Science Societies

Scientists’ contributions to agriculture: How the world looks without research

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Photo by Joseph Iboyi.

Continuous scientific research is essential to modern agriculture, enabling farmers to increase productivity while addressing climate change, pests, soil degradation, and sustainability. Without it, outdated practices would prevail, leading to crop losses, environmental damage, rising food prices, and greater hunger. Long-term investment in agricultural research underpins food security, public health, economic stability, and environmental protection for societies worldwide.

Scientific research is the cornerstone of how modern societies confront intertwined agricultural and environmental crises (Nellemann, 2009). Over the past 50 years, agricultural innovation has driven remarkable gains in productivity, yet it has also surfaced urgent questions about sustainability, biodiversity, human health, and animal welfare (National Academies of Sciences, Engineering, and Medicine, 2019). As pressures on food systems intensify, the role of science is to both sustain productivity and correct course by guiding practices that protect ecosystems while supporting the people and economies that depend on them (Garnett & Godfray, 2012).

Farmers now face a dual imperative: produce more food for a growing population while using land, water, and energy far more sustainably and doing so under a rapidly changing climate marked by recurrent droughts, floods, and heat waves. Because agriculture is both a source of environmental impacts and a potential solution, research must illuminate the links among weather, climate, and farming to inform mitigation and adaptation (Altieri & Nicholls, 2017; Garnett & Godfray, 2012; Jarvis et al., 2011). The scope of this agenda is broad, spanning improved resource efficiency, risk management, and climate-smart practices that reduce emissions and strengthen resilience.

As a systemic science, agriculture continually reshapes its own subject—real farms, real ecosystems, and real communities—so research must match that complexity (Darnhofer et al., 2012). Expectations are high that it stays relevant and forward-looking as societal goals evolve. Fields such as agricultural meteorology, once focused on profitability, now prioritize food security and sustainability (Pandey & Pandey, 2023). Meeting today's challenges requires an interdisciplinary approach that brings together meteorologists, climatologists, agronomists, plant pathologists, ecologists, and breeders. When effectively implemented, this wholeness-oriented research provides critical knowledge for improving soil and crop management, selecting climate-ready cultivars and livestock, and strengthening resilient agro-ecosystems, ultimately equipping society with the tools to mitigate climate risks and secure global food systems.

In the following sections, we will discuss the requirements, roles, and importance of research in greater detail, examining how science progresses from laboratories to farmers' fields and why continuous research remains indispensable.

Imagining a world without research

Crops would face pests, diseases, and climate extremes without new solutions

Scientific research is critical for developing new solutions to protect crops from escalating threats posed by pests, diseases, and climate extremes. Without continuous scientific intervention and the development of new solutions, the challenges faced by farming communities will only intensify. Farmers must simultaneously work to increase food production for a growing global population while also ensuring that natural resources, such as soil and water, are used in a sustainable manner.

For example, global warming facilitates the spread of pathogens into areas previously unaffected, necessitating ongoing research in agricultural entomology and plant pathology. Higher temperatures, increased CO_2 levels, and fluctuating weather patterns accelerate the rate at which exotic pests enter and establish in regions like Europe, as well as increasing the rate of evolution of existing pest populations (Barzman et al., 2015; Skend ži□et al., 2021).

Global warming facilitates the spread of pathogens into areas previously unaffected, necessitating ongoing research in agricultural entomology and plant pathology. Photo by Dr. Colin Bonser.

The unpredictable nature of these interactions among weather, cropping systems, and pests means that reliance solely on existing management strategies, such as the overwhelming use of pesticides, risks complete failure. Thus, without new, proactive scientific strategies, including the development of resilient cropping systems, breeding for resistance, and advanced international monitoring, crops face substantially increased risks of yield loss, potentially rising from losses already accounting for more than 40% worldwide (Leng &

Hall, 2019; Savary et al., 2012).

Furthermore, farming communities globally must adapt to a changing climate and extreme weather events, such as recurrent droughts or floods. Agricultural research provides the essential understanding of the interconnections among weather, climate, and farming, turning agriculture into a key ally in climate change mitigation and adaptation.

