolla can be produced on-farm with readily available materials, reducing smallholders' dependence on commercial feed while improving livestock weight gain and yields and reducing production cycles. By integrating Azolla feed, participating farmers have benefited from lower costs, less water use and labor, and higher farm profitability. In an increasingly difficult growing environment, this climate-smart feed intervention demonstrates that locally tailored regenerative solutions can drive agricultural productivity growth while reducing input costs and improving farm-level profitability.



Photo: Heifer International

Integrated crop-livestock systems and silvopasture

Integrated crop-livestock production systems offer compelling long-run TFP growth potential through the natural capital and output stabilization channels; however, payback periods and income gaps during transition mean that potential is largely inaccessible without policy support or blended revenue streams. Research across 230,000 hectares of Australian farmland found higher natural capital associated with better economic performance through three pathways: raising output, reducing input costs, and stabilizing income over time (Heagney et al., 2026).

Ley-arable rotations, the periodic rotation of cropland into a temporary grass or pasture phase before returning to crops, reliably increase SOC without reducing yields during the cropping phase, but the grass phase removes cropland from arable

production. This requires restructured livestock feeding or reduced output to avoid compensatory cultivation elsewhere (Jordon et al., 2022).

The most ecologically intact integrated crop-livestock systems have demonstrated greater financial resilience but lower gross margins. This suggests that natural capital's economic benefits involve production-resilience trade-offs rather than a uniform win-win (Heagney et al., 2026). In silvopasture, fodder-producing species such as mulberry can reach break-even in under 10 years, but timber- and nut-dominant systems generally take 11 to 30 years. Slow-growing hardwoods such as black walnut may require 60 years, and some species such as hybrid poplar fail to break even within the 30-year modeled horizon, placing them outside the planning horizon of most operators without carbon pricing support (Greene et al., 2023).

GAP PARTNER STORY

Productivity to Restore Bolivia's High-altitude Wetlands and Camelid Production

Inter-American Institute for Cooperation on Agriculture (IICA)

In Bolivia's Altiplano, restoring high-altitude wetlands, known as bofedales, is helping reverse declines in camelid productivity and strengthen rural livelihoods. Through the Wetlands-Camelids-People project funded by the Spanish Agency for International Development Cooperation (AECID), IICA, local communities, and government partners are testing and scaling regenerative practices that improve water retention, forage availability, and grazing management. Using a "living laboratories" approach, producers combine local knowledge with scientific expertise to restore degraded bofedales. Pilot activities across eight municipalities have improved pasture productivity, enhanced livestock health, and built local capacity. The initiative demonstrates how investing in ecosystem restoration can increase livestock productivity, food security, and incomes in vulnerable pastoral systems.



Photo: IICA

Poultry integration: Silvopasture, crop rotation, and market conditionality

Integrating poultry into regenerative systems increases natural capital and crop yields and improves bird welfare. This regenerative practice is very conducive to smallholder, specialty crop, and lower resource production systems. A study in Iowa found that rotating poultry with vegetables and cover crops produced leaf lettuce yields at least 86 percent higher and water infiltration rates 108 to 148 percent higher than comparison plots, reflecting how poultry can function as a nutrient-cycling mechanism. The authors note that off-farm purchased feed still accounts for a substantial share of the nutrients cycled through the manure, complicating any claim of full input independence (Carey et al., 2025).

Silvopasture access, separately, has been shown to reduce bird fearfulness and improve footpad health relative to open pasture in fast-growing broilers, supporting the welfare case for these systems (Paneru et al., 2023). While not necessarily appropriate for commodity-scale systems because of lower-density, longer-cycle production and price competition, the productivity contribution of poultry integration is a strong candidate for smallholder production systems, particularly in SSA or LAC. It is a strong example of a regenerative, productivity-enhancing system that also contributes to higher-order outcomes, including smallholder livelihoods and nutrition security.



Photo: SaskOilseeds

GAP PARTNER STORY

From Soil Loss to Soil Health: Saskatchewan's No-Till Revolution

SaskOilseeds

Saskatchewan farmers have transformed a pressing environmental challenge into a productivity advantage by adopting reduced and zero-tillage systems. Facing soil erosion and moisture loss, producers minimized soil disturbance and retained crop residue. From 1980 to 2000, summerfallow acres drastically decreased, improving soil health and water retention. Strong collaboration and knowledge sharing among producers and public and private partners helped accelerate adoption across the province. This shift also drove innovation in seeding equipment, as manufacturers developed technologies to operate in high-residue systems. The result has been more efficient production – lower fuel and labour inputs alongside stable yields – demonstrating that farmer-led innovation can strengthen both sustainability and productivity while positioning Saskatchewan as a global leader in conservation agriculture.

AQUACULTURE SYSTEMS

Regenerative aquaculture systems present a compelling TFP growth opportunity, primarily by increasing output of aquaculture commodities. However, the gap between biophysical potential

and realized productivity growth reflects regulatory and market barriers rather than limits in the production systems themselves.

EVIDENCE SUMMARY

●●● Strong

●●○ Mixed

●○○ Limited

	INTEGRATED SYSTEMS Integrated multi-trophic aquaculture	CIRCULAR SYSTEMS Circular aquaculture
TFP CHANNEL	Input Reduction Output Improvement	Input Reduction Output Improvement
KEY CONDITION	Co-cultivation raises profitability in trial conditions; commercial-scale validation across diverse production contexts is needed before results are broadly applicable.	Waste conversion and feed reformulation show strong near-term potential; commercial-scale validation and feed reformulation progress are needed before results are investable.
EVIDENCE STRENGTH		
Input reduction	●●○	●●○
Output improvement	●●○	●●○
Output stabilization	●○○	●○○

GAP PARTNER STORY

Black Soldier Fly for Boosting Aquaculture Productivity in Timor-Leste

Purdue

Purdue University and Catholic Relief Services are advancing a regenerative, locally producible fish-feed solution in Timor-Leste using black soldier fly (BSF) larvae raised on organic waste. Current aquaculture systems rely on low-productivity methods, such as adding manure to stimulate phytoplankton growth for tilapia to feed on. Commercial feeds, while more effective, are largely inaccessible to most rural households. Through participatory research with smallholder farmers, BSF larvae were shown to produce the largest and fastest-growing fish, outperforming imported pellets by 13% based on weight. The project has demonstrated the value of BSF production, strengthening local capacity to produce protein, and removing dependence on external inputs. Ongoing work is refining BSF production and expanding it as a source of feed for other livestock. This positions BSF as a locally appropriate tool to accelerate aquaculture productivity growth.



Photo: Purdue

Integrated multi-trophic aquaculture and ecosystem service valuation

Integrated Multi-Trophic Aquaculture (IMTA), in which fed species are co-cultured with extractive species such as bivalves and seaweeds, demonstrates the output improvement channel by harnessing ecosystem function. Co-cultivating fed and non-fed species converts waste into biomass and generates more output from the same water column and infrastructure than monoculture systems can achieve. Non-fed species, including bivalves and seaweeds, also generate ecosystem benefits such as nitrogen removal and fish habitat that extend beyond primary food production. However, existing market and regulatory frameworks do not compensate producers for these benefits, so standard financial analysis systematically underrepresents the full productivity-growth case (Barrett et al., 2022; Krause et al., 2022).

A field trial co-culturing seaweed with shrimp and fish in Central Java, Indonesia, found that integrated ponds generated 1.1 to 2.6 times the revenue of seaweed monoculture (Nauta et al., 2025). With only three ponds per treatment, however, the study could not rule out that these differences arose by chance. An unanticipated flood mixed water across all ponds partway through the trial, which likely narrowed the measured differences between treatments. Nevertheless, the evidence base is promising but geographically

narrow, and commercial-scale replication across diverse production contexts is needed before these results can be treated as broadly applicable.

Circular systems

Circular aquaculture technologies offer productivity growth opportunities through the input reduction channel most directly, converting waste into productive inputs and reducing dependence on feed ingredients that compete with human food supply chains. A proof-of-concept trial pairing a recirculating aquaculture system (RAS) with a polyhydroxybutyrate (PHB) biological treatment process reduced production costs by 41 to 56 percent compared to conventional recirculating systems. However, these figures require commercial-scale validation before they can be treated as industry benchmarks (Asiri and Chu, 2020).

Commodity groups in the U.S. point to aquaculture feed demand as a source of market diversification for row-crop producers, particularly for soybean, sorghum, and wheat growers seeking additional outlets amid volatility in traditional export channels (United Soybean Board, 2026; United Sorghum Checkoff Program, 2026; U.S. Wheat Associates, 2026), a condition that is important for RA transition. However, the link between aquaculture-driven market diversification and RA adoption has not been empirically tested and should be read as a plausible hypothesis rather than an established finding.

GAP PARTNER STORY

Getting More From Every Input: Biochar Improves Nutrient Retention in Nebraska Soils

Daugherty Water for Food Global Institute at the University of Nebraska

Biochar, an ancient soil amendment, may help farmers make more efficient use of nutrients on a large scale while building healthier, more productive soils. Using biochar produced from invasive eastern redcedar, a team of researchers affiliated with the Daugherty Water for Food Global Institute at the University of Nebraska (DWFI) led an evaluation of its effects across irrigated and rainfed systems in Nebraska. The study found that biochar improved nutrient retention, increased nitrate and phosphate availability over time, and stored nearly all of the carbon applied. In irrigated fields, an additional 7 to 13 pounds of nitrate per acre remained within the crop root zone. Early indicators of improved water retention also suggest biochar may help agricultural systems better withstand acute drought.



GAP PARTNER STORY

Regenerative Agriculture and the Biofuels Nexus: A Farm Centric Business Case at Bayer

Bayer Crop Science

Bayer is helping farmers capture new opportunities at the intersection of productivity and clean energy. In 2026, Bayer partnered with BP to commercialize camelina through its newgold® seed brand, creating new market pathways for renewable diesel and sustainable aviation fuel feedstocks. As a short-season, low-input oilseed, camelina can be grown between main crops or on underutilized land, enabling farmers to generate an additional harvest without displacing food production. By integrating camelina into existing rotations, farmers can improve land-use efficiency, strengthen soil health, and access emerging biofuel markets, aligning agricultural productivity growth with broader decarbonization goals.

GAP PARTNER STORY

Conservation Agriculture in Drylands: Enhancing Productivity, Yield Stability, and Climate Resilience

The International Center for Agricultural Research in the Dry Areas

For farmers in rainfed drylands, the greatest challenge is often not achieving high yields in favorable years, but maintaining output when rainfall is low and unpredictable. Through long-term research and field validation, ICARDA, together with its partner, has shown that conservation agriculture practices such as no-tillage, crop diversification, and maintaining soil cover can help address this challenge. These practices improve soil health, enhance water infiltration and retention, and reduce production risks under drought conditions. The result is not only higher and more stable farm income, but improved resource-use efficiency and resilience—showing that sustainable intensification in drylands can drive productivity growth without degrading soil, water, and environmental systems. In Morocco, the evidence generated by ICARDA, INRA, and its partners is supporting the national ambition to expand conservation agriculture to one million hectares.

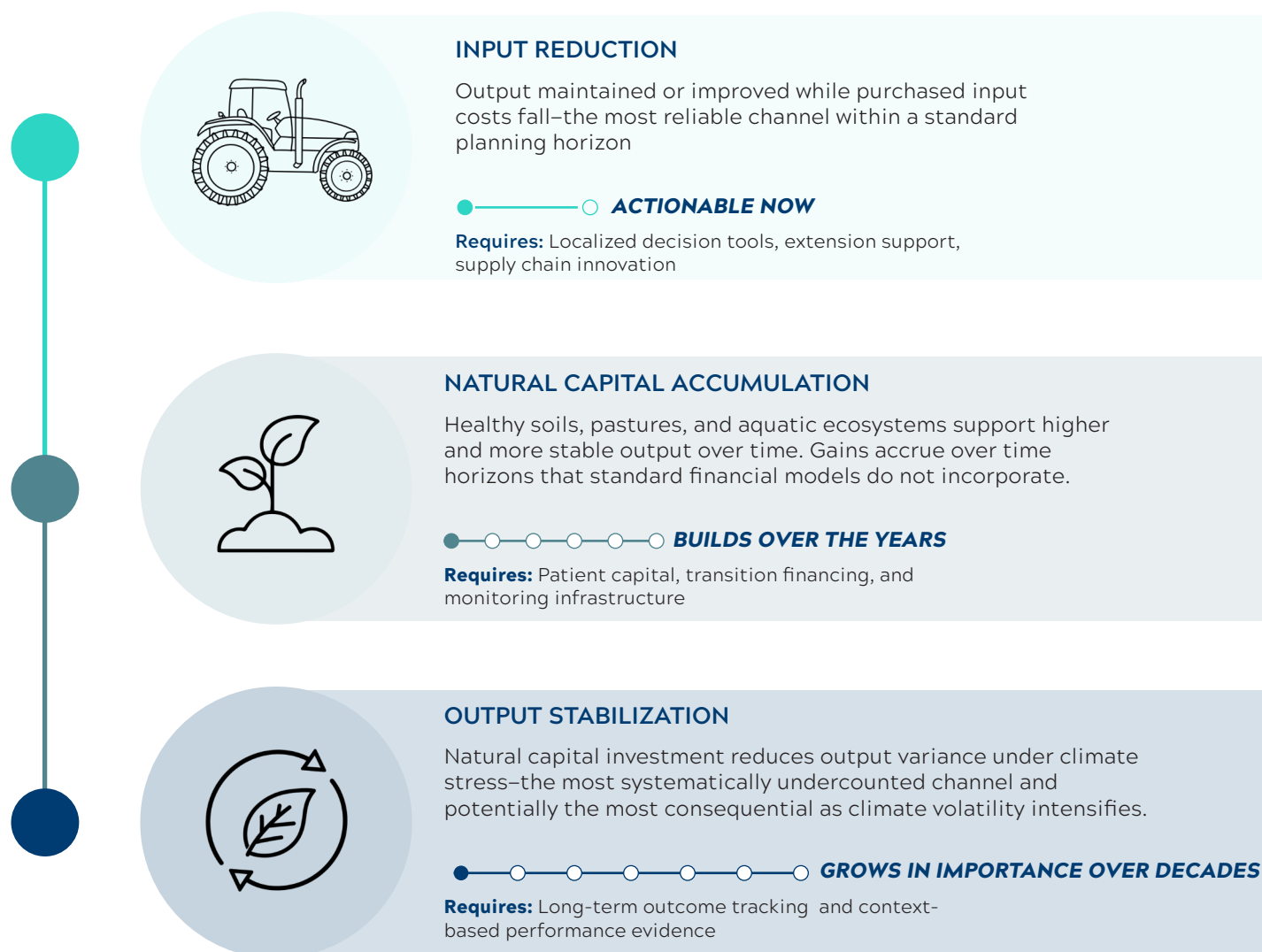


CHAPTER SYNTHESIS

THREE CHANNELS. DIFFERENT TIMELINES.

One pathway to productivity growth.

The practice-level evidence across crop, livestock, and aquaculture systems supports all three productivity-enhancing channels set out at the start of this chapter, but the channels operate on different timelines and carry different levels of near-term actionability.



Across all three channels, the binding constraint are the same. The market infrastructure, regulatory pathways, investment mechanisms, and decision support tools needed to translate biophysical potential into realized TFP growth do not yet exist at scale.

Chapter 03

Productivity Growth and Regenerative Agriculture in the EU

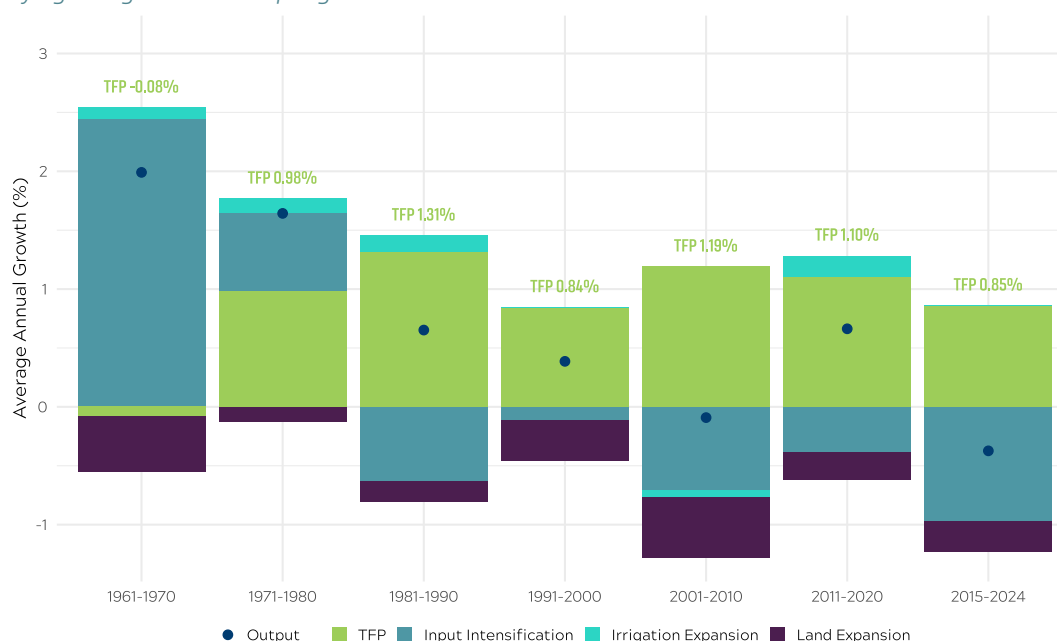
Agri-environmental and climate payments are one of the EU's primary policy levers for financing the transition to regenerative agriculture. Yet their relationship to productivity outcomes has been understudied. Under the Common Agricultural Policy (CAP), 32 percent of the €64 billion European Agricultural Fund for Rural Development (2023-2027) is allocated to agri-environmental and climate interventions (OECD, 2025). The International Institute for Applied Systems Analysis (IIASA), in collaboration with the GAP Initiative, examined how payment design relates to productivity across EU sub-regions, drawing on three decades of farm-level income and cost data from the EU Farm Accountancy Data Network (FADN). This chapter places those findings in the context of EU-27 TFP growth trends and their drivers, and considers the future implications for financing the regenerative transition.

TFP Growth is the EU's Only Remaining Source of Output Growth

EU agricultural output growth has declined for six decades, from roughly 2.0 percent annually in the 1960s to negative 0.37 percent annually during 2015-2024 (Figure 6). Input intensification turned negative in the 1980s, while cultivated area has continued to contract. TFP growth has therefore become the EU's only remaining source of sustained output growth, averaging 0.85 percent annually in 2015-2024. When TFP growth has been insufficient to offset declining land and purchased inputs, output has contracted. Since the CAP effectively closed off input-led output growth four decades ago, output growth must come from innovation, productivity-enhancing tools and more efficient use of existing land, labor, capital, and purchased inputs.

Figure 6. EU - 27 Sources of Output Growth, 1961-2024

TFP growth is carrying EU agricultural output growth.