Farmers would rely on outdated practices, leading to lower yields and soil degradation

Scientific research is crucial because, without continuous introduction of new solutions and management practices, farmers would be compelled to rely on outdated, unsustainable practices, resulting in decreased crop yields and exacerbated soil degradation (Kassam et al., 2013; Leng & Hall, 2019). The rapid development of agriculture over the last half century has resulted in a substantial rise in productivity but has concurrently caused problems concerning sustainability, leading to the degradation and exhaustion of soil and land.

When farmers do not adopt appropriate practices, such as those promoting soil health, the consequences can be severe. Photo courtesy of Adobe Stock/Tenebroso.

When farmers do not adopt appropriate practices, such as those promoting soil health, the consequences can be severe: Soil degradation reduces yields and forces farmers to seek new land. Historically, improper agricultural practice and soil over-exploitation have consistently led to the detrimental exhaustion of productive lands (Gomiero, 2016).

Intensive conventional agriculture makes soils highly prone to water and wind erosion. The loss of topsoil due to erosion is particularly detrimental, as the removed soil is richer in organic matter than the soil left behind, leading to nutrient loss (Rhodes, 2014). Soil degradation compels farmers to use more inputs (such as fertilizers and irrigation) to compensate for reduced fertility (Rashmi et al., 2022).

However, small and poor farmers often lack the capital to invest in the necessary inputs and technology, locking them into a poverty trap that is worsened by declining soil health. In fact, adopting practices that are detrimental to long-term soil conservation, such as extensive monocultures combined with a general lack of biodiversity, cause soil degradation through wind and water erosion, soil organic matter (SOM) depletion, and nutrient loss (Belete & Yadete, 2023).

Conversely, scientific advancements provide solutions: modern agricultural research, often viewed as a systemic science, is tasked with addressing these complex issues and developing innovative methods (Alrøe & Kristensen, 2002). For instance, adopting alternative approaches like agroecology or no-till agriculture can help reduce soil loss, increase SOM content, and restore soil fertility and biodiversity (Temegne et al., 2021).

These practices, and others like proper crop rotation and the development of perennial crops, are crucial for long-term yield stability and buffering against climate adversity. Without embracing such evidence-based sustainable practices, agriculture remains vulnerable, forcing farmers into a cycle of diminishing returns and environmental decay.

Food prices would rise, hunger would increase, and global food security would collapse

Without new scientific solutions and effective policies, the global food system would face severe instability, characterized by sharply rising food prices, increased hunger, and a potential collapse of food security (Barrett, 2021; Gonzalez, 2011). High and volatile international food prices and short-term price spikes are already among the main challenges faced by 21st-century agriculture, driven by complex factors including extreme weather events, increasing demand, and market speculation (Tadasse et al., 2016).

A failure to maintain or increase productivity, especially if compounded by soil degradation, would likely result in an increased cost of production, which would inevitably be transmitted to consumers as higher prices (Rickson et al., 2015). For poor people, who spend a high proportion of their income on food, rising prices cause a reduction in real income and increase income instability. Econometric evidence from food crises in 2007–2008 and 2010–2011 demonstrated that these price spikes

Without new scientific solutions and effective policies, the global food system would face severe instability, characterized by sharply rising food prices, increased hunger, and a potential collapse of food security. Photo courtesy of Flickr/Billy Brown. CC BY 2.0.

pushed tens of millions of people into poverty and hunger globally (Field, 2016; Gouel, 2014; Harrigan, 2014).

The immediate consequence of unchecked price increases and volatility is an increase in hunger and malnutrition. High food prices compel poor households to shift from more nutritious food (like meat and milk) to less nutritious, cheaper alternatives (like cereals and root crops), making children immediate victims of consumption adjustments (Brinkman et al., 2010; Zezza et al., 2009).

Furthermore, reliance on outdated agricultural practices and failure to adapt to climate change would reduce production capacity, leading to lower yields and exacerbating land degradation, which in turn leads to a strong relationship between land degradation and poverty (Anderson et al., 2020; Barbier & Hochard, 2018). This self-reinforcing feedback loop would undermine global efforts toward sustainability and food security, particularly in poor regions.

Seeds of progress: Scientists' daily work

Climate change presents a serious threat to global agriculture with rising temperatures, erratic rainfall, and extreme weather projected to reduce crop yields by up to 18% by 2050 (Mushtaq et al., 2024; Rezaei et al., 2023). Traditional breeding methods, though foundational, are slow and constrained by limited genetic diversity in high-yielding varieties. Modern breeding tools such as marker-assisted selection, genomic selection, and next-generation sequencing are accelerating the discovery and transfer of stress-tolerant traits (Seelam & Jespersen, 2025; Upadhyay et al., 2025). Emerging approaches like pangenomics, which capture broader genetic diversity, and pre-breeding, which taps into wild relatives and landraces, are expanding the genetic toolbox for resilience (Petereit et al., 2022). Coupled with strategies such as shuttle breeding, speed breeding, and genome-editing technologies like

CRISPR/Cas9, scientists are rapidly advancing climate-resilient crop development.

Climate change presents a serious threat to global agriculture with rising temperatures, erratic rainfall, and extreme weather projected to reduce crop yields by up to 18% by 2050. Photo courtesy of Adobe Stock/BIB-Bilder.

The pressure on global food systems is unprecedented with the population projected to reach 9.7 billion by 2050 and food production needing to increase by 70–90% (Mergos, 2022; Valavanidis, 2023). Simultaneously, climate change undermines productivity through rising temperatures, shifting precipitation patterns, and increased outbreaks of pests and diseases. Farmers face mounting challenges, such as soil degradation, water scarcity, and extreme events like floods and droughts while consumers confront food insecurity and rising costs. To address these vulnerabilities, breeding priorities are shifting from yield alone toward resilience. By combining traditional knowledge with genomic tools, breeders are identifying genes linked to traits such as drought tolerance, heat and cold resistance, salinity adaptation, and pathogen defense, paving the way for climate-smart agriculture (Ahmad et al., 2023; Seelam et al., 2025).

Advances in plant genomics, phenotyping, and bioinformatics are reshaping how breeders develop crops for the future. Tools such as QTL mapping, marker-assisted gene pyramiding, and high-throughput phenotyping enable precise trait improvement at scale. Genomic resources, such as pangenomes, alongside technologies like CRISPR/Cas9, enable the discovery and deployment of novel alleles that enhance resilience (Zenda et al., 2021). Yet, the success of these innovations relies on sustained investment, global collaboration, and farmer-centered implementation. By merging traditional breeding with modern technologies, agriculture can meet the dual challenge of feeding a growing population while safeguarding productivity against climate stress.

Science at the farmer's side

Scientific research alone is insufficient to drive agricultural transformation. The critical factor is the translation of knowledge from laboratories and experimental fields into practical innovations for farmers. This connection is established through extension systems, participatory research, and iterative engagement between scientists and growers. The section below expands on how this process unfolds and why it is vital.

From lab to land: The role of extension systems

Extension systems (or agricultural advisory services) serve as conduits that carry research-based knowledge into the field. In the United States, for example, the Cooperative Extension System, the result of the 1914 Smith-Lever Act, creates a three-tier structure in which federal, state, and local agents collaborate to deliver training, technical assistance, and outreach to farmers. Extension agents incorporate farmer feedback on the ground into the research agenda, helping scientists identify what constraints are most binding, which practices might scale regionally, and how local heterogeneity affects adoption. In this manner, extension acts as both a dissemination pathway and a feedback loop, ensuring that research remains grounded in real-world constraints.

Farmer–scientist partnerships and participatory approaches

To maximize relevance and adoption, many research programs engage farmers directly in the design, testing, and refinement of new practices or varieties. Such participatory research approaches ensure that innovations are adapted to local soils, climate, and social settings (e.g., labor constraints and risk tolerance). The McKnight Foundation's Collaborative Crop Research Program, for instance, funds projects that link researchers with smallholder communities to iterate on technologies together. In practice, this might take the form of on-farm trials where scientists and farmers jointly compare new treatments (e.g., fertilizer regimes, varieties, or crop rotation schemes) under real farm conditions rather than on ideal experimental stations. The on-farm approach reduces the "lab–field gap" and catches emergent constraints that would be invisible in controlled settings.