Source: Fuglie, 2026

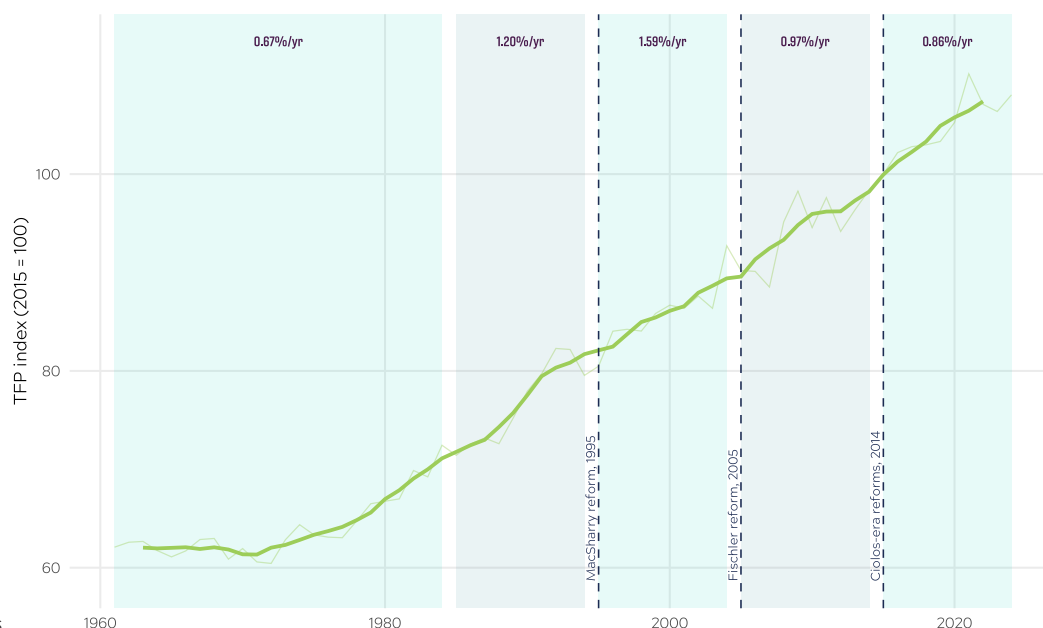
Note: Additional charts on TFP growth and sources of output growth are available on the GAP Initiative website. Additional analysis in collaboration with IIASA is forthcoming in the GAP Bulletin.

The policy environment plays a critical role in productivity growth, shaping the conditions under which producers invest, adopt new technologies, and change management practices. The CAP has not yet reversed the productivity slowdown. TFP growth peaked at 1.59 percent annually in 1995-2004 after the *MacSharry* reform, which cut guaranteed prices and compensated producers

with direct payments decoupled from sales volume. Growth slowed to 0.97 percent in 2005-2014 after the 2003 *Fischler* reform shifted support to a hectare basis conditional on cross-compliance, and to 0.86 percent in 2015-2024 after the 2013 *Ciolo* reform tied a share of direct payments to crop diversification, permanent grassland, and ecological focus areas.

Figure 7. EU - 27 TFP Growth Trends

Productivity growth has slowed across successive CAP eras.



Source: Fuglie, 2026

Drivers of EU productivity growth trends

The EU's reliance on TFP growth is a notable achievement, consistent with the requirements for a sustainable agri-food system. However, at its current pace, productivity gains cannot support the output growth required by the EU's economic, environmental, and producer livelihood goals. Evidence from the channels that drive TFP growth—technical change, technical efficiency, and scale and mix efficiency—points to a leading constraint: uneven and lagging adoption of proven productivity-enhancing tools, particularly management practices.

Technical change, the outward shift of the productivity frontier, has been the long-run driver of EU TFP growth. Genetic yield gains in northwest European wheat, for example, averaged 74 to 84 kg per hectare per year from 1994 to 2016; yet, realized yields have plateaued since the mid-1990s (Silva et al., 2026). Climate trends account for roughly 10 percent of the slowdown in European wheat and barley yields between 1989 and 2009 (Moore and Lobell, 2015). However, analysis of the EU's highest-yielding regions attributes the yield gap to agronomic management rather than genetic ceilings or climatic variability (Silva et al., 2026). In TFP terms, technical change has advanced while efficiency change has lagged.

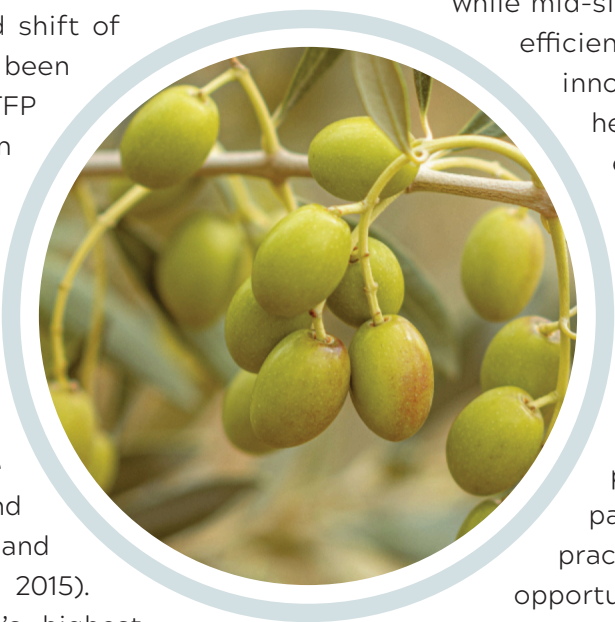
Technical efficiency, how close producers operate to the existing productivity frontier, improves as they adopt available tools, technologies, and practices. In EU crop production systems, average efficiency ranges from 80 to 88 percent of the frontier. Farms in member states that joined after 2003 operated farther from the frontier than those in earlier member states, and the gap did not close between 2004 and 2017 (Makiela et al., 2025). Lithuania, Poland, and Latvia recorded the fastest TFP growth in the EU in 2010-2023, a period when

EU gains came mainly from replacing departing labor with machinery (European Commission, 2024). Limited management capacity also contributes to lagging efficiency gains—71 percent of EU farm managers rely on practical experience alone (Eurostat, 2025).

Scale and mix efficiency, the gains from spreading fixed costs across more output and from a more productive mix of inputs and outputs, has also contributed to EU TFP growth, though unevenly. Economies of scale remain only partly exploited (Bokusheva and Čechura, 2017). Large farms operate close to the frontier in technically advanced regions and well below it elsewhere, while mid-sized farms are usually the least efficient (Makiela et al., 2025). Though innovative mechanisms that aim to help operations capture scale efficiencies, such as machinery rings, contractors, and inter-farm arrangements exist, farms under 200 hectares are less likely to use them (Gscheidle et al., 2025).

Wider adoption of proven productivity-enhancing tools, particularly management practices, is the EU's near-term opportunity for TFP growth. Renewed R&D investment is also needed to push the frontier outward, as public agricultural R&D spending in high-income countries has fallen in real terms since 2009, most sharply in Southern Europe (Heisey and Fuglie, 2018). Without new technology, meeting the Farm to Fork strategy's 2030 targets for pesticides, fertilizer, and organic area could reduce EU agricultural output by 7 to more than 20 percent (Wesseler, 2022).

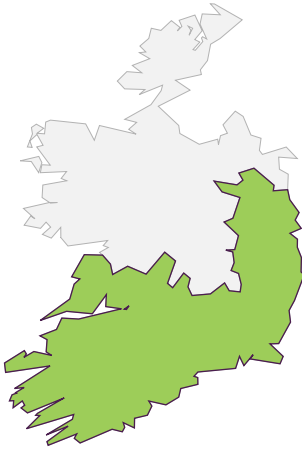
Contracting domestic output would undermine the EU's competitiveness and producer incomes and could shift production, and its emissions, to suppliers operating under different environmental standards (Barreiro-Hurle et al., 2021). **The rate of TFP growth therefore determines whether the EU can meet its economic, environmental, and producer livelihood goals together.**



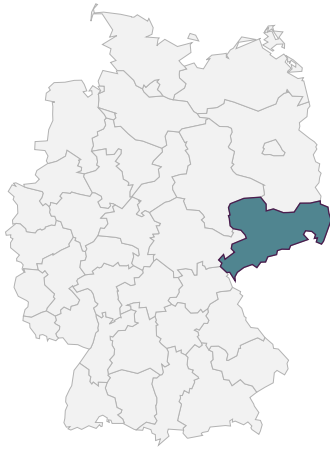
WHAT THREE DECADES OF EU ENVIRONMENTAL PAYMENTS SHOW

Agri-environment payments compensate EU producers for practices intended to protect soil, water, and biodiversity. Harmonized farm accounts from the past 30 years can show whether paying for those practice changes has contributed to productivity growth. With EU TFP growth short of the rate its objectives require, that record provides critical evidence to inform the design of future incentive structures.

Southern and Eastern Ireland



Sachsen



Aragón



IIASA calculated annual TFP growth for each of the EU's 213 farming regions, using FADN farm accounts covering 1990 to 2020. Each region's TFP growth was compared with the agri-environment payments it received per hectare. Three regions, Aragón, Sachsen, and Southern and Eastern Ireland, were selected to represent the EU's range of environmental payment intensity.

Aragón, in northeastern Spain, has predominantly dryland cereal production, with crops accounting for 65 percent of output value. Sachsen, in eastern Germany, farms crops and livestock on large, consolidated holdings. Ireland primarily produces grass-based livestock, with crops accounting for only 22 percent of output value. In 2010, agri-

environment payments were €12.70, €40.00, and €70.10 per hectare in Aragón, Sachsen, and Ireland, respectively, compared with an EU regional median of €27.40.