Many research programs engage farmers directly in the design, testing, and refinement of new practices or varieties. This is a photo of a research team meeting with their farmer-collaborators. Photo by Zach Wolf.

Challenges and enablers

Although the ideal of science–farmer integration is compelling, the process faces challenges:

- **Institutional and resource constraints**: Many extension systems are underfunded, understaffed, or lack sufficient technical training. The mismatch between the pace of research and the scale of extension remains a perennial issue.

- **Heterogeneity of farms**: Farmers differ in scale, risk preference, soil types, access to capital, and local microclimates. A one-size-fits-all recommendation often fails; thus adaptation is required on a case-by-case basis.

- **Adoption barriers**: Even when farmers are aware of new methods, they may resist adoption due to perceived risk, cultural inertia, credit constraints, or limited labor. The extension–scientist partnership must include demonstration plots, farmer champions, and incremental adoption pathways.

To counter these challenges, some enablers are currently emerging:

- **Digital platforms and information and communication technology**: Tools such as decision-support apps, SMS-based advisories, chatbots, and participatory sensing allow extension to reach more farmers more frequently. For example, *FarmerChat*, a generative-AI chatbot, is being explored as a tool for personalized agricultural advice in multiple countries.

- **Smart connected farms and networks of farmers**: Integrating sensor networks, data analytics, and farmer networks helps coalesce granular information across many fields, allowing scientists to calibrate recommendations and detect system-level patterns.

- **Public–private partnerships**: When extension agencies, universities, NGOs, and private firms collaborate, they can pool resources, scale outreach, and ensure that scientific innovations reach farmers faster.

Beyond the farm: society's benefit

Agricultural research reaches far beyond the farm gate. It supports stable food systems, better health, stronger economies, and a safer environment. From developing improved crop varieties and sustainable farming methods to advancing nutrition and climate-smart practices, science continues to improve daily life for people around the world.

Stable food supply and prices

A reliable food supply is essential for every society, and agricultural research helps make this possible. The U.S. Wheat and Barley Scab Initiative (USWBSI), a national program supported by the USDA, has helped reduce losses from Fusarium head blight in more than 30 states. With $15 million in annual funding through the farm bill, the program supports research on resistant varieties, better fungicide use, and disease forecasting. In 2023, 35 new resistant cultivars were released, saving farmers about $170 million in losses. For every dollar invested, the program returns about $71 in benefits. These efforts have improved yield stability, strengthened rural economies, and helped keep grain supplies and prices steady.

"A reliable food supply is essential for every society, and agricultural research helps make this possible."

Public health and nutrition

A farmer holds up a high-iron pearl millet variety that was bred as part of the HarvestPlus global program to improve nutrition. Photo by AS Rao (ICRISAT). CC BY-NC 2.0.

Agricultural research also improves public health by making food more nutritious and accessible. The HarvestPlus program, part of CGIAR, works to reduce “hidden hunger” through biofortified crops that contain more iron, zinc, and vitamin A. In 2024, more than 360 million people across Asia, Africa, and Latin America consumed these nutrient-rich foods. Varieties such as zinc wheat in Pakistan and iron millet in Nigeria helped farmers produce both higher yields and healthier grains while school meal programs reached one million children with better diets. These achievements show how scientific progress in agriculture helps communities live healthier, more productive lives.

Economic and national security

Research and innovation also support economic growth and national stability. Improved crops, technology, and management practices make farming more efficient and reliable, even during difficult seasons. Programs such as the Agriculture and Food Research Initiative (AFRI) fund advances in crop breeding, precision farming, and resource management that help reduce import dependence and strengthen rural livelihoods. The benefits of research are clear in recent production and trade outcomes. In 2024–2025, U.S. wheat exports rose 16% to 820 million bu (22.3 million metric tonnes) after a 9% increase in production, driven by drought-tolerant varieties. Strong harvests supported trade with key markets such as Mexico, South Korea, and Thailand, helping stabilize global food supply. Continued research ensures that agriculture remains productive, competitive, and vital to both national and global security.