Payment histories differed as much as payment levels (Figure 8). Ireland's rose from almost zero in 1995 to €68.70 per hectare by 2005 under the Rural Environment Protection Scheme and held near €70 through 2010. They then fell to €19.10 in 2015 after the scheme closed, before recovering to €54.80 by 2020. Sachsen's more than halved between 2005 and 2009, from €62.30 to €24.00, as national co-financing tightened, then recovered to €58.00. Aragón never exceeded €12.70 in any year of the series.

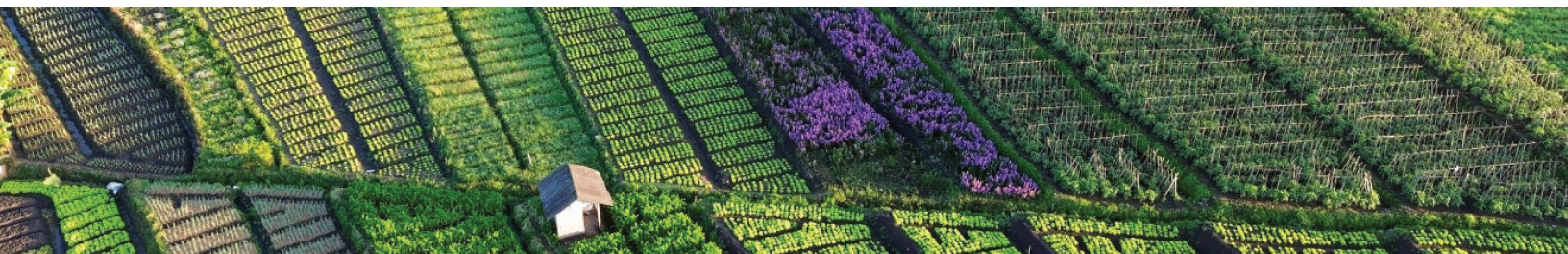
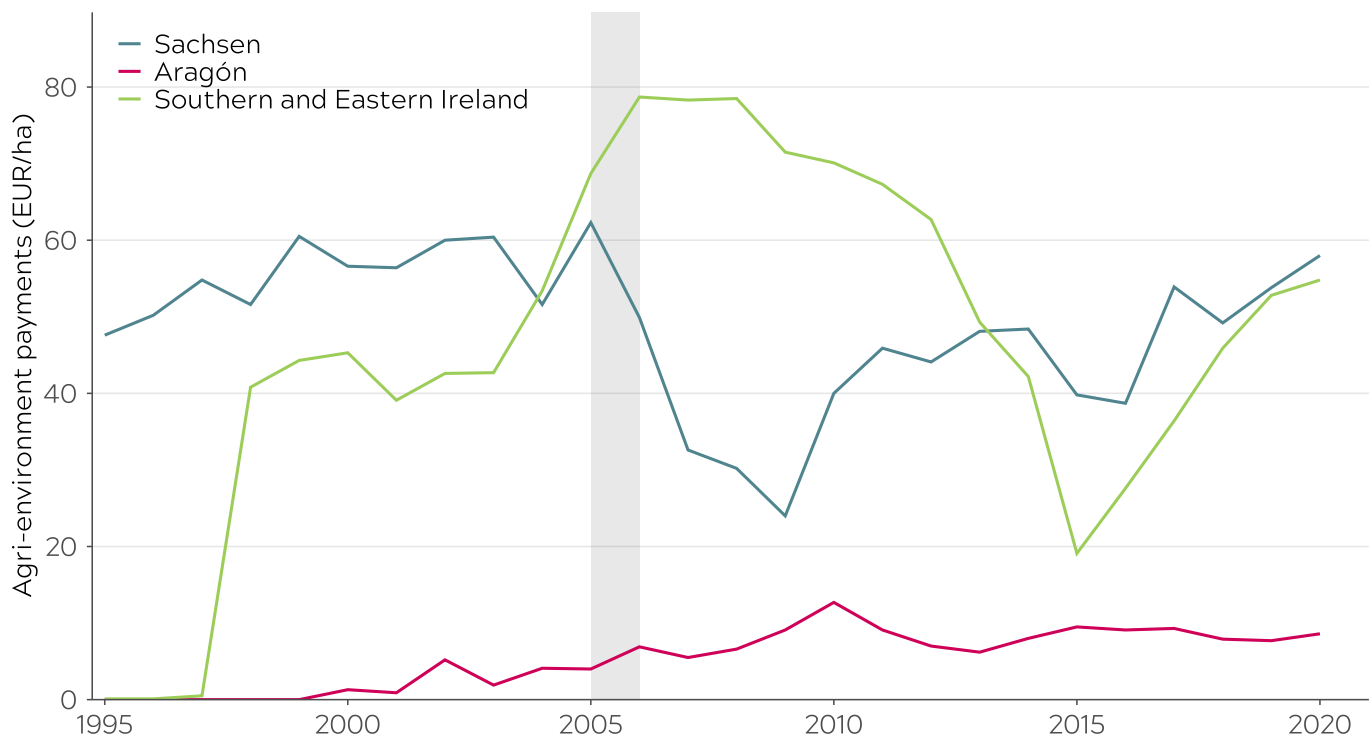


Figure 8. Agri-Environment and Climate Payment per Hectare of Utilized Agricultural Area

Payment levels and trends vary across the three regions.



Source: Krisztin et al., 2026

Note: Current euro, FADN variable SE621, Pillar II, weighted to regional totals.

TFP growth moves opposite to payment intensity

Aragón received the lowest per-hectare payment rate and recorded the fastest TFP growth, which almost tripled after Spain implemented decoupled payments in 2006, rising from 0.57 to 1.66 percent per year. Sachsen accelerated from 0.20 to 0.79 percent annually. Ireland received the most support and was the only one of the three with decreasing TFP growth, falling from 1.11 percent per year before the reform to 0.48 percent after it (Figure 9). Ranking the three regions by payment intensity yields the exact inverse of ranking them by TFP growth.

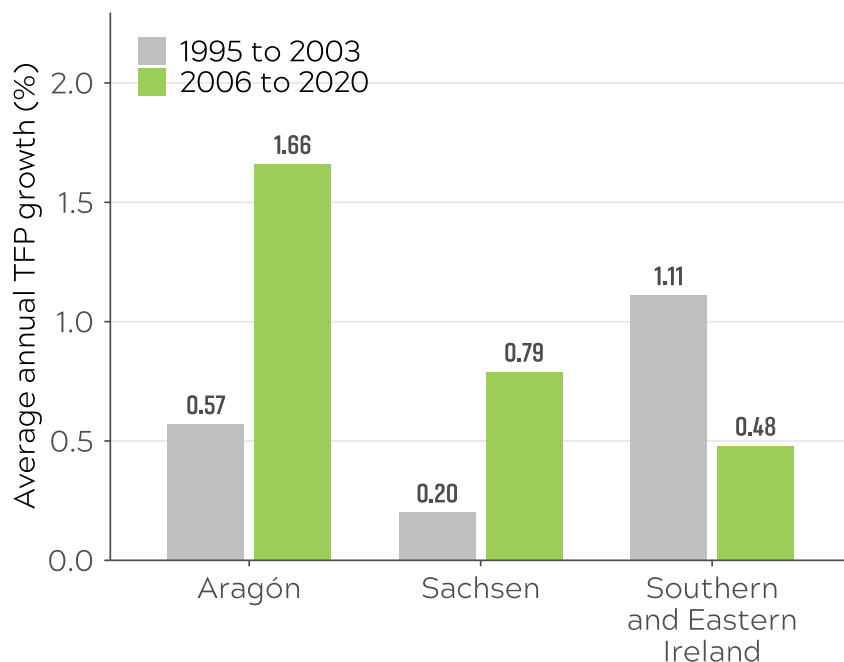
Aragón is the only region where producers used fewer inputs while output grew. Input use shifted from 1.21 percent annual growth to a 0.36 percent annual decline, while output continued to grow at 1.30 percent a year. In Ireland, input use fell by 1.53 percent a year, but output contracted by 1.05 percent a year; TFP growth persisted only because

output declined more slowly than inputs. In Sachsen, output and input use expanded by 4.77 and 3.97 percent a year, respectively, as farm structure consolidated. Across the three regions, higher payment intensity did not correspond to greater TFP growth.

The inverse relationship between payment intensity and TFP growth observed in Aragón, Ireland, and Sachsen does not extend across all 213 regions; no consistent relationship emerges, and direction varies. Direction is difficult to interpret in any case, since agri-environment schemes deliberately target land that is less productive, more constrained, or already farmed less intensively. Analyzing the same 213 regions, Garrone et al. (2019) find that almost all of the CAP's productivity effect is driven by decoupled direct payments based on farm area, rather than through the rural development funding that includes the agri-environment and climate payments.

Figure 9. TFP Growth in Three EU Regions

Higher payment intensity did not correspond to higher TFP growth.



Source: Krisztin et al., 2026

Note: Chart shows trend growth in Törnqvist TFP indices from FADN farm accounts, before and after the implementation of decoupled direct payments, applied in Germany and Ireland from 2005 and in Spain from 2006.

Why payment effects on TFP growth are undetected

Agri-environmental payments make up a small share of the support EU producers receive. In 2010, they accounted for just 16.4 percent of total support in Ireland, 9.7 percent in Sachsen, and 5.2 percent in Aragón; the remainder carried no environmental conditions beyond cross-compliance. Payment levels have also been unstable. In Sachsen, agri-environment payments fell by more than half between 2005 and 2009 as national co-financing declined. Because agri-environmental payments are small relative to total support and vary over time, their effect on TFP growth cannot be separated from other factors at work.

Agri-environmental contracts specify the management practices producers must carry out, and audit whether those practices were carried out; however, environmental and productivity outcomes fall outside the audit's purview. Documenting compliance imposes costs on administrations and producers alike. Those costs encourage participation among farms where

compliance is easiest to document and away from land where the environmental return would be highest. The European Court of Auditors found a similar pattern in the CAP's eco-schemes: they largely reward practices producers already use without changing on-farm behavior (European Court of Auditors, 2024).

Farm accounts record input spending without identifying the practices behind it. As a result, they cannot show whether payments change practices or whether those changes affect TFP growth, the same measurement gap Chapter 2 identifies. Between 2010 and 2020, the shares of variable costs spent on fertilizer and crop protection in Sachsen each fell by roughly a quarter, while the feed share rose from 36 to 49 percent. Ireland's cost shares moved in the same direction as Sachsen's while its dairy herd expanded. In Aragón, the crop protection share rose from seven to 12 percent while the fertilizer share fell. Declining input shares may reflect a shift toward regenerative practices, or they may reflect changes in input prices, which alter cost shares without any change in practice.

THE FUTURE OF AGRI-ENVIRONMENTAL PAYMENT DESIGN

The post-2027 CAP proposal's shift in environmental delivery "from prescriptive conditions to rewarding positive actions" opens a window to introduce customizable, blended practice-outcome-principle based payments in the next programming period. This target-based approach, backed by monitoring, reporting, and verification (MRV) would make the contribution of

regenerative practices to TFP growth observable and allow payment design to be refined over time toward the EU's economic, environmental, and producer livelihood goals. However, introducing them before indicators are defined and affordable MRV systems are established could remove the income support producers depend on, slowing TFP growth and deepening the output contraction.



GAP PARTNER STORY

Agricultural Drones: A New Route to Productivity Growth

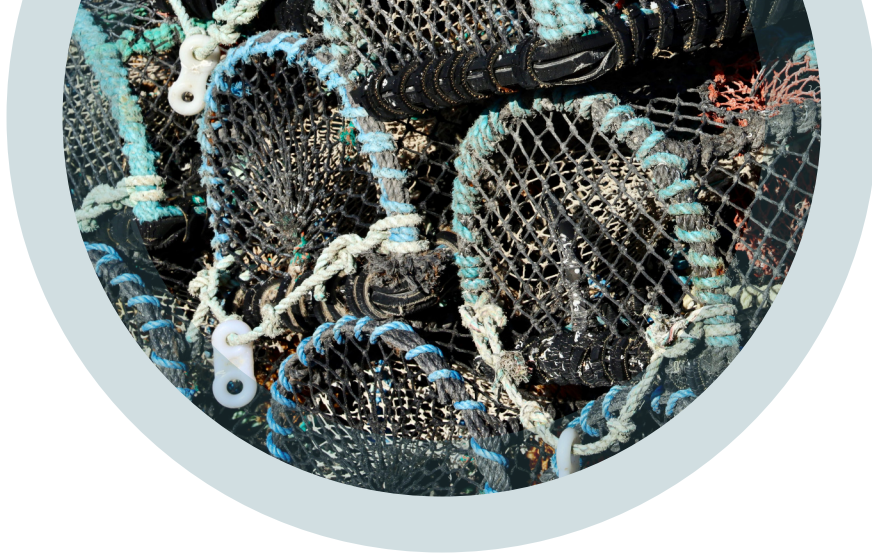
Agricultural Drone Initiative

Wilting, spots, or stunted growth - when first seen - are new to the farmer, but not the plant. Those visual indicators are symptoms of disease pressure which arrived in-field days or weeks prior. Agricultural drones, integrated with other advanced monitoring technologies, can detect and resolve many of those pressures earlier, with fewer inputs. The Agricultural Drone Initiative (ADI) works with partners across the agricultural industry to realize the full potential of agricultural drones in the United States. ADI also develops open-source software and educational content to facilitate access and innovation in this important technology. Agricultural drones are not simply terrain-agnostic tractors - they can transform agricultural practices, able to assess and respond to fertilizer, pesticide, and irrigation needs in real time, with accuracy-resolution to the meter. By shifting application of inputs between planting and harvesting to the air, drive-rows could be eliminated, with preliminary estimates indicating the recovery of as much as 1 in 4 acres for wandering crops and 1 in 10 acres for corn through that process alone. However, more research is needed to validate and refine these practices for the real world. We are hard at work to understand and realize the full potential of this technology as soon as possible. Given the rapidly changing climate, and growing resource-instability the world over, the advancement and adoption of this technology cannot develop fast enough. ADI is working with state and federal governments in the U.S. to unlock research dollars and lower barriers to adopting the drone technology that can help farmers achieve regenerative practices at lower cost and improve productivity through input use reduction.



Photo: ADI

04



POLICY AND INVESTMENT PRIORITIES FOR RA AT SCALE

For RA practices serve as a tactic to restart TFP growth, adoption of single and bundled practices and tools need to scale dramatically. Over the next decade, Chapter 2's evidence points to three sequential structural bottlenecks that determine RA's plausible TFP growth potential.

Without reliable outcome data, new tools cannot be built; without tools, producers cannot predict the economic outcomes of adoption; and without predictable outcomes, adoption will not become economically rational at scale, no matter how well policy and investments are designed.

BOTTLENECK #1



Build the Evidence Base

Localized, performance evidence is needed to show what works, where, and under what conditions.

BOTTLENECK #2



Pair Decision Tools with Extension

Producers need practical tools, paired with extension support, that translate evidence into farm-level adoption decisions.

BOTTLENECK #3



Align Policy and Investment

Finance, incentives, and market structures must make adoption viable at scale.

BOTTLENECK #1

BUILD THE RESEARCH BASE AND DATA INFRASTRUCTURE THAT UNLOCKS ADOPTION

The same regenerative practice or tool can improve productivity and profitability in one region and erode it in another. Aggregate evidence cannot resolve which outcome will occur on a given farm. Without reliable, localized performance data, producers cannot make confident adoption decisions, investors cannot identify where capital

will have the highest impact, and policymakers cannot track whether programs are working.

The data systems needed to produce reliable, localized performance data at the resolution that adoption decisions and conservation investment actually require do not yet exist at scale.

THE PRIORITY ACTION

(1) Investment in long-term research and integrated data systems—combining satellite remote sensing, farmer surveys, and in-field verification—to establish the evidence, and (2) MRV infrastructure that adoption and investment decisions will depend on. This will give producers, investors, and policymakers a shared, credible picture of what is working, where, and for whom.

What research RA most needs: Closing the long-run evidence gap

The highest-priority research need to unlock RA as a TFP growth reinvigoration tactic is whole-farm studies that track trends in inputs and outputs over the full transition period.

Most existing studies run for three years or fewer and focus on single practices. Furthermore, no study in the current literature directly measures TFP growth change attributable to RA adoption. Until that gap is closed, the productivity growth case for RA rests on inference from practice-level findings rather than direct measurement, making the case plausible rather than proven. This is unlikely to redirect the volume of capital and policy attention needed to realize RA's potential contribution to restarting global TFP growth.

What do we need?

We need long-term, whole-farm studies that track practices, tools, input amounts and costs, output volumes, variability, and prices alongside soil health and other metrics, across a range of farm types and growing conditions (Kleinman et al., 2018; Rasmussen et al., 1998; Robertson et al., 2008). Longer-term studies will generate the time-series data needed to build empirical models that can estimate TFP growth outcomes attributable to regenerative practices and tools.

How can we do it?

Closing the long-run evidence gap requires public funding, philanthropic capital, and pre-competitive industry collaboration structured around on-farm partnerships that outlast typical grant cycles. The right funding mix will vary by political and institutional context, but all three

THE MOST PRESSING RESEARCH NEEDS BY SYSTEM

01

IDENTIFY WHICH CROP-PRACTICE TOOL COMBINATIONS DELIVER FARM-LEVEL RETURNS AND UNDER WHAT CONDITIONS:

Reliable guidance on which practice and tool combinations work under which conditions, and economic models that track the full cost and return picture over multiple rotation cycles rather than a single season.

02

RESOLVE THE STOCKING RATE QUESTION IN LIVESTOCK SYSTEMS:

The central unresolved question is whether AMP grazing outcomes are driven by rotation pattern or simply by reduced stocking pressure. This ambiguity directly undermines investment confidence and is unlikely to be resolved by industry-funded research given documented conflicts of interest in the existing literature.

03

MOVE AQUACULTURE SYSTEMS FROM PROOF-OF-CONCEPT TO INVESTMENT-GRADE EVIDENCE:

IMTA, biofloc technology, and RAS-PHB systems show strong proof-of-concept results but lack the multi-site, commercial-scale replication needed for investment-grade evidence. Moving these systems from demonstration to bankable proposition requires the same long-run, multi-site trial infrastructure that crop systems need.

systems share a common requirement: sustained, multi-year commitment from funders willing to wait for results.

AI and advances in multimodal data integration offer a complementary near-term path: foundation models trained on satellite imagery, soil data, and farm management records can surface productivity growth patterns from existing data at a scale and resolution that field trials alone cannot match and create an opportunity to reactivate decades of observational farm data that were never designed with TFP measurement in mind but contain relevant signals. Drawing longer-run insights from existing data while purpose-built longitudinal studies are being funded and designed could meaningfully compress the timeline for closing the RA-TFP growth evidence gap.

MRV infrastructure: From practice to outcome verification

Credible MRV infrastructure is critical to track, credit, insure, and finance RA at scale.