Climate and environmental solutions

As climate change brings new challenges, agricultural research helps farmers adopt more sustainable practices. The USDA's Partnerships for Climate-Smart Commodities, a $3 billion program, supports about 140 projects that promote methods such as cover cropping, no-till farming, nutrient management, and precision irrigation. These practices improve soil health, store carbon, and reduce greenhouse gas emissions. The initiative aims to reach 25 million acres of farmland and capture more than 60 million metric tons of carbon dioxide equivalent, the same as taking 12 million cars off the road.

As climate change brings new challenges, agricultural research helps farmers adopt more sustainable practices like precision irrigation. NRCS photo by Tracy Robillard.

Why research must continue

The long game of progress

Every new crop variety, irrigation technique, or pest-resistant trait originates from research that began years, often decades, before practical application in the field. Similar to the progression of a plant from seed to harvest, the development of research-based solutions requires a gradual process of refinement before they become effective and widely adopted management strategies. The risks that crops face are constantly changing and evolving with new pests, diseases, and climate risks being found each year. Identifying these risks, their causes, and the subsequent management solutions requires significant time and resources; yet, this research process plays an essential role in feeding the world.

Agricultural research operates on long timescales. Well-developed breeding programs, soil heath monitoring networks and guidelines, climate resilience management strategies, and scientist–farmer partnerships take time to develop, and they can often take 10–15 or more years to fully mature. The long time that it takes to develop is not inefficient; conversely, it is this methodical and thoughtful pace that makes the results increasingly enduring and reliable. Scientists working in tandem with farmers across multiple growing seasons enable the causes and effects of scientific innovation and intervention to reveal which management strategies are most impactful in adapting to today's challenges.

"The long time that [agricultural research] takes to develop is not inefficient; conversely, it is this methodical and thoughtful pace that makes the results increasingly enduring and reliable."

The cost of standing still

Unlike the scientific process, climate, emerging pests, and population growth can change quickly and frequently. These threats are not dependent on funding or resource availability; they are constantly evolving. Without steady investment in proper response, prevention, and resilience to the numerous risks our farms face, the progress and success that enable our farms to thrive may falter. If research into new drought-tolerant species of staple crops pauses, farmers in the next decade may face fields of failed crops. While funding for soil conservation implementation may dry up, erosion will continue. Without investment, progress halts, but these threats do not.

Today’s experiments, tomorrow’s solutions

The breakthroughs that define modern agriculture began as small-scale experiments decades ago. Drought-tolerant maize varieties were developed over years of breeding and genetic research that sought to help farmers withstand unpredictable rainfall. Integrated pest management grew from ecological studies of insect behavior and subsequent crop health responses, increasingly leading to the replacement of broad pesticide use with more sustainable control methods. Precision agriculture, increasingly used worldwide, was once an ambitious idea tested by scientists experimenting with sensors and satellite data. Each of these innovations proves that the discoveries taking place in labs, greenhouses, and test plots today have the potential to become the everyday tools that secure tomorrow’s harvests.

The genetic studies of stress-tolerant crops will guide new breeding programs decades from *now. Photo by Aduragbemi Amo.*

Agricultural progress is not a series of isolated achievements but a snowballing effect of discovery. Each generation of scientists builds on the knowledge, data, and techniques of those before them, constantly refining and expanding what is possible. This process allows for the implementation of new strategies while continuing to adapt and respond to the ever-changing needs and risks facing the agricultural industry. The soil sensors being tested today will inform the next wave of water-saving technologies; the genetic studies of stress-tolerant crops will guide new breeding programs decades from now. In this way, research acts as a bridge linking the curiosity of the present with the security of the future.

Investing in the future

The success of future agricultural productivity is not a luxury; it is the result of constant agricultural research, both lab and field-based. This research is the foundation of success for future harvests, food security, and resilience in a changing world. The challenges that farmers face will only grow more complex, and if we slow or halt research efforts, our ability to meet these challenges will be greatly hindered. Meeting them requires the steady, dependable, and forward momentum that only research can provide.

Stopping that momentum means forfeiting the innovations of tomorrow. Without continued public and private investment, the discoveries that protect our soils and crops may remain out of reach. With this vital support and the collaborative opportunities produced by farmer–scientist partnerships, our food systems become more resilient and productive, leading to stronger communities, increased economic performance, improved public health, and a safer environment. By offering support to agricultural resources, society signals its investment not just in science, but in the stability and health of the world.

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