First, verification costs tend to fall on producers and erode the margin the outcome was meant to reward. Keeping verification costs proportionate to payment is a design requirement, not an implementation detail. Second, current policy and market frameworks verify practices rather than outcomes. A producer is credited for adopting cover crops, not for the soil carbon, nitrogen efficiency, or yield stability the cover crops deliver. Verifying outcomes rather than practices would make the productivity growth case for RA more broadly legible. The challenge is that meaningful outcomes differ across groups, contexts, and

stakeholders. Without clear regeneration targets set against a measured baseline, regenerative agriculture risks becoming a rebrand of conservation agriculture. Producers need farm-level financial signals, investors need metrics tied to efficiency and viability, and policymakers need indicators linked to national competitiveness objectives. No single metric can serve all three, and outcome-based verification can be costly and complex.

The path forward is to create a customizable, blended framework that recognizes contextually appropriate practice adoption, outcome metrics that speak to all three audiences, and deployment of regenerative principles (e.g., use of soil amendments). Harmonized public- and private-MRV infrastructure could enable such a blended approach without creating undue strain on producers.

What do we need?

Shifting from a practice-based approach to a customizable, blended MRV system is crucial for developing a regenerative, productive agricultural system. Practice-based verification can remain a near-term evaluation metric while the practice-outcome-principle framework is developed. Achieving this shift will first require aligning on outcome metrics that benefit producers, investors, and policymakers, including necessary contextual adjustments. These metrics should include established indicators such as SOC, nitrogen use efficiency, yield, input use, and TFP growth. Credible methods for evaluating how producers apply regenerative principles are also needed. Finally, this transition requires investment in

regional data infrastructure and foundational models.

How can we do it?

The first step is to set contextually appropriate regeneration targets. Each target starts from a measured baseline for the soil, water and farm system, then defines what a reasonable level of regeneration looks like for that production system and region over a set period. Brummitt et al. (2024), drawing on a large-scale commercial soil carbon program, found that rewarding the measured effects of practices directs the right management to the right field for maximum impact.

Producers then need flexibility to pursue those targets through the practices, tools and principles best suited to their operation, since prescriptive requirements rarely fit the diversity of real production systems. Verification should also stay in proportion to what measurement costs. The Sustainable Agriculture Initiative (SAI) Platform allows practice adoption to stand in for some regenerative outcomes when sampling and verification would otherwise be too costly, and treats these proxies as transitional until direct measurement is feasible (SAI Platform, 2024).

Finally, harmonized public- and private-sector MRV infrastructure can let payers, lenders and regulators draw the outcome information they each need from a single verified record, sparing producers repeated burdens of proof. Harmonization depends on data security guarantees, so producers keep ownership of their data and control over who can access it and for what purpose.



“Reliable agricultural data is foundational to the future of American agriculture.

The partnership between NASDA and NASS helps ensure farmers, researchers and policymakers have trusted information to improve productivity, strengthen resilience and support long-term sustainability across U.S. agriculture.

– Ted McKinney, NASDA CEO

”



Photo: NASDA

GAP PARTNER STORY

Better Data Builds Better Agricultural Decisions

The National Association of State Departments of Agriculture

For agriculture to be productive and profitable, farmers, policymakers and researchers need reliable data to guide decisions and measure progress. NASDA's partnership with USDA's National Agricultural Statistics Service has long filled this need. NASDA and NASS continue modernizing agricultural data collection to meet the evolving needs of farmers and the agriculture industry. As agriculture faces increasing pressures, access to credible, science-based information will remain critical to restarting productivity growth. Continued investment in agricultural statistics, farmer participation, and partnerships will help ensure farmers have the tools and information needed to adapt, innovate and remain competitive.

BOTTLENECK #2

TRANSLATE EVIDENCE INTO TOOLS PRODUCERS CAN ACTUALLY USE

Without localized decision tools that convert variable, context-specific evidence into farm-specific financial projections, economically rational adoption is not possible. Producers cannot confidently predict what RA practices will deliver on their own operations. That is an information problem before it is an agronomic one (Maples et al., 2026; Nicolau et al., 2026).

Existing decision support tools are largely designed around high-income country commodity

crops. Tools for smallholder and low- and middle-income country contexts require deliberate investment, not just adaptation of those developed for other contexts. It will also require investment in data infrastructure, local calibration, and connectivity. Across regions and production systems, most tools remain at the pilot stage and cannot scale without public or philanthropic support (Ofosu-Ampong et al., 2025).

THE PRIORITY ACTION

Public and philanthropic investment in open-access, locally calibrated decision support tools that translate performance evidence into adoption recommendations and farm-specific financial projections across diverse production systems and geographies, giving producers the information they need to make confident, economically rational adoption decisions.

Closing the tools gap: Getting knowledge to producers

The practices and tools with the strongest input reduction and natural capital evidence tend to be those most sensitive to local conditions, management quality, and implementation timing. Getting those decisions wrong not only reduces farm profitability but produces the variable, context-dependent outcomes that erode confidence in RA as a productivity growth strategy and slow the adoption rates needed to accelerate TFP growth.

What do we need?

Better integration between economic modeling,

digital decision tools and extension infrastructure. Effective decision tools need to translate performance evidence into adoption recommendations and farm-specific economic projections that account for local soil conditions, input costs, output prices, and transition timing. Without these layers, producers have no basis for comparing an RA scenario against their current system. Tools such as the Predictive Soil Health Economic Calculator demonstrate that this is technically feasible (Maples et al., 2026); however, without human support uncertainty and skills gaps reinforce adoption delays. Farmer-to-farmer peer networks consistently outperform government extension services in driving adoption of complex

practices and tools, yet peer learning infrastructure remains systematically underweighted relative to technology investment globally (Jayasinghe et al., 2023). In smallholder and low-income contexts, extension worker intermediation is closely tied to effective digital tool adoption, with digital tools designed around extension agents' workflows seeing stronger uptake (Oyinbo et al., 2020). Pairing digital extension services with in-person training also produced substantially higher technology adoption than training alone in a smallholder Nepal study (Karki Nepal et al., 2025).

How can we do it?

Delivering digital and human extension integration

requires investment from multiple actors working toward the same goal. Public and philanthropic funders are best positioned to build open-access platforms and fund local calibration where commercial markets will not. Supply chain actors could also take a more direct role in contexts where producer behavior affects sustainability goals. Private-sector extension providers, from input suppliers to commercial digital advisory services, already deliver significant reach where public extension capacity is limited. Public agricultural universities and their extension networks are an underutilized delivery mechanism, offering locally embedded capacity and producer trust that digital platforms alone cannot replicate.



Photo: CAST

GAP PARTNER STORY

From Knowledge to Practice: How Improved Management Can Boost Productivity and Deliver Environmental Benefits

The Council for Agricultural Science and Technology

American agriculture is well positioned to improve resource-use efficiency, build soil health, and generate environmental benefits through wider adoption of regenerative practices already in use on leading farms. Research from USFRA and CAST demonstrates that conservation tillage, precision nutrient management, improved grazing, and cover crops can reduce input costs, strengthen farm resilience to weather variability, and offset a meaningful share of agricultural greenhouse gas emissions when adopted at scale.

The most significant finding is the practice gap between what farmers know works and what they are able or incentivized to implement. Closing that gap requires measurement systems farmers and markets can trust, economic incentives that work across farm sizes, and technical support that translates national science into field-level decisions.

BOTTLENECK #3

CONSTRUCT POLICY AND MARKET ENVIRONMENTS THAT MAKE ADOPTION ECONOMICALLY RATIONAL

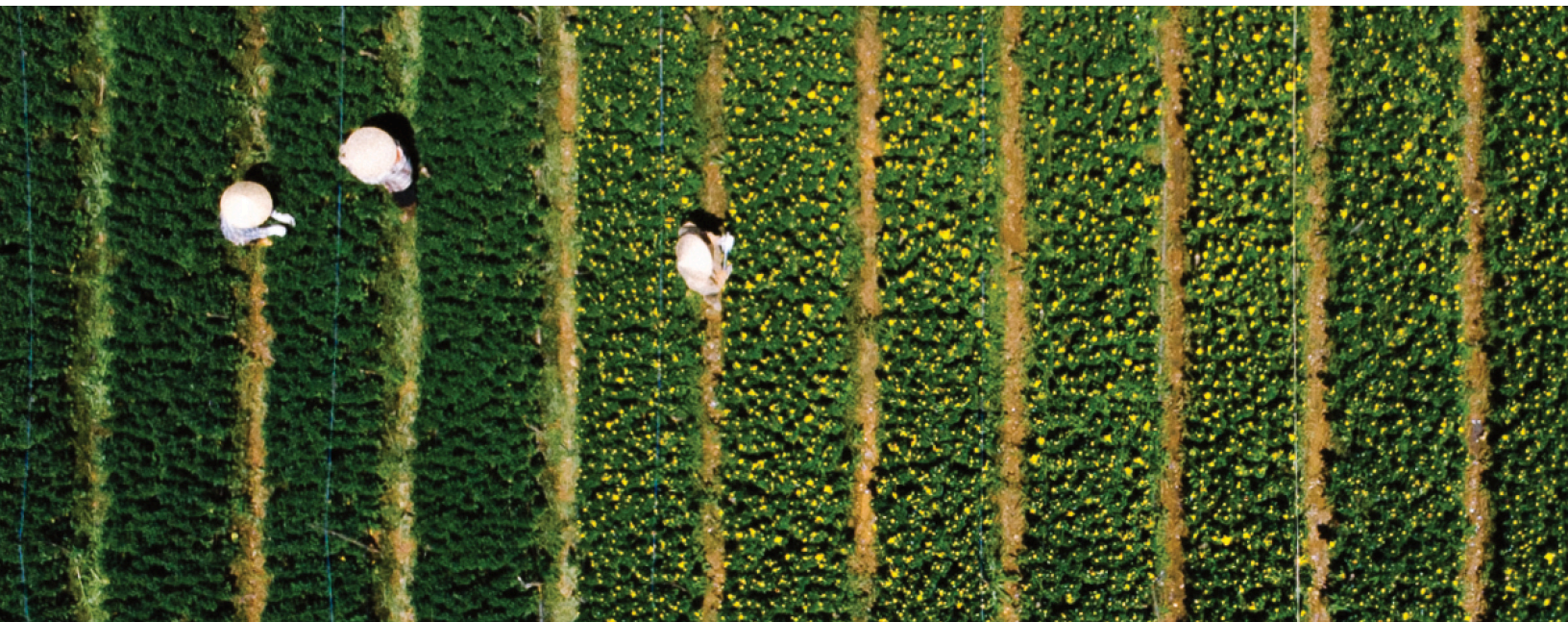
Data and tools address the information problem. Three structural problems remain: the mismatch between when adoption costs are incurred and when benefits are realized, the absence of markets that compensate producers for ecosystem services they already generate, and regulatory frameworks that prevent regenerative systems from operating at scale. Each of these is as much a policy problem

as a market one, and progress on each is unlikely without deliberate policy attention.

Without systems that recognize transition risk, compensate ecosystem service outputs, and create viable regulatory pathways, the gap between what RA can deliver and what producers can rationally choose to do will persist regardless of how strong the evidence base becomes.

THE PRIORITY ACTION

Moving from recognizing these barriers to addressing them requires designing specific policy instruments, financing instruments, market mechanisms, and regulatory reforms for each one.



Policy and financing instruments for the transition period

The opportunity costs associated with the transition period to RA impede the plausible contribution to TFP growth. Every year producers cannot bridge these costs—including upfront investment, potential yield changes, and time requirements—is a year that input efficiency gains, natural capital accumulation, and output stabilization benefits remain unrealized. The scale of the gap varies by system and context but is significant across all three sectors.

In commodity crop systems, returns from regenerative practices generally lag conventional production for the first several years after adoption (Datta et al., 2025; Lorenzetti and Fiorini, 2023; Myers et al., 2019), and most producers cannot self-fund that shortfall without external support. The problem is more acute in smallholder systems, where much of what is grown is consumed directly by the household. A temporary decline in yield can threaten both food security and income (Muthini et al., 2020; Touch et al., 2024). Timber-dominant systems can require far longer payback periods. Most break even in 11 to 30 years, but slow-growing hardwoods such as black walnut can take 60 years, placing them outside the planning horizon of most farm operators without intergenerational commitment or institutional ownership structures. Even for shorter-cycle timber species, standard financial instruments often prove inadequate without concessional finance or upfront ecosystem service payments (Greene et al., 2023).

Policy volatility creates risk. For example, the 2025 U.S. government funding freeze on contracted conservation payments left thousands of

producers unreimbursed and required litigation to resolve, underscoring the need for transition finance structures resilient to abrupt shifts in public support (Huffstutter and Douglas, 2025). Land tenure insecurity is also a critical issue as it discourages producers from making the long-term investments (Adere et al., 2022; Akber et al., 2024; Lovo, 2016; Mkandawire et al., 2025).

Disadoption of regenerative practices remains an underappreciated challenge. Programs that do not account for conditions under which producers stop

using practices are likely to overstate their potential impact. Adoption is only

the first step. Producers need support through the full transition window.

Adoption that reverses before natural capital and input savings compound forfeits the productivity growth practice – level evidence suggests is possible.

“ But we cannot do this alone. Without supportive policy, adequate public finance, and regulatory reform, progress will be too slow. ”

- Petra Laux, Syngenta Group Chief Sustainability Officer

What do we need?

Instruments designed for multi-year capital lock-up, yield uncertainty, and the mismatch between when costs are incurred and when benefits are realized. No single instrument is sufficient. Effective transition finance requires catalytic capital to bridge early transition years, ecosystem service monetization to provide an additional long-run revenue stream, and an anchoring organization to coordinate across capital sources and producers and verify outcomes (WEF, 2024). These instruments also need to be paired with land tenure arrangements secure enough to justify multi-year investment, and structured to remain available long enough to prevent disadoption before natural capital and input savings compound.

How can we do it?

A layered financing model in which public and concessional capital take on early transition risk

creates the track record and de-risked pipeline that attracts private investment over time. Diversifying across public, concessional, and private capital sources, rather than relying on any single one, also reduces exposure to abrupt policy shifts that disrupted contracted conservation payments in 2025. Anchoring organizations play a critical coordinating role in that model, aggregating producers, verifying outcomes, maintaining relationships across the full transition window, and, where feasible, working with landowners and lenders to address tenure security as a precondition for investment. In low- and middle-income country contexts, development finance institutions and multilateral funds are better positioned than private capital alone to seed that model in smallholder contexts.

Carbon and ecosystem service markets: Potential, limitations, and design requirements

Carbon and ecosystem service markets can play a key role in restarting agricultural productivity growth by providing revenue streams that help bridge the transition period for the natural capital and output stabilization channels that are slow to materialize and systematically undercounted in standard farm-level financial analysis.

However, voluntary carbon market integrity problems, MRV costs, undeveloped ecosystem service markets, and producer uncertainty about return on investment signal that market mechanisms still need work. Complementary policy frameworks and standardized verification infrastructure are also critical.

What do we need?

Carbon markets with credible and harmonized verification and ecosystem service markets with the infrastructure to compensate producers for what they actually deliver. The voluntary carbon market is projected to reach upward of \$50 billion by 2030 (McKinsey & Company, 2021, Blaufelder et al., 2021), but significant integrity problems remain. A 2024 analysis of the 20 largest corporate offset buyers found that 87 percent of the offsets they purchased carried a high risk of not delivering real,

additional emissions reductions (Trencher et al., 2024). The permanence and additionality problems that make agricultural SOC changes difficult to verify are fundamental features of how SOC accumulates, not administrative details (Brummitt et al., 2024; Dynarski et al., 2020).

Ecosystem service markets present a compelling near-term case: improvements in water quality, nutrient cycling, biodiversity, drought resilience, and soil loss reductions are outcomes that local governments, water utilities, food companies, and even consumers have direct financial interests in, independent of global carbon price dynamics, and the ecosystem services RA generates are more immediately verifiable and more locally valuable than carbon credits. Willingness to pay for ecosystem outcomes without policy mandates is an obstacle. Water utilities facing treatment costs from agricultural runoff, food companies with sustainability commitments tied to supply chain sourcing, and insurers pricing drought and flood risk carry the clearest financial exposure. Their interest in these outcomes holds whether or not a mandate requires it, making them the most plausible near-term payers.

How can we do it?

Return thresholds vary widely across regenerative systems depending on growth rates, labor intensity, and time to maturity, so a floor set for one system type can leave others structurally unviable even at the same nominal carbon price. Establishing floors would require cost-return data across the full range of regenerative practices and a governing body to set and periodically revise them as production costs and voluntary market prices shift.

For ecosystem service markets, the opportunity is concrete but largely unrealized. Bivalve and seaweed farms generate nitrogen bioextraction valued at \$84 to \$505 per tonne of nitrogen removed in nutrient-priority coastal zones and \$972 to \$2,504 per hectare per year in fish habitat value to commercial fisheries. Yet, no payment mechanism currently exists for either service (Barrett et al., 2022). Closing this gap requires local buyers with a direct financial stake, such as water

Starting Design Criteria for Ecosystem Services Markets

Ecosystem service markets are most viable where:

- ✓ the service is locally valued
- ✓ the beneficiaries are identifiable
- ✓ verification cost is proportionate to the payment

Water quality credits in nutrient-sensitive watersheds, pollinator habitat payments from food companies with supply chain exposure, and flood mitigation payments from downstream municipalities all meet these criteria better than global carbon markets do for most agricultural producers.

utilities under nutrient-reduction mandates or coastal municipalities facing habitat restoration costs, to contract directly with producers for measured nitrogen removal, using the kind of quantification this research already provides as the basis for payment.

Regulatory reform for aquaculture and livestock RA systems

In aquaculture and some livestock systems, the evidence is strong, and the economics for RA are plausible, but regulatory frameworks designed for intensive or extractive production models block regenerative systems from operating at commercial scale.

What do we need?

Regulatory frameworks need to be redesigned to reflect the operational and environmental reality of regenerative aquaculture and livestock systems. Regulatory and spatial-access barriers currently constrain low-trophic marine (LTM) aquaculture expansion, and policy support tailored to non-fed systems is needed to enable growth (Krause et al., 2022). Aquafeed formulation is shifting toward ingredients that reduce reliance on wild-caught forage fish and crops also used for direct human consumption, supported in part by certification standards favoring these formulations (Boyland and Lara, 2024; Chary et al., 2024).

In livestock and mixed farming systems, the priority is closing the gap between regulatory ambition and delivery. For example, the EU's

Common Agricultural Policy (CAP) eco-schemes represent genuine policy commitment to regenerative-adjacent practices (Runge, 2022), but voluntary uptake, the absence of thresholds distinguishing meaningful practice change from routine management, and member states' use of exemptions and flexibilities have left the schemes rewarding existing practices on many farms rather than driving change (European Court of Auditors, 2024). Chapter 3's regional evidence suggests closing this gap depends on establishing the indicators and monitoring systems the CAP does not yet have, since crediting outcomes that cannot be reliably measured risks repeating the same gap in a new form.

How can we do it?

Mandates alone cannot create effective market incentives. Other regulatory reforms can maximize the functionality and benefits that reward producers for investing in public good generation. In aquaculture, the most productive pathway is engagement between low-trophic producers, coastal planning authorities, and water quality regulators around shared interests in nitrogen removal and habitat generation. This builds the case for marine spatial planning and permitting reform from demonstrated co-benefits rather than policy prescription. In livestock and mixed farming systems, the EU CAP implementation gap points to a different lever, redesigning verification from action-based to outcome-based measurement, so payments can be linked to results rather than compliance alone.

INVESTMENT AND POLICY MODELS TO RESTART PRODUCTIVITY GROWTH THROUGH RA AT SCALE

The Investment Model

The public-private co-investment model that best fits the evidence must include three components:

Catalytic public, philanthropic, and concessional capital to fund the public goods that private markets cannot supply: long-term, whole-system research; regional baselines and context-specific target benchmarks; a practice-principle-outcome framework co-designed with industry; shared MRV infrastructure with producer data protections; and extension delivery. It should also finance the transition years through blended instruments that crowd in private lenders and insurers.

Private supply chain investment in the infrastructure and evidence behind the business case for regenerative sourcing: co-investing with the public sector in harmonized, single-source-of-truth MRV to cut verification costs; funding research on links between regenerative agriculture and product quality that could support premiums; testing whether regenerative sourcing reduces supply volatility under climate variability; and contributing data and design input to the shared framework and benchmarks.

Innovation investment in decision support tools combining venture and impact capital for ag-tech start-ups with public research funding for universities for tools tailored to scale, production system, context, and commodity. Blended investment should fund extension and peer-to-peer networks to sustain adoption at scale.

The Policy Model

The policy reform model, based on the evidence, has three components:

Transition risk recognition through cost-share programs, government-backed financing instruments, and tenure reform that make multi-year adoption commitments financially viable.

Ecosystem service market development through regulatory frameworks that recognize and create pathways to compensate water quality, biodiversity, soil loss reduction, and resilience outcomes, giving producers access to revenue streams that standard markets do not yet price.

Regulatory reform to align permitting frameworks, spatial planning, and subsidy regimes with the operational and environmental reality of regenerative systems, particularly in aquaculture and livestock where current frameworks actively block commercial-scale adoption.

TFP Growth – A Foundational Outcome Indicator

The GAP Report™ has tracked trends in TFP growth at a national, regional, and global level since the early 2010s. Estimates at the subnational and subfield level are much less common; however, TFP growth is an indicator that could make the productivity case for RA. Methodological adjustments would be required, particularly to track productivity showing up in farm-level profitability. If feasible, TFP growth tracked alongside the suite of policy, investment, and farm-level performance metrics this report calls for would give policymakers (from finance to agricultural ministries), decision makers, and producers a direct signal of whether regenerative practices are contributing to both farm and system-wide efficiency. This is critical evidence needed on the tactics that can restart future-proofed agricultural productivity growth.

CONCLUSION

THE COST OF INACTION

Global agricultural TFP growth has stalled at a moment when input cost volatility, supply chain disruptions, and accelerating climate stress makes the input-driven output growth model increasingly untenable. The evidence reviewed in this report supports a plausible case for regenerative agriculture contributing to accelerating TFP growth through three reinforcing channels: input efficiency gains that reduce input intensification without sacrificing output; natural capital accumulation that raises the productive capacity of existing farmland over time; and output stabilization under climate stress. The input reduction channel has the strongest and most near-term evidence base. The natural capital accumulation and output stabilization channels take longer to deliver measurable gains. Across all three, the potential contribution to TFP growth is contingent on policy and investment conditions.

Without deliberate investment in measurement frameworks, data infrastructure, decision tools,

and transition finance, RA will remain a collection of promising practices rather than a demonstrated contributor to restarting TFP growth. Policy frameworks that recognize transition risk and compensate ecosystem service outputs are also essential to translating biophysical potential into measured productivity gains at scale.

The cost of inaction is not confined to any single income group or type of production system. Input cost volatility continues to compress farm margins in the absence of efficiency gains. Soil degradation reduces the productive capacity of farmland while raising the resource intensity required to maintain output, and climate volatility drives more frequent and more severe weather events. Meanwhile, the tools, finance, and policy needed to act on RA's productivity potential remain unevenly available. **Restarting global agricultural TFP growth depends on extending that access across the full range of producers, from commodity operations to smallholder systems.**



Photo: Syngenta

GAP PARTNER STORY

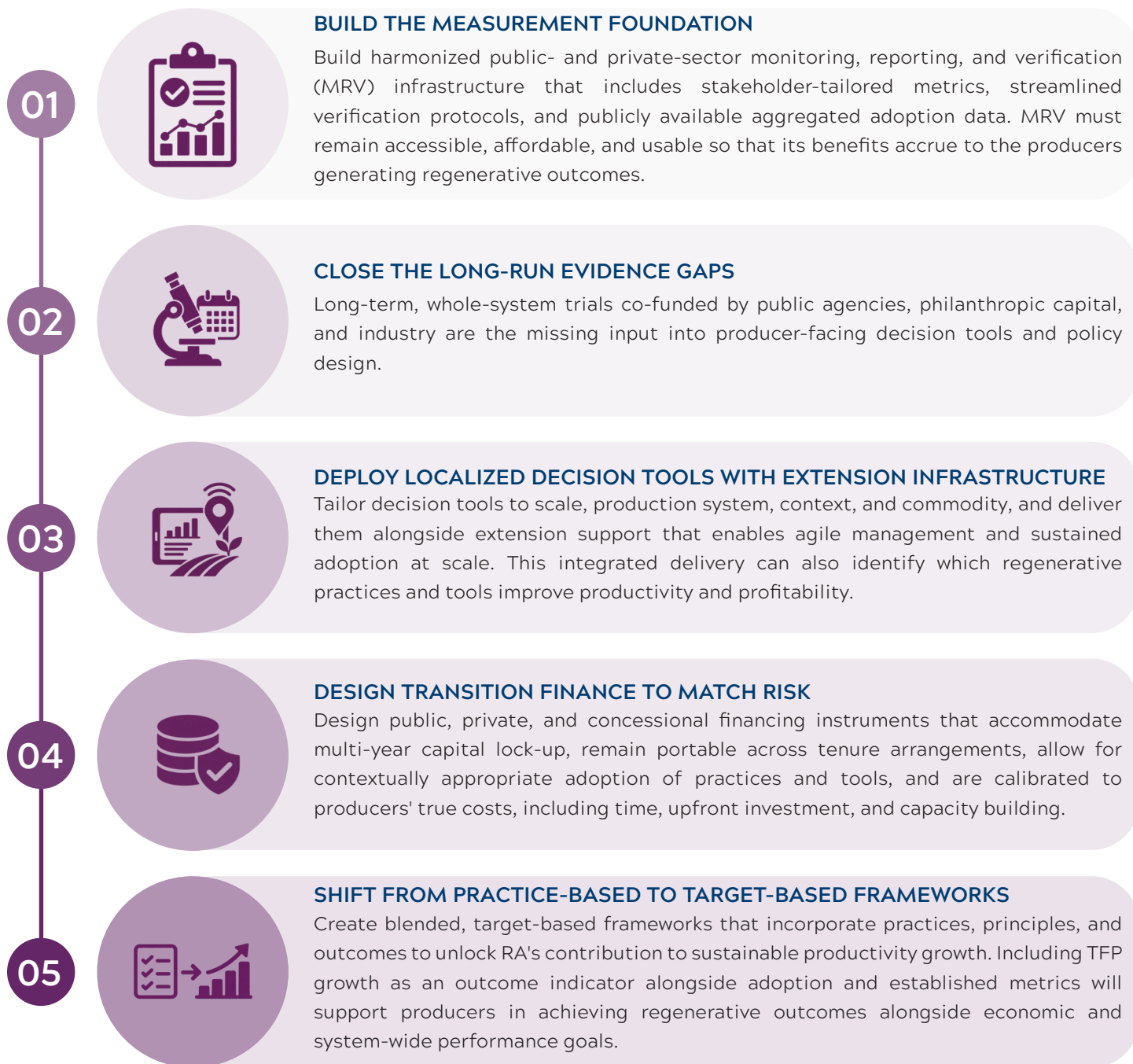
REVERTE®: Restoring Degraded Land to Productive Use

Syngenta

Degraded soils, weather extremes, and land-use pressures mean increasing food production without expanding into native ecosystems. Syngenta's REVERTE® program supports growers in transforming degraded areas into productive ones through regenerative agricultural practices, financial solutions, and input-use protocols. In Brazil, the program covers more than 282,650 hectares across 11 states and has disbursed over USD 388 million in funding. The REVERTE® model works because it addresses fundamental capital and technical barriers, giving farmers access to finance and agronomic support. REVERTE® shows that restoring degraded land can work at scale, helping deliver higher yields with lower impact.

FIVE PRIORITIES TO RESTART PRODUCTIVITY GROWTH

The path from RA's plausible productivity potential to measured TFP growth at scale runs through five investment and policy priorities:



The evidence base reviewed in this report is strong enough to act on, even as important questions about RA's outcomes for TFP growth and profitability remain unresolved. Amid climatic variability, geopolitical shifts, and volatile macroeconomic conditions, restarting TFP growth is only part of the question. How that growth is achieved, and who accrues its benefits, matters as much. The tactics this report assesses offer a path toward productivity gains that reach producers at every scale while sustaining the ecosystems those producers depend on. The long-run studies, MRV infrastructure, and policy frameworks needed to fully validate RA's contribution to TFP growth will take years to build. Sequencing investment and policy reform now, so the evidence base grows alongside near-term gains, is how that validation gets built without losing the years it would otherwise cost. **The evidence is sufficient to begin sequencing that investment now.**

Restarting productivity growth starts with turning evidence into action.

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